Chemical Insights
An Institute of
Underwriters Laboratories Inc.

A SUMMARY REPORT

The Effect of Filtration on Particle and Chemical Emissions from a 3D Printer

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1. INTRODUCTION

Chemical Insights, with our research partner Georgia Institute of Technology, School of Civil and Environmental Engineering and School of Earth and Atmospheric Sciences, has been conducting leading research on the characterization and potential health impacts of chemical and particle emissions from 3D printers. These efforts have been presented in various publications and reports (more resources on website). In addition, a consensus standard, "Standard Method for Testing and Assessing Particle and Chemical Emissions from 3D Printers", has been developed from the research, establishing test protocols and acceptable emissions criteria for 3D printers. Primary research findings show that emissions released during the 3D printing process include large numbers of volatile organic compounds (VOCs) and particles, primarily in the ultrafine size range. Toxicity responses have also been obtained. Since these studies demonstrate the potential for adverse human health effects, research is continuing to further assess toxicity and to evaluate options for reducing emission exposures.

Recent research has focused on the use of local filtration as a means of mitigating the emissions. A desktop 3D printer was tested for emissions of particles (ultrafine, fine and coarse) and VOCs in a controlled exposure chamber according to ANSI/CAN/UL 2904.[2] Emission data were obtained with and without the use of local filtration. The filtration consisted of a carbon filter, a HEPA (high-efficiency particulate air) filter, and a fan pulling air through the filters, housed by a plastic cover on top of the printer.

2. METHODS AND MATERIALS

Emission measurements were made in a 6 m^3 exposure chamber with the 3D printer placed in the middle of the chamber. The design and the characterization of the chamber have been previously described in ISO 16000-9.[3]

Particles with diameters from 7 to 300 nm were measured using a scanning mobility particle sizer spectrometer, and particles with diameters from 0.3 to 10 μm were measured by an optical particle sizer.[4] Particle emission rate (emission per print time) and particle yield (emission per mass of filament extruded) during printing were calculated according to ANSI/CAN/UL 2904.[2] VOCs as well as formaldehyde and other low-molecular weight carbonyl compounds were collected onto sorbent media separately, and then analyzed by gas chromatography - mass spectrometric or high performance liquid chromatography, respectively.[5] Emission rates for individual VOC and total VOC were calculated in accordance to ANSI/CAN/UL 2904.[2]

The tested print filament materials included Nylon black color (extruder nozzle temperature 250 °C), ABS (acrylonitrile butadiene styrene) natural color (245 °C), ASA (acrylonitrile styrene acrylate) black color (245 °C), PC-ABS (polycarbonate-ABS) black color (260 °C), and PC-ABS-FR (PC-ABS with flame retardants, FR) black color (260 °C). All studied filaments were printed on the same printer. Support materials were loaded and extruded at the beginning of print with limited amount of filaments. The printer chamber temperature was 30 °C for Nylon, 85 °C for ABS and ASA, and 95 °C for PC-ABS and PC-ABS-FR. Each filament was tested once without the installation of the filter and again with filter installed.

3. RESULTS

3.1 Effect of filtration on particle emissions

Particle emissions for prints without the filter setup are compared to our existing particle emission database of 372 tests, which includes 184 tests of ABS filaments, 157 tests of PLA filaments, 15 tests of Nylon filaments, 6 tests of HIPS (high impact polystyrene) filaments, 7 tests of PVA (polyvinyl alcohol) filaments, and 3 tests of metal filaments, as shown in Figure 1. In general, particle emission rates and yields were low except for the Nylon filament in this study. Emissions from ASA, PC-ABS and PC-ABS-FR filaments were below 25th percentiles of the database, while Nylon filament emissions were near 75th percentiles of the database. Particle emissions from ABS filament were too low for calculations, thus no data was shown for ABS filament.

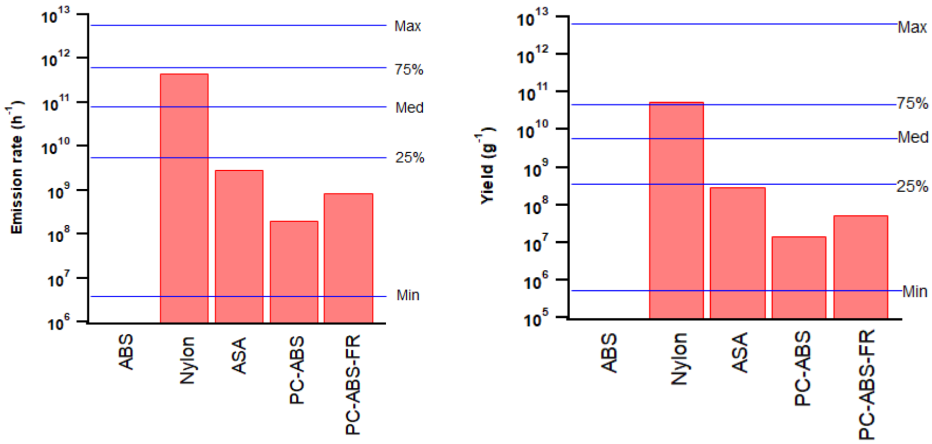

Figure 1. Particle emission rate (left) and yield (right) for prints without the filter setup, compared to previous database. Lines indicate the maximum (Max), median (Med), minimum (Min) and 25th and 75th percentiles of the database.

