

# Particle Number Emission Rate Calculations Used in Measuring Emissions from Fused Deposition Modeling 3D Printers

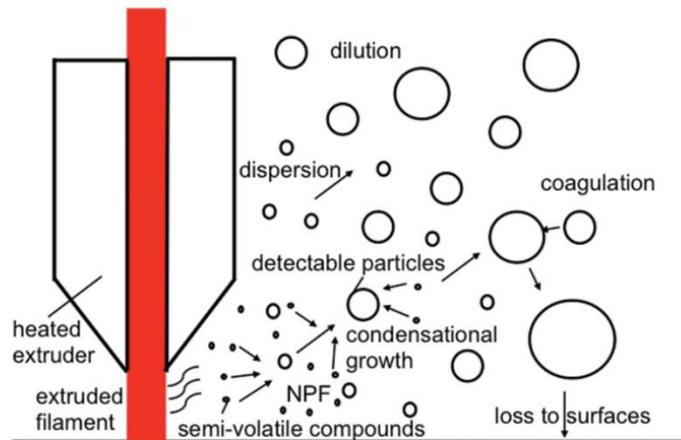
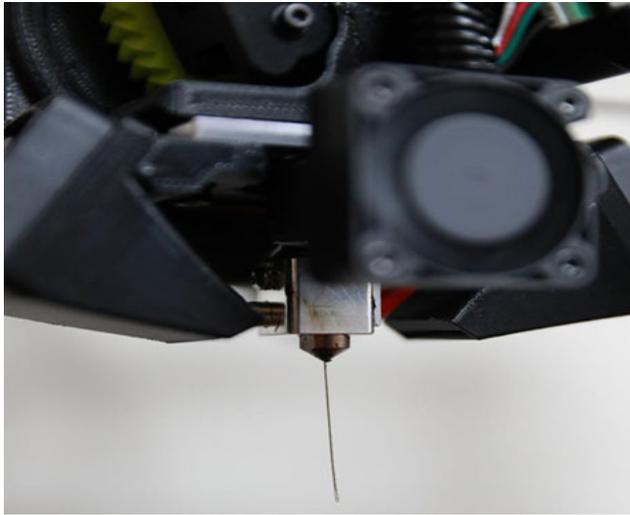
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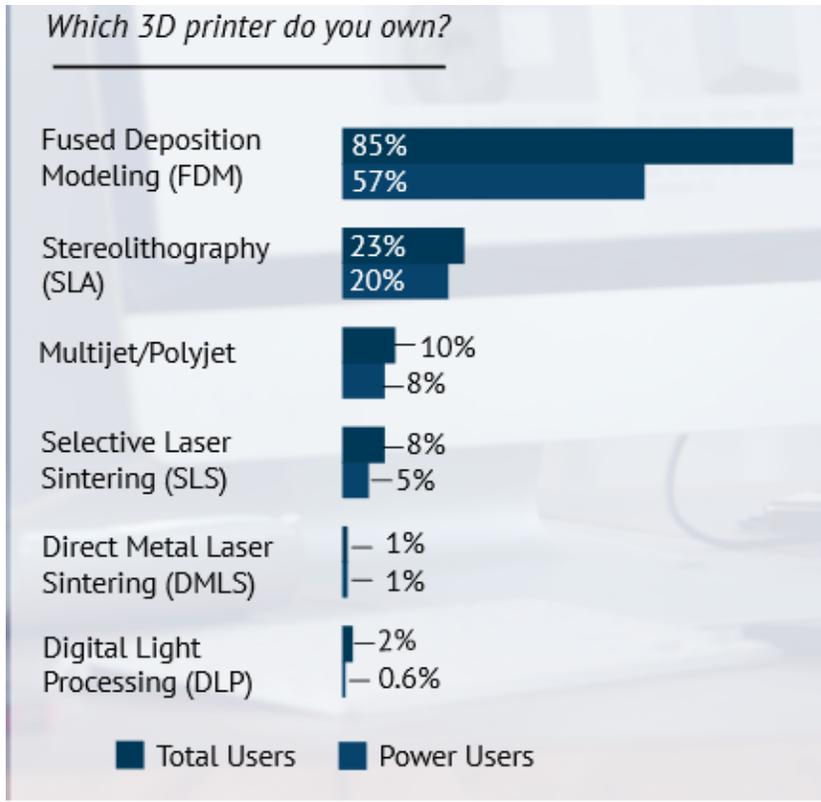
<sup>3</sup>*Exposure Methods & Measurements Division, National Exposure Research Laboratory, USEPA*

