ASSESSING 3D PRINTER EMISSIONS IN THE BREATHING ZONE

APPLICATION NOTE EEPS-010 (A4)

Contents

Introduction

Why 3D Printer Emissions are Important

Particle emissions from desktop 3D printers have been observed by numerous researchers (Azimi *et al* 2016, Stephens *et al* 2013, Kim *et al* 2015, Stabile *et al* 2016, Steinle 2016, Yi *et al* 2016, Mendes *et al* 2017, Stefaniak *et al* 2017). Studies measuring the emissions from industrial 3D printers, in contrast, have not been published to date. While desktop 3D printers are likely more numerous, industrial 3D printers have been utilized in numerous industries and workplaces for well over a decade. Since industrial 3D printing continues to be integrated into a growing group of industries, worker safety concerns are now being raised surrounding these emissions. Measuring industrial 3D printer emissions to assess these risks is now a pressing need for 3D printer manufacturers and for organizations that utilize 3D printing.

How to Measure 3D Printer Emissions

Measuring these emissions poses several challenges. First and foremost, particle generation within a 3D printer is not a constant event; particles are often emitted in bursts, depending upon the feedstock composition and specific details of the object being printed. Furthermore, particle sizes ranging from <3 nm to >100 nm have been observed.

Given these considerations, measuring these emissions accurately is a challenge. In order to accurately capture the transient nature of particle generation within the 3D printer, a TSI instrument with 10 Hz time resolution—the model 3090 Engine Exhaust Particle Sizer™ (EEPS™) Spectrometer—was employed. The EEPS spectrometer is able to measure its full range of particle sizes (5.6 – 560 nm) ten times per second. This makes it ideal for measuring transient aerosol dynamics like those present in 3D printer emissions.

In addition, a 3776 Condensation Particle Counter (CPC) was used to monitor total particle concentrations of particles larger than 2.5 nm. With a response time of 0.8 seconds, the 3776 CPC is able to respond to fast changes in aerosol number concentration. This application note describes measurements of 3D printer emissions in a worker's breathing zone using these two instruments.

Experimental Setup

The Printer

An industrial 3D printer (Dimension sst 1200es) was used for particle emissions measurement. The 3D printer used ABS (acrylonitrile butadiene styrene) as its feedstock. ABS is one of the most common feedstocks in 3D printing. The printer also utilizes a water-soluble support material, which acts as a scaffold. Overhanging features of the 3D printed object (such as a shelf) are supported during the print by a fast-curing support material. After the print is complete, the part is soaked in warm water to dissolve away the scaffold. The printer used in this work utilized an acrylic copolymer support material.

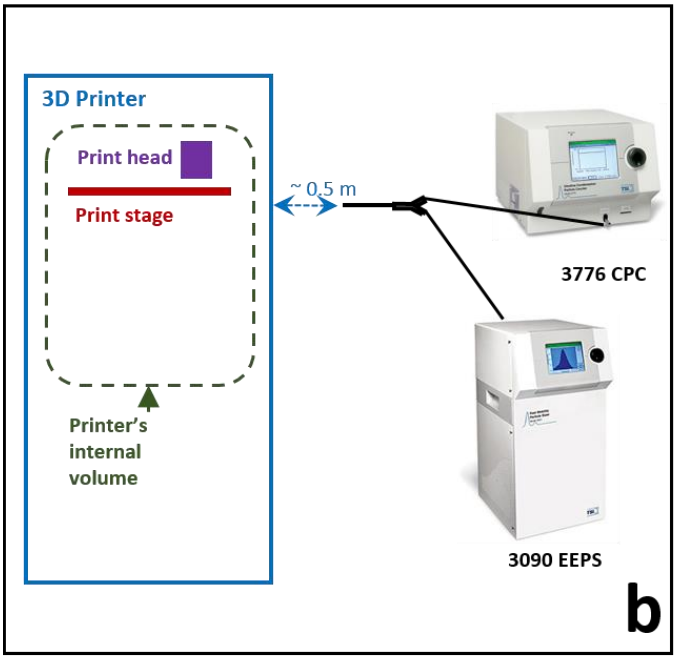
The Printed Object

The objected printed during this study was small and square in shape [~2.25 inches long on all sides, and ~0.2 inches thick (ABS portion only)]. Printing this object entailed printing 10 layers of the water-soluble support material followed by 10 layers of the feedstock (acrylonitrile-butadiene styrene, ABS). The final ABS object (after the water-soluble material was dissolved away) had a mass of 10.4 g.