The use of filtration significantly reduced particle emissions for all filament types. With the filter, particle emissions from all filaments were reduced to low levels, below quantitative emission rate determinations. For the Nylon filament, both particle emission rate and yield exceeded standard criteria without filtration; but fell below the maximum acceptable criteria when the filter was used. Figure 2 shows a comparison of maximum particle concentrations during print. Filtration was able to reduce maximum particle concentrations by at least one order of magnitude, and the reduction rates were 95% or greater.

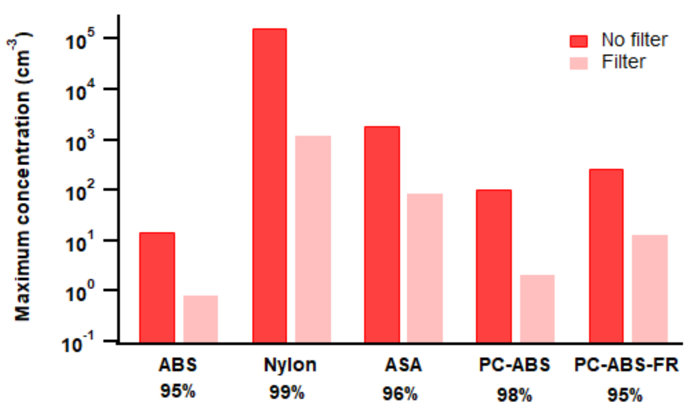

Figure 2. Particle maximum concentration during printing for with and without filtration. Percentage indicates the reduction due to filtration.

3.2 Effect of filtration on VOC emissions

Total VOC (TVOC) emission rates measured in this study were compared to previous dataset that included 33 tests of 3D printers operating with ABS (12 runs), PLA (14), Nylon (4), HIPS (1), PVA (1) and metal (1) filaments, see Figure 3. The use of the filter setup showed an increase in TVOC emission rates for all filaments except ABS (Figure 3). However, all TVOC emission rates were within the criteria in ANSI/CAN/UL 2904.[2]

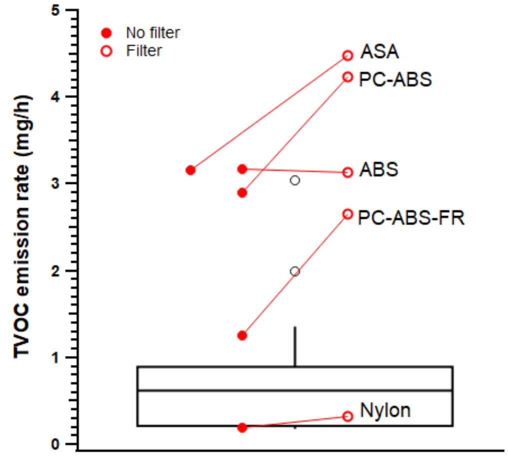

Figure 3. TVOC emission rates for each filament with and without filtration, compared to existing database. The box indicates 25%, median and 75% quartile; the whiskers indicate 10% and 90% values; the outliers are larger than 1.5 times of whisker length.

Individual VOC emissions from ABS, ASA, PC-ABS and PC-ABS-FR filaments shared 4 out of 5 chemicals in common for the top 5 detected chemicals, which were styrene, phenol, formaldehyde and 1-propanol, 2-methyl (isobutyl alcohol). In addition, ethylbenzene was in top 5 chemical lists for ABS and ASA filaments. While the Nylon filament had relatively different emitted VOC profiles; the top 5 detected chemicals were caprolactam; 1,2,3-propanetriol, 1-acetate; octanal; 5,9-undecadien-2-one, 6,10-dimethyl-, (E)-; and hexadecane. Chemicals of concern are VOCs listed in health-related regulation and guidance.[2,6–8] For the top 5 chemicals of concern, ABS, ASA, PC-ABS, and PC-ABS-FR filaments had 4 chemicals in common (styrene, phenol, formaldehyde and 1-propanol, 2-methyl). Among them, styrene is categorized as a possible carcinogen by International Agency for Research on Cancer (IARC); formaldehyde is carcinogenic to humans according to IARC; phenol is known for developmental and reproductive toxicity. Additionally, ethylbenzene was a common chemical of concern for ABS and ASA filaments, and 1-butanol (n-butyl alcohol) for PC-ABS and PC-ABS-FR filaments. Caprolactam is an irritant and usually found emitted from Nylon filaments. Acetaldehyde, a possible carcinogen by IARC, was one of the top 5 chemicals of concern for Nylon filament; it was also detected from all the rest filaments but at relatively lower emission rates.

The effect of filtration on individual VOC removal was not conclusive and depended on print conditions, material, and the property of each chemical. In general filtration appeared to decrease emission rates of some chemicals, including styrene, formaldehyde, ethylbenzene, 1-propanol, 2-methyl, and 1-butanol, while some VOCs tended to have increased emission rates, including phenol, 1-hexanol, 2-ethyl and 2,6-di-tert-butyl-4-methylphenol (BHT). It is suspected that the filter material themselves were sources of VOCs. There was indication that plastic related VOCs such as phenol and various acrylates as well as numerous heavy hydrocarbons could be associated with the filtration materials. Research will continue to further understand the VOC findings.

4. REFERENCES

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