# How Do FDM 3D Printers Emit Particles?



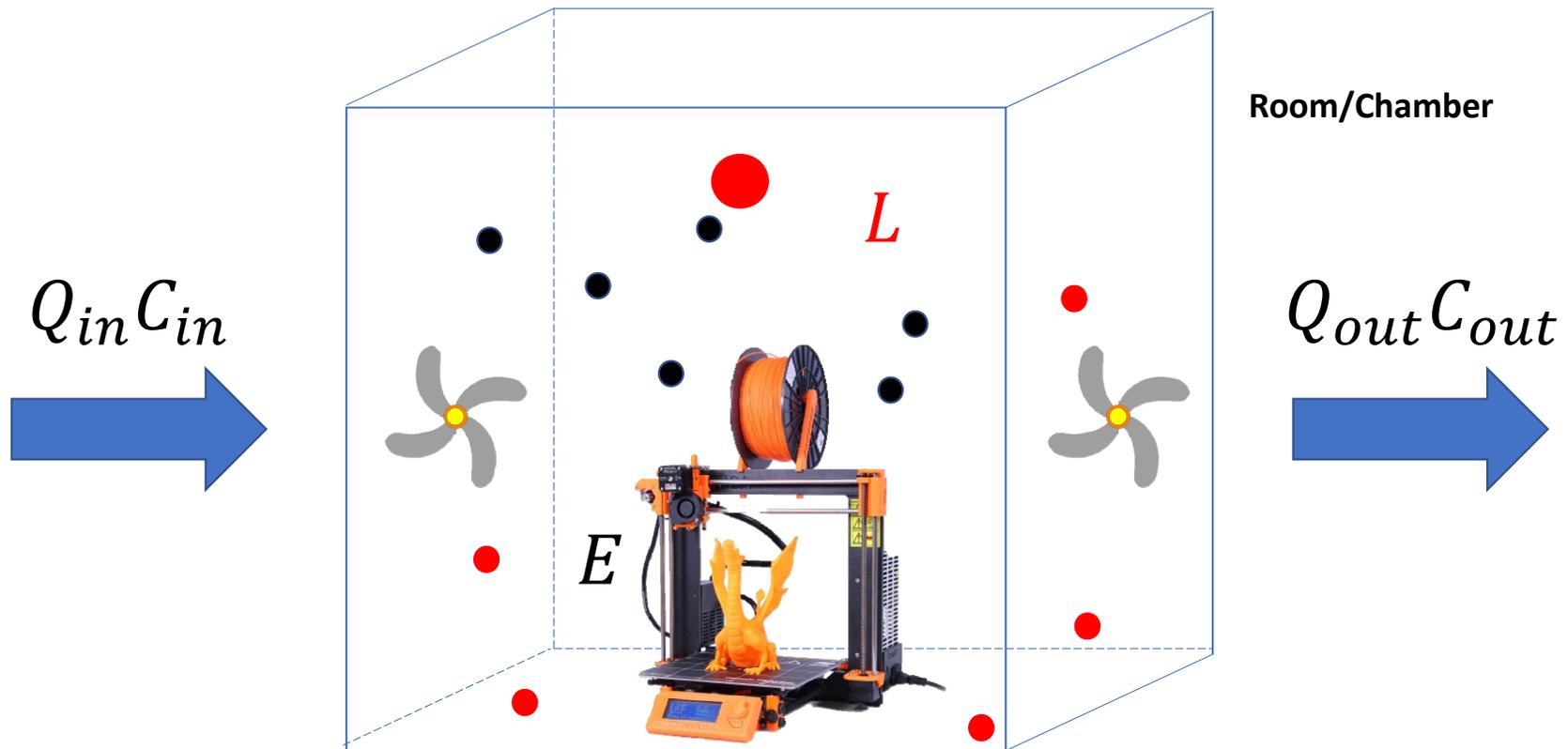
- As filament is pushed through the nozzle, the nozzle is at around 200 deg C
- Billions of particles per minute released
- Majority of particles in the ultrafine range (<100 nm in diameter)
- Volatile organic compounds including styrene may be released
- Metals?

# Why Should We Care About FDM 3D Printers?



- FDM printers are extremely popular for at home or office use
- 278,000 desktop 3D printers (under \$5,000) were purchased worldwide in 2016 (majority in U.S., Europe, South Korea)
- As 3D printers penetrate the consumer marketplace more, public opinion will shape the fate of this industry

# When Measuring Particles Emitted from a 3D Printer...There's a lot to Consider



$$PER_{t+1} = V \cdot \frac{C_{t+1} - C_t}{\Delta t} + Q_{out} \bar{C} + L - Q_{in} C_{in}$$

# Particle Number Emission Rate Methods

$$PER_{t+1} = V \cdot \frac{C_{t+1} - C_t}{\Delta t} + Q_{out} \bar{C} + L - Q_{in} C_{in}$$

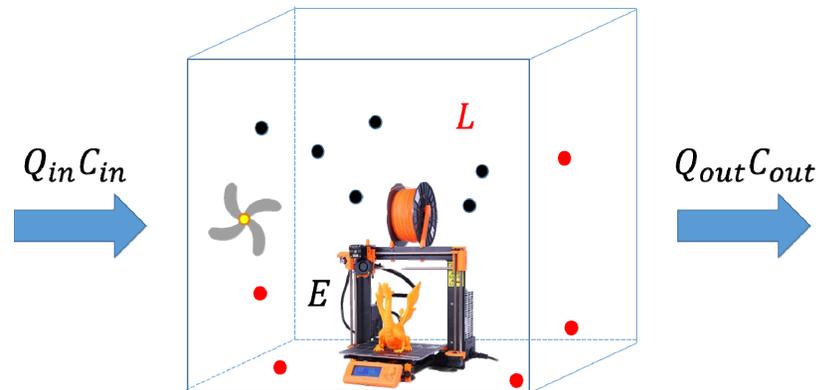
Yellow=Standard terms  
Red=Unique loss or  $Q_{in}$  terms

Study/Report - Equation	Consider Change in Concentration	Consider Outflow	Consider Settling	Consider Inflow	Consider Agglomeration	Combine Losses into One Factor	Separate Losses into Several Factors	Relies on Taylor Series to Form Equation
Yi et al., 2016 - 1	✓	✓						
Azimi et al., 2016 - 2	✓	✓	✓	✓		✓		
Vance et al., 2017 - 3	✓	✓	✓				✓	
Floyd et al., 2017 - 4	✓	✓	✓			✓		
German RAL-UZ-171 - 5 (Barthel et al., 2013)	✓	✓	✓			✓		✓

# Negative Emission Values?

- Printers are either off or emitting. They cannot “suck up” emissions in the chamber
- This tells us that some loss is unaccounted for
- Agglomeration, settling onto surfaces, leakage
- “...the emission model...does not account for aerosol agglomeration...to adjust for this effect, negative emission values were eliminated before the total aerosol emissions were calculated...”

$$PER_{t+1} = V \cdot \frac{C_{t+1} - C_t}{\Delta t} + Q_{out} \bar{C} + L - Q_{in} C_{in}$$



# The Need for a Standard Testing Apparatus and Emission Rate Methodology

- Influxes and losses unaccounted for in the measuring chamber can affect emission rate results drastically
- There needs to be both a standard testing procedure used **and** a standard equation used based on that experimental setup to accommodate influxes and losses
- Zhang et al., 2017 includes some recommendations on how to best to perform 3D printer measurements
- New 3D printer filaments with ENMs including carbon nanotubes, graphene and metal particles will need to be tested

# Slide 8 References

Yi, J., et al. (2016). "Emission of particulate matter from a desktop three-dimensional (3D) printer." *J Toxicol Environ Health A* 79(11): 453-465.

Azimi P, Zhao D, Pouzet C, Crain NE, Stephens B. Emissions of Ultrafine Particles and Volatile Organic Compounds from Commercially Available Desktop Three-Dimensional Printers with Multiple Filaments. *Environ Sci Technol*. 2016;50(3):1260–8.

Vance, M. E., Pegues, V., Van Montfrans, S., Leng, W., & Marr, L. C. (2017). Aerosol Emissions from Fuse-Deposition Modeling 3D Printers in a Chamber and in Real Indoor Environments. *Environ Sci Technology*, 51(17), 9516-9523.

Floyd, E. L., Wang, J., & Regens, J. L. (2017). Fume emissions from a low-cost 3-D printer with various filaments. *J Occup Environ Hyg*, 14(7), 523-533.

Barthel, M., Seeger, S., Rothhardt, M., Wilke, O., Horn, W., Juritsch, E., . . . Jann, O. (2013). Measurement of Fine and Ultrafine Particles from Office Devices during Printing in order to Develop a Test Method for the Blue Angel Ecolabel for Office-Based Printing Devices.

# Basis of Dynamic Mass Balance Particle Number Emission Rates

