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Clearing the air about 3D printing emissions

Measuring VOC and nanoparticle emissions during fused filament fabrication

French Bulldog by yuchiayeh

Published August 18, 2014
www.thingiverse.com/thing:431981

Wall-mounting bracket for Cisco 8945 VOIP phone by elfarmcrew

Published December 10, 2013
www.thingiverse.com/thing:200337

Following the successful use of three-dimensional (3D) printing technology for rapid prototyping and small-scale manufacturing, desktop printers are becoming more common in homes, schools, and office environments.

Unlike commercial fused filament fabrication (FFF) printing facilities, nonindustrial 3D printers are often stand-alone units without mechanical exhaust ventilation or filtration accessories (Stephens et al., 2013). Yet, there is very little research in the literature that measures the indoor emission of volatile organic compounds (VOCs) and nanoparticles from these devices and the filament polymers that are commercially available for them.

Recently, Eastman conducted experiments to test emission of VOCs and nanoparticles from three polymers during 3D printing in a small office environment. The tests presented on the following pages were performed with easily repeatable protocols, using accepted methodologies for sampling and data treatment. The results have been submitted to a peer-reviewed industrial hygiene journal.

TRENDING SENSITIVITY TO AIR QUALITY

- Formaldehyde offgassing from construction materials
- Public demand for low-VOC paints
- Indoor air quality
- Growing threat of regulatory pressure to limit workplace VOCs and, potentially, nanoparticulates
- Unpleasant odor is not desirable.

3D PRINTING FILAMENT ADOPTION PATTERNS

- Most nonindustrial 3D printer applications use acrylonitrile butadiene styrene (ABS) or polylactic acid (PLA).
- Users traditionally start with PLA for printing 3D prototypes because its odor is less offensive and it can be easier to work with than ABS.
- When users move past simple prototyping to more technical and functional parts that require more durability, they traditionally move from PLA to ABS, where the drawbacks of odor and a heated bed are offset by functionality benefits.
- Now, a third option—Eastman Amphora™ 3D polymer AM1800—provides a styrene-free copolyester that combines durability with exceptionally low odor during printing.

Comparing office environment emissions and offgassing of three 3D polymers

Frog Sculpture by chrisniederer

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Air quality will become a growing concern for those who use desktop 3D printers in confined spaces. Eastman, a world leader in polymer solutions, conducted a series of indoor air experiments to compare VOC and nanoparticle emissions of PLA, ABS, and Eastman Amphora™ 3D polymer AM1800 during 3D printing.

DESIRABLE 3D POLYMER TRAITS

For end-use part functionality

- Strength, toughness, and flexibility for long-lasting parts
- Melt temperature sufficient to meet part temperature specifications
- Good UV resistance
- Regulatory clearances appropriate for intended end use (e.g., U.S. Food and Drug Administration [FDA] and European Food Safety Authority [EFSA] regulations for food contact)

For processability/printability

- Flexible enough to spool; rigid enough to feed systems
- Melt temperature low enough to print on most machines
- Good shelf life; stable material
- Adequate melt flow viscosity/rheology to permit effective printing
- Compatible with colorants and additives
- Low odor (Odor is generally a subjective property that may not correlate with toxicity; odor often points to potentially undesirable activities, such as VOC generation or nanoparticle emissions.)

Experiment 1: Office environment sampling—VOCs and nanoparticles

Goal

Measure and evaluate the actual airborne concentrations of volatile aldehydes, VOCs, and nanoparticles observed in an office environment during 3D printing with ABS, PLA, and Eastman Amphora™ 3D polymer AM1800.

Conditions

- Simulated office environment (office volume 45 m^3) with a stand-alone 3D printer
- Ventilation air-turnover rate of 1.75 × per hour (typical home/office turnover rate)
- Consumer-grade fused filament fabrication printer
- Print "test frog" at recommended filament print temperatures.
- Simultaneously sample air for aldehydes, VOC, and nanoparticles.
- Repeat each sample three times.

Methods

Accepted sampling methodologies for VOC and nanoparticle detection

- Volatile aldehyde emission monitoring (formaldehyde and acetaldehyde)
  - Pump air sample through a cartridge containing dinitrophenylhydrazine (DNPH) for 1 hour (aldehydes react with DNPH to form a stable, easy-to-detect product).
  - Remove contents from cartridge with a solvent.
  - Separate and detect using liquid chromatography.
- Hydrocarbon VOC emission monitoring (styrene, ethylbenzene, and benzene)
  - Thermal desorption gas chromatography—mass spectrometry for VOC analyses
  - Gerstel TDS3 sampler on Agilent 6890 GC with mass selective detector
- Nanoparticle emission study
  - Samples of office air taken before, during, and after printing to monitor buildup, total count, and recovery.
  - TSI Model 3910 ultrafine particle analyzer (total particle count and particle size distribution from 0–400 nm)

We performed analysis on the concentrations of aldehydes in the air, and no significant concentrations were observed relative to the background measurements.

Table 1 shows the results of hydrocarbon VOC collection and analysis. Table 2 presents OSHA regulatory limits as a reference.

Table 1: Hydrocarbon VOC emission test results

	Detected concentrations in air (ppb)		
Filament material	Styrene	Ethylbenzene	Benzene
	Avg.	Avg.	Avg.
ABS	0.7	1.6	No detection
Eastman Amphora AM1800	**No detection**	**No detection**	**No detection**
PLA	No detection	No detection	No detection

Table 2: OSHA (U.S.A.) regulatory limits (ppb)*

	Styrene	Ethylbenzene	Benzene
STEL	100,000	—	5,000
8-hour TWA	50,000	100,000	1,000

**Source: OSHA CFR 1910.1028*

Figure 1 shows the results of ultrafine particle analysis.

