PARTICLE DEPOSITION FOR ENERGETIC MATERIALS

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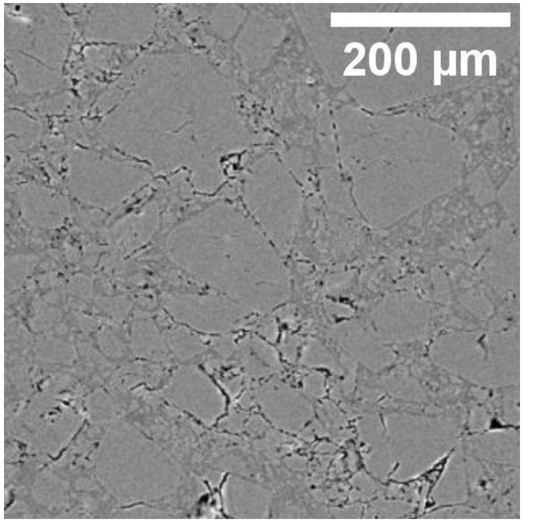
Motivation

- Polymer-bonded explosives (PBXs) are manufactured by die-compacting molding powder or prills
- Imprecise die filling before pressing offers limited control over microstructure, including defects such as porosity and cracks, leading to uncertainty in energetic performance and sensitivity
- Accurate, direct filling of a die with raw energetic powder and binders could allow better control of microstructure and reduce uncertainty in PBX sensitivity
  - Particle deposition processes are a prime candidate to enable this idea of improved PBX manufacturing
  - Our goal is to determine how we can control particle deposition and to characterize the particle flow



Prill-based PBX 9501 microstructure [1]

[1] Yeager, J; Kuettner, L; Duque, A; Hill, L; Patterson, B; Microcomputed X-ray tomorgraphic imaging and image processing for microstructural characterization of explosives. Materials. 2020, 13, 4517.

Particle Deposition Overview

- Powder behavior (i.e., flowability) depends primarily on particle size and density [2]
  - Fine particles are cohesive and resist flow
  - Coarse particles typically flow more freely
- Internal stress fields near a hopper's orifice can create stable arches
  - Collapsing this arch via applied vibration induces powder flow
  - Stopping vibration allows the arch to reform and prevent further deposition
- Key advantage: mechanically simple process to actuate and stop flow
  - Has a history in other industries (i.e., pharmaceuticals, etc.)

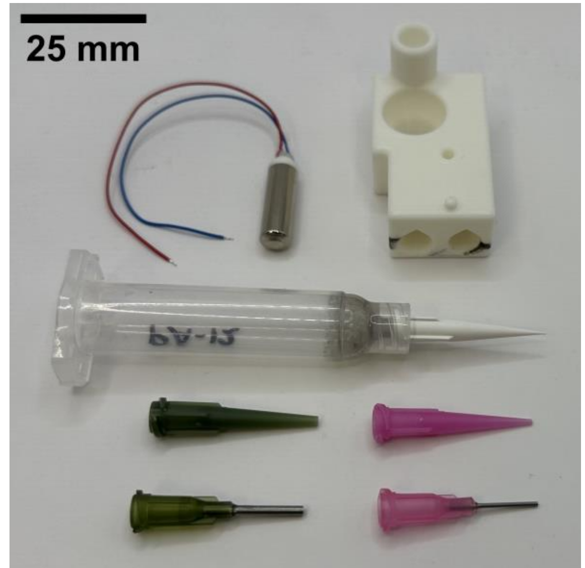
Fine metal powder arching in a glass nozzle [3]

Fine metal powder flowing due to applied vibration [3]

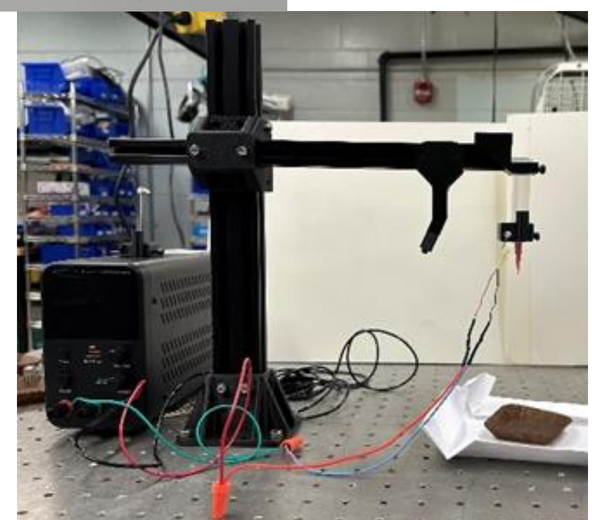
[2] Geldart, D; Types of gas fluidizaion. Powder Tech. 1973, 7, 285-292
[3] Chiarabutra, S.; Mellor, B.; Yang, S.; A dry powder material deliver device for multiple material additive manufacturing. University of Southampton, UK, 2020.

