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Title: 3D Printing – Evaluating Particle Emissions of a 3D Printing Pen

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Author Questionnaire

1. Microscopy: Does your protocol require the use of a dissecting or stereomicroscope for performing a complex dissection, microinjection technique, or similar? **N**

2. Software: Does the part of your protocol being filmed demonstrate software usage? **Y**

Videographer: All screen capture files provided; do not film

3. Interview statements: Considering the Covid-19-imposed mask-wearing and social distancing recommendations, which interview statement filming option is the most appropriate for your group? **Please select one**.

☒ Interviewees wear masks until the videographer steps away (≥6 ft/2 m) and begins filming. The interviewee then removes the mask for line delivery only. When the shot is acquired, the interviewee puts the mask back on. Statements can be filmed outside if weather permits.

4. Filming location: Will the filming need to take place in multiple locations (greater than walking distance)? **N**

Protocol Length
Number of Shots: **35**

Introduction

1. Introductory Interview Statements

REQUIRED:

1.1. **Peter Laux**: 3D printers and pens may emit particles and volatile substances. We have developed a method to analyze the emission of 3D pens **[1]**.

1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

REQUIRED:

1.2. **Heike Sigloch**: Our method is simple, easy to implement, and cost-effective to set up and can be used to characterize particle emissions near the breathing zone of the user **[1]**.

1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

OPTIONAL:

1.3. **Frank Bierkandt**: This technique can also be used to analyze aerosol emissions from other sources or devices, like spray products and abrasion processes**[1]**.

1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

Protocol

2. Protocol Setup

2.1. Before beginning an experiment, select a 3D printing pen capable of generating temperatures greater than 200 degrees Celsius **[1]** and select filaments with a 1.75-millimeter diameter suitable for the 3D pen **[2]**.

2.1.1. WIDE: Talent selecting pen

2.1.2. Talent opening container of filaments

2.2. Clean the inside of a desiccator with an inlet on one side for inserting the 3D printing pen and an outlet on the top for inserting the sampling tube **[1]**.

2.2.1. Talent cleaning desiccator *Videographer: Important step; Video Editor: please emphasize 3D printing pen inlet and sampling tube outlet when mentioned*

2.3. Make sure that an air inlet at the connection to the 3D pen is established **[1-TXT]**.

2.3.1. Talent checking air inlet *Videographer: Important step* **TEXT: Ambient air use as background**

2.4. The outlet tubing should be 10 centimeters from the tip of the 3D printing pen to mimic the distance between the user's head and the emission source **[1-TXT]**.

2.4.1. Shot of outlet tubing and pen tip **TEXT: Use as short and straight piece of tubing as possible**

3. 3D Pen Aerosol Emission Measurement Setup

3.1. Ten minutes before starting the 3D pen aerosol emission measurement, switch on the CPC (C-P-C) and SMPS (S-M-P-S) online measurement instruments **[1-TXT]** and preload the 3D pen with the filament of interest **[2]**.

3.1.1. WIDE: Talent turning on instruments **TEXT: CPC: Condensation Particle Counter and SMPS: Scanning Mobility Particle Size**

3.1.2. Talent loading pen with filament

3.2. When the pen has cooled, attach a HEPA filter to the SMPS inlet **[1]** and run a clean check measurement with the SMPS to ensure that the SMPS is not contaminated from previous measurements **[2-TXT]**.

3.2.1. Talent attaching filter to inlet

3.2.2. Talent running measurement *Videographer: Important step* **TEXT: Do not measure particles if SMPS not clean**

3.3. Connect the chamber outlet to the CPC inlet **[1]** and use the CPC to check the concentration inside the chamber to ensure that the chamber is clean and that the experiments are running under the same conditions **[2]**.

3.3.1. Talent connecting chamber outlet to CPC inlet

3.3.2. Talent checking concentration in chamber *Videographer: Important/difficult step*

4. 3D Pen Aerosol Emission Measurement

4.1. To measure 3D pen aerosol emissions, insert the preloaded and cooled down 3D pen into the chamber **[1]** and make sure that the outlet tubing of the chamber is connected to the CPC **[2]**.

4.1.1. WIDE: Talent inserting pen into chamber

4.1.2. Talent connecting tubing to CPC

4.2. Start the computer connected to the CPC **[1]** and open a new file with a name suitable for the measurements to be taken **[2]**.

4.2.1. Talent starting computer

4.2.2. Talent opening file, with monitor visible in frame

4.3. Make sure that the **CPC flow** is set to 0.3 liters/minute **[1]** and measure the background concentration for 10 minutes **[2]**.

4.3.1. Talent setting CPC flow to 0.3 L/min

4.3.2. SCREEN: screenshot_1: 00:22-03:30 *Video Editor: please speed up*

4.4. At the end of the measurement, switch on the 3D pen **[1]** and select the appropriate temperature for the loaded filament **[2]**.

4.4.1. Talent switching on pen

4.4.2. Talent setting temperature on 3D printing pen NOTE: in one step with 4.4.1

4.5. When the filament temperature has been reached, start the printing process **[1]** and let the 3D pen print for 15 minutes **[2]**.

4.5.1. Talent 3D pen printing

4.5.2. Pen printing

4.6. At the end of the printing period, connect the outlet tubing to the SMPS **[1]** and obtain size distribution measurements every 3 minutes for the next 30 minutes **[2]**.

4.6.1. Talent connecting tubing to SMPS

4.6.2. SCREEN: screenshot_2: 00:32-02:41 *Video Editor: please speed up*

4.7. When all of the measurements have been acquired, remove the printed filament **[1-TXT]** and clean the chamber **[2]**.

