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Investigating Particle Emissions from a Consumer Fused Deposition Modeling 3D Printer with a Lognormal Moment Aerosol Dynamic Model

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Introduction
• Fused deposition modeling (FDM) 3D printers are popular with general public and usually used in indoor environments not designed for manufacturing.¹
• High levels of nanoparticles and gases from 3D printers were reported, depending on printer and filament properties,²,³ which may cause adverse health effects.⁴
• Particle formation mechanism and aerosol dynamic processes involved have not been systematically investigated.

Objective
• Examine 3D printer particle emission and evolution mechanism with a lognormal moment model using chamber experiment data.
• Investigate key factors that influence particle emissions.
• Potential mitigation method.

Method
Chamber experiment
• Chamber condition: Temperature 23 ± 1°C, Relative humidity 3.0 ± 0.2%.
• Aerosol measurement: Particle number distributions as a function of time.

Lognormal moment model
• Control volume (CV) defined by x, h, b, and the control volume.
• Assumptions: No external processes at/ across CV boundary, Neglect particle losses to chamber surfaces, Particles were chemically homogeneous, No chemical reactions, Temperature (T) in CV uniform and constant, Out of CV only dilution.
• Governing equations: 0th moment: \( \frac{dN}{dt} = \frac{D_n}{v_{gi}} \), 1st moment: \( \frac{d\langle D_n \rangle}{dt} = \frac{1}{v_{gi}} \), 2nd moment: \( \frac{d\langle D_n^2 \rangle}{dt} = \frac{1}{v_{gi}} \), Vapor balance: \( \frac{dV}{dt} = \frac{dV}{dx} - \frac{1}{\rho} \frac{dP}{dx} \).

Results
• Input (R, f, P, T, s) → Output (steady state N, \( D_{50} \), \( \sigma_d \)).

Observation
Fig.3 Total particle number concentrations and geometric mean diameters measured in chamber.
Fig.4 Average particle size distributions at the steady state.

Sensitivity analysis
Fig.5 The simulated steady state particle characteristics (N, \( D_{50} \), \( \sigma_d \)) as a function of each vapor property (P, f, R) separately when controlling the other two.

Discussion & Conclusion
• A lognormal aerosol moment model is capable of capturing the particle characteristics at steady state during printing phase.
• Modeled aerosol processes: particles are formed from nucleation of semi-volatile vapors emitted from the heated filament, and then grow by vapor condensation and particle coagulation in a small control volume close to extrusion nozzle.
• These dynamic processes were interrelated and depended on some key properties of the condensing vapors (R, f, P).
• Printing conditions (filament material, filament brand and extrusion temperature) influenced the steady state particle characteristics and could be related to the differences in the model predicted properties.
• Particles are formed from semi-volatile compounds associated with additives in filaments (i.e., different from bulk filament).
• Vapor generation rate from the filament largely drove the particle emissions and linked to printer extruder temperature.
• Possible mitigation strategy: remove the newly formed small particle near the extruder nozzle by thermophoresis.

References