Emissions Measurements

To investigate potential worker exposure to 3D printer emissions, measurements were taken outside of the printer while this small object was printed. Figure 1a depicts the 3D printer as well as the particle measurement instruments, with the sampling tube sampling air from a worker's breathing space. During a print, approximately 0.5 m from the printer's exterior wall. Tubing lengths were scaled to instruments' flow rates to align the transfer times of the aerosols to the instruments, and are not shown to scale in this schematic.

Figure 1: a) The 3D printer (left) with the particle measurement instruments' sampling line positioned in the breathing space outside of the printer. b) Sampling schematic showing the instruments used to measure particles in the worker's breathing space during a print, approx. 0.5 m from the printer's exterior wall.



Results

Measurements in the breathing space of a printer operator standing near the printer did reveal elevated particle number concentrations. Figure 2b shows a time trace of the particle number concentration as measured by the 3776 CPC and by the 3090 EEPS (using 5-second averaging and the Soot matrix).[1] The two total number concentrations overlie each other very well, and indicate a significant increase in breathing-zone particle concentration nearly concurrent with the onset of support material printing.

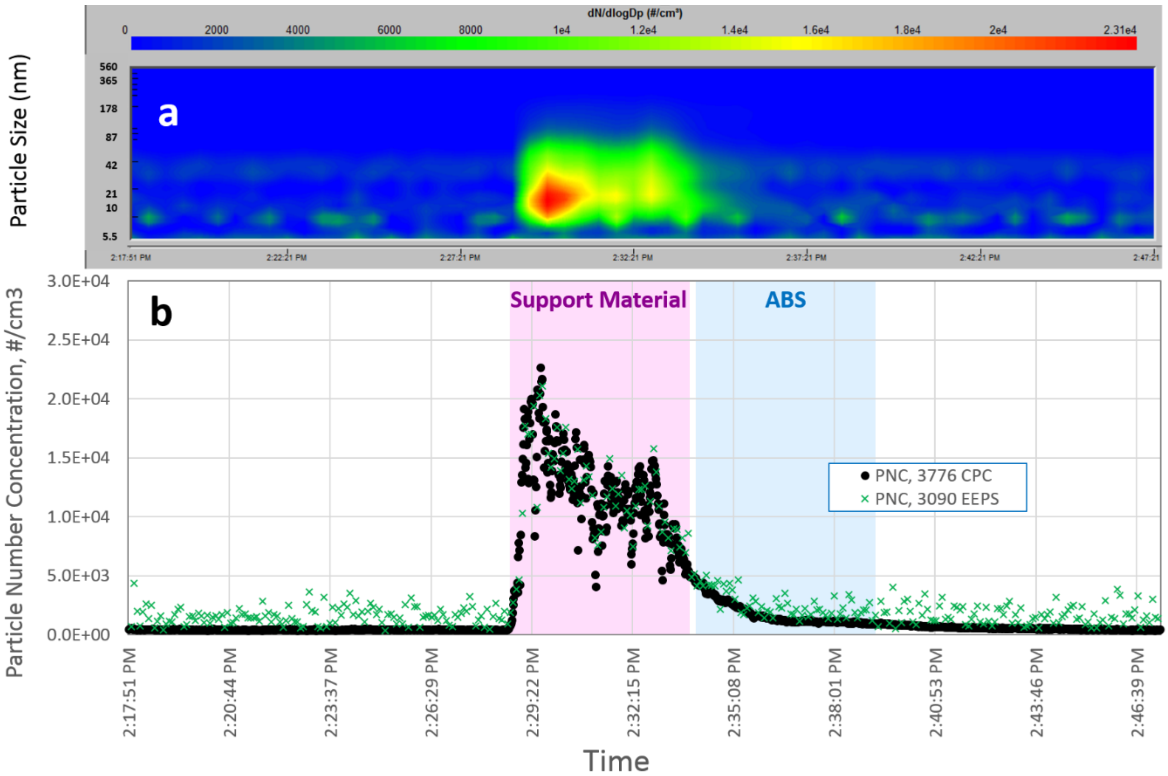


Figure 2: a) EEPS contour plot of particles measured in the worker's breathing space. b) A time series of particle number concentrations as measured by the 3776 CPC and the 3090 EEPS. The time ranges of the contour plot in (a) and the Particle Number Concentration time trace in (b) are identical, so the "plume" shown in the contour plot occurred simultaneous to the printing of support material.