4.7.1. Talent removing filament **TEXT: Repeat each measurement x3**

4.7.2. Talent cleaning chamber *Videographer: Important step*

5. Metal Content Quantification

5.1. To quantify the sample preparation by inductively coupled plasma mass spectrometry, print the filament of interest on a plastic surface to avoid contamination with metal **[1]** and use a ceramic knife to cut the filament into smaller pieces **[2]**.

5.1.1. WIDE: Talent printing filament

5.1.2. Talent cutting filament into smaller pieces

5.2. Weigh out approximately 150 milligrams of both bulk and printed filament **[1]** and transfer the filament pieces into microwave vessels **[2]**.

5.2.1. Talent adding filament to weight boat
5.2.2. Talent adding pieces to vessel

5.3. Add 1.5 milliliters of water, 3.5 milliliters of nitric acid, and 1 milliliter of hydrogen peroxide to each sample **[1-TXT]**.

5.3.1. Talent adding acid to water, with acid and peroxide containers visible in frame
TEXT: CAUTION: Add water before acid!

5.4. Place the vessels into the microwave **[1]** and heat the samples to 200 degrees Celsius for 20 minutes **[2]**.

5.4.1. Talent placing vessel(s) into microwave
5.4.2. Talent setting/starting microwave

5.5. At the end of the digestion, dilute all of the filament samples in ultrapure water for which a high metal concentration is known or suspected to avoid contamination of the instrument **[1]**.

5.5.1. Talent adding water to sample, with solution container visible in frame

5.6. Then use a survey scan to determine which metals are in the samples **[1]** and quantify the metal content **[1-added]** of the specific metals using the appropriate calibrations standards **[2]**.

5.6.1. Talent using survey scan to assess sample
5.6.1.1 Added shot: Machine sampling
5.6.2. Talent quantifying metal contents of sample, with monitor visible in frame

Protocol Script Questions

A. Which steps from the protocol are the most important for viewers to see? Please list 4 to 6 individual steps.

2.2.1., 2.3.1., 3.2.2., 3.3.2., 4.7.2.

B. What is the single most difficult aspect of this procedure and what do you do to ensure success? Please list 1 or 2 individual steps from the script above.
3.3.2., clean chamber again, wait until background concentration is low as in previous measurements.

Results

6. Results: Representative Particle Size and Geometric Mean Diameter Distribution and Sample Imaging

6.1. As observed **[1]**, higher numbers of ABS (A-B-S)-black particles are released during printing **[2-TXT]** compared to printing with PLA (P-L-A)-black **[3-TXT]**.

6.1.1. LAB MEDIA: Figure 3
6.1.2. LAB MEDIA: Figure 3 *Video Editor: please emphasize ABS-black data line* **TEXT: ABS: acrylonitrile butadiene styrene**
6.1.3. LAB MEDIA: Figure 3 *Video Editor: please emphasize PLA-black data line* **TEXT: PLA: polylactide**

6.2. Increasing the temperature during the printing of PLA results in higher particle number concentrations with no significant effect on the geometric mean diameter of the particles **[1]**. Printing with ABS results in high particle number concentrations and larger particles compared to printing with PLA **[2]**.

6.2.1. LAB MEDIA: Figure 4 *Video Editor: please emphasize red and yellow PLA data line peaks*
6.2.2. LAB MEDIA: Figure 4 *Video Editor: please emphasize blue data line peak*

6.3. As expected, a clear trend in difference in the geometric mean diameter is observed **[1]** between the particles emitted during printing with ABS and PLA filaments **[2]**.

6.3.1. LAB MEDIA: Figure 5 *Video Editor: please emphasize ABS data bars*
6.3.2. LAB MEDIA: Figure 5 *Video Editor: please emphasize PLA data bars*

6.4. Transmission electron microscopy imaging shows particle sizes mostly around 50 nanometers for PLA **[1]** and almost consistently larger particles up to 100 nanometers for ABS black **[2]**.

6.4.1. LAB MEDIA: Figures 8A and 8B *Video Editor: please emphasize particles in Figure 8A*
6.4.2. LAB MEDIA: Figures 8A and 8B *Video Editor: please emphasize particles in Figure 8B*

6.5. PLA-copper filaments contain copper **[1]** mostly in crystalline form **[2]** as well as PLA particles **[3]**.

6.5.1. LAB MEDIA: Figure 8C
6.5.2. LAB MEDIA: Figure 8C *Video Editor: please emphasize circle/particle in circle*
6.5.3. LAB MEDIA: Figure 8C *Video Editor: please emphasize arrow/particle indicated by arrow*

6.6. In this image, a released carbon nanotube from a PLA-carbon nanotube filament is possibly observed **[1]**.

6.6.1. LAB MEDIA: Figure 8D *Video Editor: please emphasize particle in circle*

6.7. The release of small steel particles during the printing with a PLA-steel filament **[1]** and a possible agglomeration of silver aluminum-flakes during printing with PLA-compound with an incredibly high silver aluminum-flakes amount may also be observed **[2]**.

6.7.1. LAB MEDIA: Figures 8E and 8F *Video Editor: please emphasize particle in circle in Figure 8E*
6.7.2. LAB MEDIA: Figures 8E and 8F *Video Editor: please emphasize particle in circle in Figure 8F*

Conclusion

7. Conclusion Interview Statements

7.1. **Heike Sigloch**: Further analysis of the aerosol by online coupling of ICP-MS short for inductively coupled plasma mass spectrometry can facilitate the quantification of emitted metals **[1]**.

7.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

7.2. **Heike Sigloch**: Our fast and cost-effective method can also be used to identify particle emissions in other areas that could benefit from aerosol characterization **[1]**.

7.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera