Filtration Requirement for 3-D Printers

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1. Introduction

- 3D printer market estimated to have a compound annual growth rate of 44% (Alto, 2013)

- Among all the 3D printers, fused deposition modeling (FDM) printers are
  - relatively inexpensive and convenient to use, making them accessible to the general public
  - printing principle: heating a filament to semi-liquid state and depositing it to build a 3-D object by layers

- Thermoplastics as filament material : acrylonitrile butadiene styrene (ABS); polylactic acid (PLA); polyethylene terephthalate (PET); polyamide (nylon)

2. Particle Formation in the FDM 3D printing

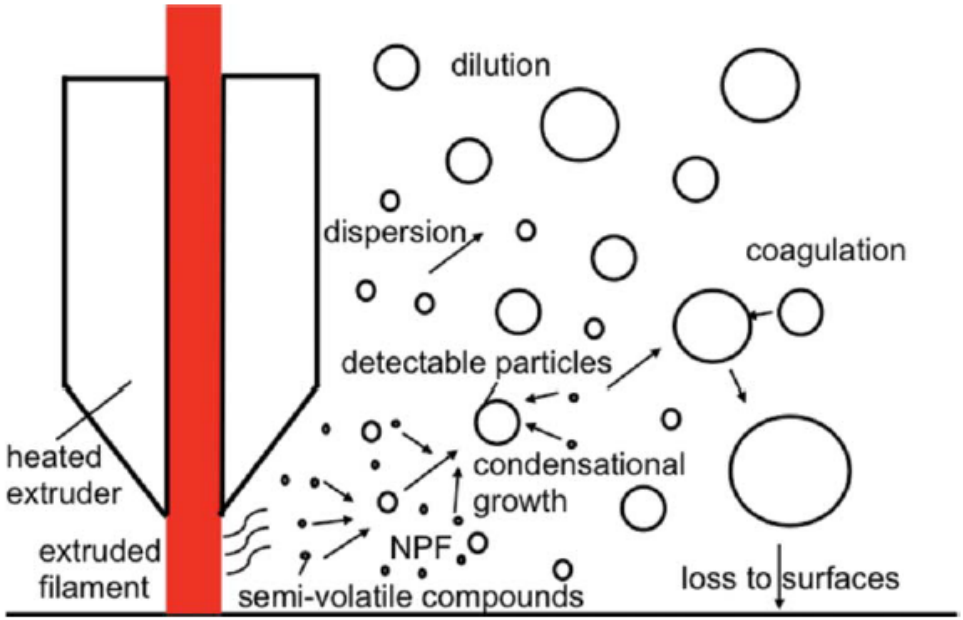


Table 1. Specifications of printers tested in this study.