The size distribution of particles during ABS printing featured a mode (most commonly detected particle size) at or below 25 nm throughout the support material print. Figure 2a is a contour plot of particles measured by the 3090 EEPS spectrometer during the support material print. In this plot, color indicates concentration, the y-axis indicates particle size, and the x-axis indicates time. "Slicing" through this three-dimensional contour plot produces a size distribution at one point in time. Figure 3 shows the size distribution of particles measured during the heart of the support material print (i.e., the reddest portion of Figure 2a.)

[1] While the EEPS spectrometer always collects data at 10 Hz, it is possible to display that data with different averaging times. Figure 2 uses 5-second averaging in order to conveniently display the entire print event in one figure.

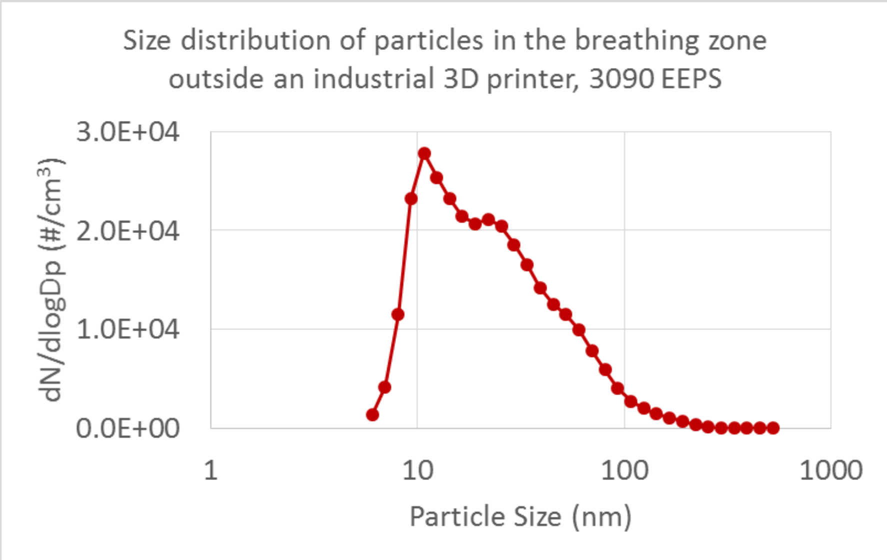


Figure 3: A size distribution of particles measured during the support material print. The peak of the size distribution represents particles approximately 15 nm in size.

Conclusions

An industrial-scale 3D printer has been observed to generate high concentrations of nanoparticles in the breathing space of a worker standing near the printer. The concentration and size of the generated particles depends on the feedstock used, and also likely varies by printer model. Given the widespread use of industrial-scale 3D printers, this particle generation may pose a worker health hazard. Proper ventilation around, and potentially inside of, 3D printers would help to reduce worker exposure to particles generated by these devices. Monitoring of particle number concentrations in the vicinity of 3D printers would ensure that inadequate ventilation would be noticed, and could be remedied. TSI's EEPS spectrometer is an ideal tool for this application, providing accurate particle concentration and size measurements at high time resolution, which is suitable for a dynamic process such as 3D printing.

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