Figure 1: Ultrafine particle analysis for ABS, PLA, and Eastman Amphora™ 3D polymer AM1800

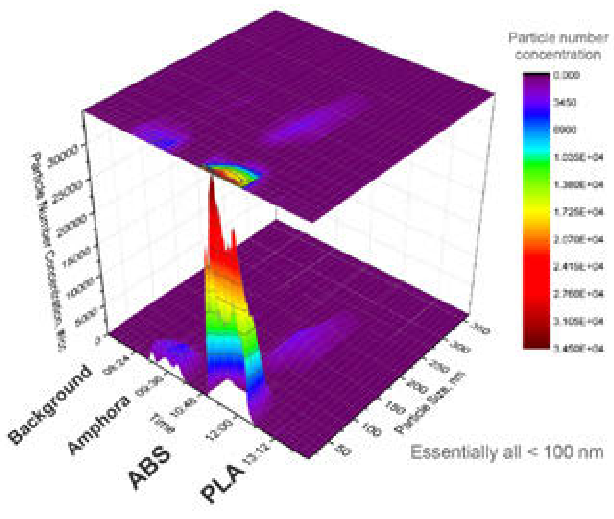
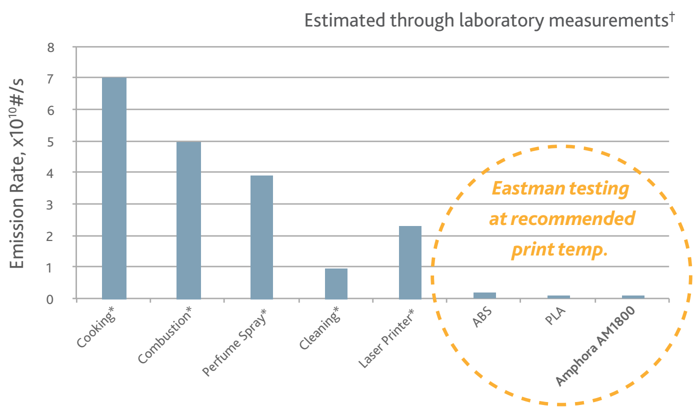


Figure 2 compares the nanoparticle generation of these three polymers with nanoparticle generation by other sources found in the office.

Figure 2: Total nanoparticle emission rate source comparison*



** Data collected from Gehin et al., 2008*

† ABS and PLA emission rates estimated through our studies are consistent with estimates by Stephens et al., 2013.

Experiment 2: Total offgassing from FFF filament

Goal

To identify and measure all VOCs emitted from ABS, PLA, and Eastman Amphora™ 3D polymer AM1800 when the filaments are heated to their respective recommended printing temperatures.

Conditions

Fixed sample weights of each filament were heated in air to their respective recommended printing temperatures. Experiments were conducted using heating times of 1 and 3 minutes. All VOCs released from the filaments were cryogenically trapped and subsequently analyzed by gas chromatography–mass spectrometry.

Methods

Thermal desorption gas chromatography–mass spectrometry

Hypothesis

Expected much higher analytical component results than open air study because:

- No dispersion/dilution in the room
- No time for nanoparticle formulation

Table 3: Offgas components detected

			Detected concentrations (μg/g)			
			1-minute heat		3-minute heat	
Filament	Temp. (°C)	Component	Rep 1	Rep 2	Rep 1	Rep 2
ABS	255	Acetaldehyde	37	60	172	173
		Styrene	504	576	1,222	960
		Ethyl benzene	966	1,029	1,797	1,467
PLA	208	Acetaldehyde	9	12	21	29
Eastman Amphora AM1800	245	Acetaldehyde	40	36	56	29
		p-xylene	15	16	26	25

Concentrations of select major offgas products in micrograms per gram of filament material

CONCLUSION

- For ABS, PLA, and Eastman Amphora™ 3D polymer AM1800, open-air VOC emission concentration results in the office environment we tested registered several orders of magnitude below regulatory agency concern levels.
- Combined trace VOCs coupled with unknown olfactory effects of nanoparticle results may exceed odor threshold limits, especially for ABS.
- Nanoparticle generation for all filaments tested is lower than that generated by many common household tasks.

Regardless of reported results, 3D printing should always be done in a well-ventilated work area following the printer manufacturer's instructions for safe operation.

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Eastman Amphora™ 3D polymer AM1800 is a low-odor, styrene-free choice that is uniquely suited for 3D printing applications. With Amphora, 3D printed items can be more functional, durable, efficient, and attractive compared to using ABS or PLA materials.

Amphora 3D polymer offers a wide range of advantages, including:

- Toughness required for truly functional parts
- High melt temperature but printable from 240°–260°C (ABS is ~220°C; PLA is ~180°C [Stephens et al., 2013])
- Accepts colorants and additives effectively
- Printed parts have an attractive gloss and luster.
- Parts have good dimensional stability.
- Compliance with certain FDA and EFSA regulations for food contact applications
- Exceptionally low odor during printing

Amphora 3D polymer AM1800 is a product of Eastman Chemical Company, one of the world's largest producers of high-performance polyester polymers, with technical and support scientists to help ensure success with your innovations For more information, visit EastmanAmphora.com.

References

Eastman Chemical Company, 2014. SDS: Eastman Amphora™ 3D Polymer AM1800.

Gehin, E., Ramalho, O., and Kirchner, S., 2008. Size distribution and emission rate measurement of fine and ultrafine particle from indoor human activities. Atmos Environ, 42, 8341-8352.

Stephens, B., Azimi, P., El Orh, Z., and Ramos, T., 2013. Ultrafine Particle Emissions from Desktop 3D Printers. Atmos Environ, 79, 334-339. Available at http://www.sciencedirect.com/science/article/pii/S1352231013005086. (Accessed September 4, 2015).

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