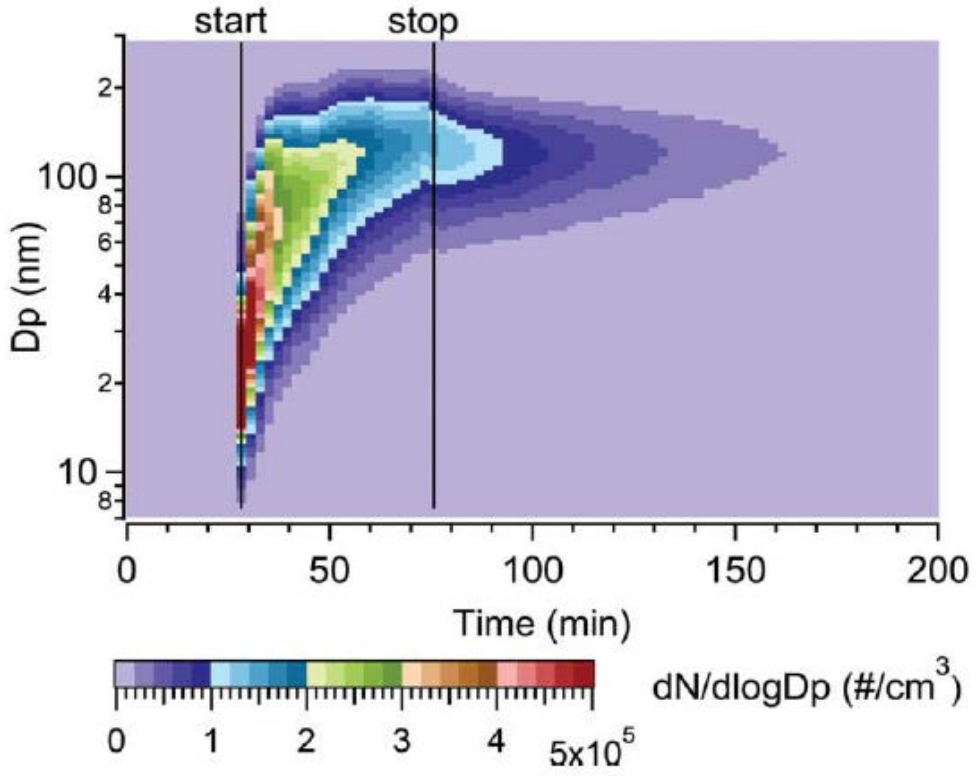
	Extruder temperature (°C)				Appearance	
Printer brand	ABS	PLA	Nylon	Build plate	Sidewalls	Ceiling
A	270	210	243	Heat[a]	No	No
B	n/a	215	n/a	Tape	4	No
C	260	230	n/a	Glue	2	Yes
D	n/a	215	n/a	Tape	1	No
E	230	n/a	n/a	Tape/Heat (110°C)	4	Yes
F	270	210	n/a	Heat[a]	4	Yes

[a]100°C for ABS and nylon; 50°C for PLA

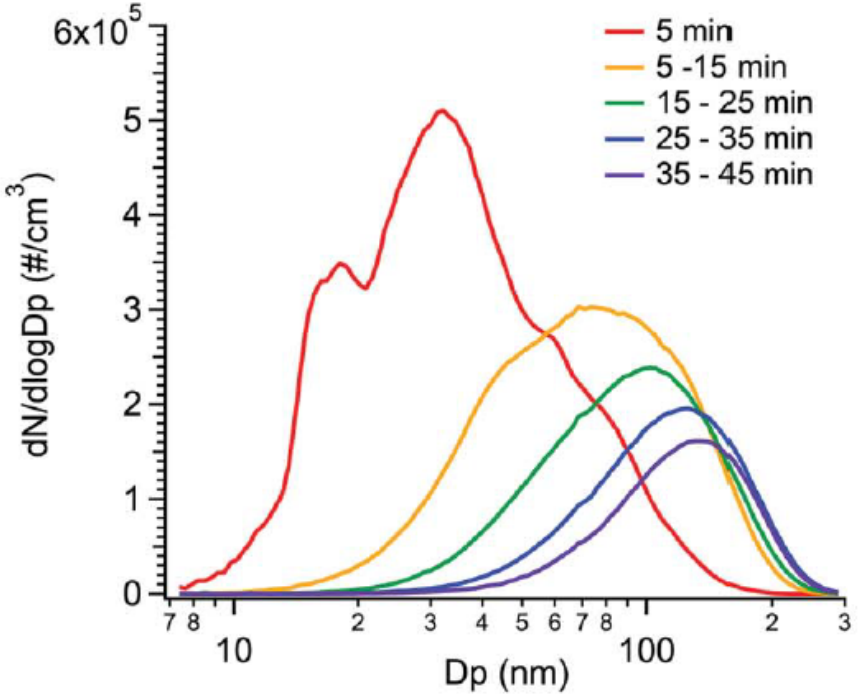
NPF: new particle formation

Zhang et al, AS&T 2017

3a. Particulate Emission from FDM 3D printers (ABS filament)



Evolution of size distribution



Average particle number distribution during the printing separated in 5 time intervals

Zhang et al, AS&T 2017

3b. Particulate Emission from FDM 3D printers

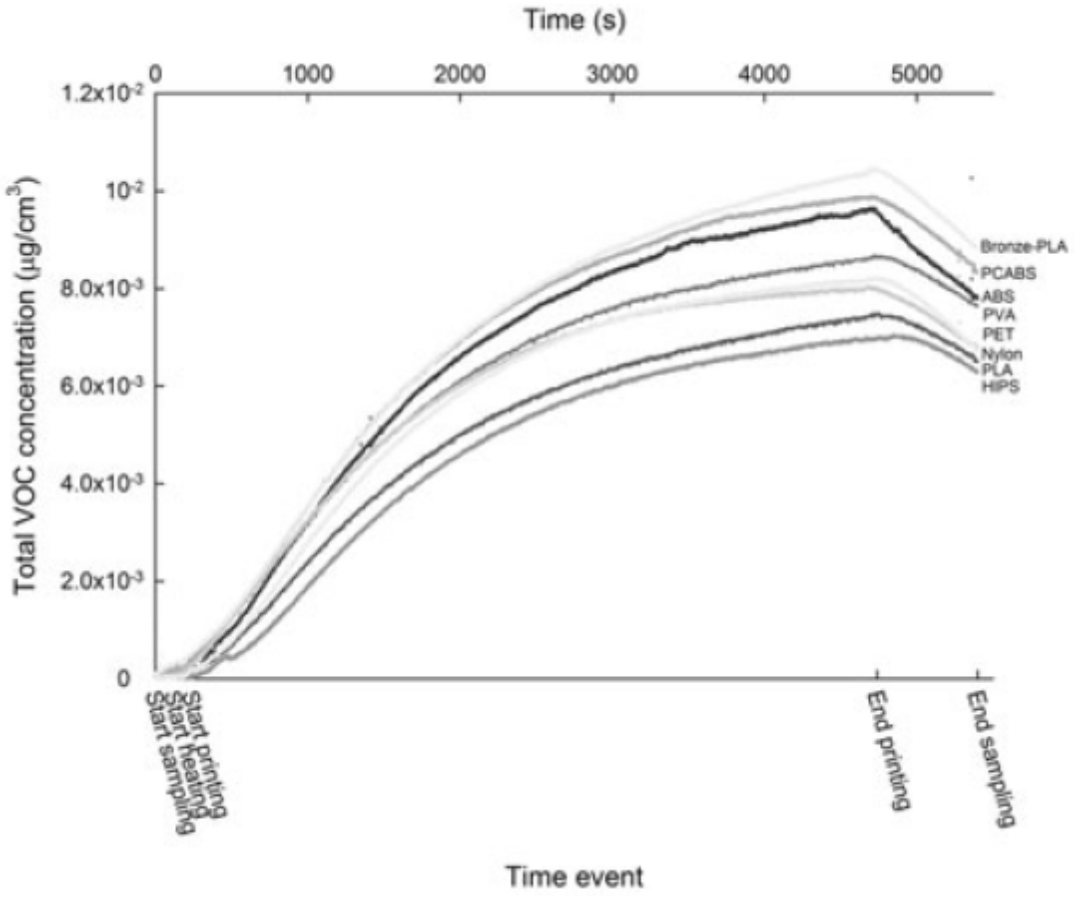
Table 5. Average geometric mean (GM) particle size and average ± standard deviation particle emission rates (PER) for 3-D and laser printers.

Printer	Consumable	Print job	Avg. GM[a] (nm)	SMPS (# < 0.66 µm min^{-1})
HP2055dn	Monochrome toner	80 pages @ 5%	39.6	$7.1 \pm 0.7 \times 10^{10}$
HP2600	Monochrome toner	80 pages @ 5%	168.3	9.8×10^{7}
3-D[b]	ABS natural	3 combs	53.7	$1.6 \pm 0.0 \times 10^{10}$
	ABS blue	2 combs	63.1	$7.5 \pm 1.0 \times 10^{9}$
	ABS red	2 combs	49.9	$1.4 \pm 0.3 \times 10^{10}$
	ABS black	2 combs	45.3	$1.0 \pm 0.2 \times 10^{10}$
	PLA true red	4 combs	36.4	$1.3 \pm 0.5 \times 10^{10}$
	PLA army green	4 combs	36.1	$1.3 \pm 0.2 \times 10^{10}$
	PLA ocean blue	4 combs	36.5	$1.1 \pm 0.7 \times 10^{10}$
	PLA transparent blue	4 combs	37.7	$1.6 \pm 0.2 \times 10^{10}$

[a]Mobility diameter from electrical low-pressure impactor (ELPI) measurements.
[b]Scanning mobility particle sizer (SMPS) data from Yi et al.,[19] ABS = acrylonitrile butadiene styrene, PLA = polylactic acid.

Stefanial et al, JOEH (2017)

4. VOC Emission from FDM 3D printers



Floyd et al, JOEH (2017)

Table 2. Average ± standard deviation of TVOC SER_u values for 3-D and laser printers.

Printer	Thermoplastic	Replicates	Cover SER_u ($\mu g\ h^{-1}$)	
3-D	ABS natural	2 combs	On	3552 ± 549
3-D	ABS natural	1 comb	Off	3430
3-D	ABS natural	1 comb [malfunction]	Off	6454
3-D	ABS blue	2 combs	On	2385 ± 82
3-D	ABS red	2 combs	On	2383 ± 357
3-D	ABS black	2 combs	On	1085 ± 217
3-D	PLA ocean blue	2 combs	On	ND
3-D	PLA transparent blue	2 combs	On	131 ± 37
3-D	PLA true red	2 combs	On	ND – 49
3-D	PLA army green	2 combs	On	ND – 51
HP2055dn	Monochrome toner	80 pages @ 5%	N/A	5782
HP2600	Monochrome toner	80 pages @ 5%	N/A	7735

Note. N/A = not applicable for laser printers, ND = not detected using real-time TVOC instrument, ABS = acrylonitrile butadiene styrene, PLA = poly-lactic acid.

Stefanial et al, JOEH (2017)

5. Final Remark

- For FDM 3D printers:
  - High level of fume particles emission rate ($1.0x10^{7}$ to $1.2x10^{11}$ #/min) in the size range less than 500 nm with the mode size of 40 - 100 nm were produced.
  - VOC concentration emission from FDM 3D printers are in general much lower than the occupational exposure limit.
- Because 3D printers are often used in public and residential spaces, the good public and particularly susceptible populations such as children and elders can be exposed to high concentration of nanoparticles
- Due to the concern of nanoparticle toxicity, filtration strategy is required to control nanoparticles emitted from FDM 3D printers

6. Sample references:

- Aleksandr B. Stefaniak, Ryan F. LeBouf, Jinghai Yi, Jason Ham, Timothy Nurkewicz, Diane E. Schwegler-Berry, Bean T. Chen, J. Raymond Wells, Matthew G. Duling, Robert B. Lawrence, Stephen B. Martin Jr., Alyson R. Johnson & M. Abbas Virji, (2017) "Characterization of chemical contaminants generated by a desktop fused deposition modeling 3-dimensional Printer," Journal of Occupational and Environmental Hygiene (JOEH), 14:7, 540-550.

- Qian Zhang, Jenny P. S. Wong, Aika Y. Davis, Marilyn S. Black & Rodney J. Weber (2017), "Characterization of particle emissions from consumer fused deposition modeling 3D printers", Aerosol Science and Technology (AS&T), https://doi.org/10.1080/02786826.2017.1342029

- Evan L. Floyd, Jun Wang & James L. Regens (2017) "Fume emissions from a low-cost 3-D printer with various filaments," JOEH, 14:7, 523-533.

- Szymon Wojtyła, Piotr Klama & Tomasz Baran (2017) "Is 3D printing safe? Analysis of the thermal treatment of thermoplastics: ABS, PLA, PET, and nylon," JOEH, 14:6, D80-D85