Testing Equipment

- 5cc Luer-lock syringes used as powder hoppers
- Polypropylene tapered and stainless steel blunt-end 14-27Ga Luer-lock nozzle tips
- 7x25 mm 3V DC vibration motor
  - Driven by DC power supply
  - Custom mount
- Custom test stand
  - Adjustable configuration



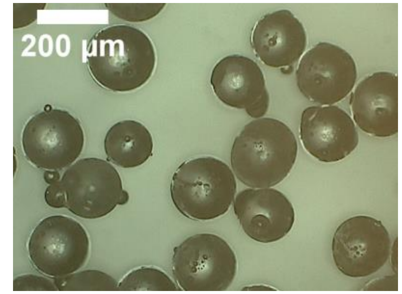
Motor, motor mount, syringe with 27Ga tip, 14Ga (olive) and 20Ga (pink) tips



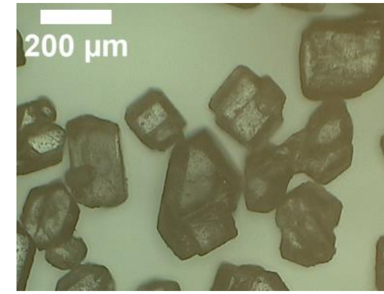
Test stand with syringe and motor in place

Materials

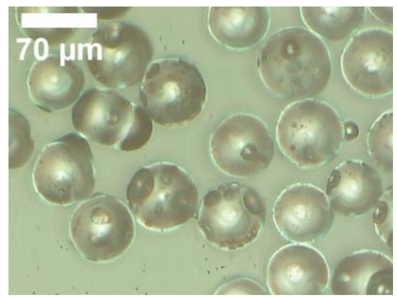
- Soda lime (SL) microspheres
  - Density: 2.5 g/cm^3
  - Sizes: 150-212 µm, 63-90 µm, 53-75 µm, 13-45 µm (as received)
- Granulated sugar
  - Density: 1.6 g/cm^3
  - Size: 150-212 µm (sieved)
- PA12 SLS 3DP powder
  - Density: 1 g/cm^3
  - Size: 42-71 µm (as received)



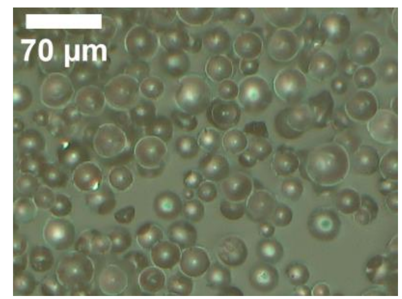
150-212 SL



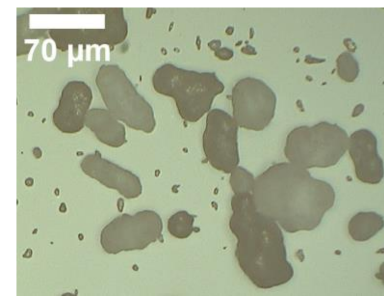
150-212 Sugar



53-75 SL



13-45 SL



PA12

Sugar 150-212 53-75 13-45 PA12

Soda Lime

Each pile is 1 gram of powder

Experiments and Data Collection

- Arching behavior classification
  - Explore the effect of the ratio between powder diameter and the orifice diameter (diameter ratio)
  - No vibration applied
- High-speed video recordings
  - Recorded on Phantom VEO-E 340L
  - 1600 fps, 1280x720 10-µm square pixels
  - 0.1s playback at 24 fps (slowed down 66.7x)
  - Voltage varied from 1.3V-3.4V (~140-320Hz)
  - Tested effect of tapered and blunt end tips, nozzle size, particle type, and particle size

Video Set	Material and Nozzle Tip
1	150-212 µm soda lime 20Ga tapered tip
2	150-212 µm soda lime 20Ga Blunt-end tip
3	150-212 µm sugar 20Ga tapered tip
4	150-212 µm sugar 20Ga blunt-end tip
5	53-75 µm soda lime 25Ga tapered tip
6	13-45 µm soda lime 20Ga tapered tip
7	13-45 µm soda lime 25Ga tapered tip
8	42-71 µm PA12 22Ga tapered tip

Arching Behavior Classification

Tip Gauge	Tip ID (µm)	Sugar (150-212)	Glass (150-212)	Glass (63-90)	Glass (53-75)	Glass (13-45)	PA12 (42-71)
14	1530	***7.22***	*7.22*	*17.00*	*20.40*	**34.00**	*21.55*
16	1180	***5.57***	*5.57*	*13.11*	*15.73*	**26.22**	*16.62*
18	830	**3.92**	*3.92*	*9.22*	*11.07*	**18.44**	*11.69*
20	620	**2.92**	**2.92**	*6.89*	*8.27*	**13.78**	**8.73**
22	410	<u>1.93</u>	**1.93**	*4.56*	*5.47*	**9.11**	**5.77**
25	300		<u>1.42</u>	**3.33**	**4.00**	**6.67**	**4.23**
27	230			<u>2.56</u>	**3.07**	**5.11**	<u>3.24</u>

Tip Gauge	Tip ID (µm)	Sugar (150-212)	Glass (150-212)	Glass (63-90)	Glass (53-75)	Glass (13-45)	PA12 (42-71)
14	1600	***7.55***	***7.55***	***17.78***	***21.33***	**35.56**	*22.54*
15	1370	***6.46***	***6.46***	***15.22***	***18.27***	**30.44**	*19.30*
16	1200	***5.66***	***5.66***	***13.33***	***16.00***	**26.67**	*16.90*
18	840	**3.96**	***3.96***	***9.33***	***11.20***	**18.67**	*11.83*
20	600	**2.83**	**2.83**	***6.67***	***8.00***	**13.33**	***8.45***
21	510	**2.41**	**2.41**	***5.67***	***6.80***	**11.33**	*7.18*
22	410	<u>1.93</u>	**1.93**	*4.56*	***5.47***	**9.11**	**5.77**
23	340		<u>1.60</u>	**3.78**	***4.53***	**7.56**	*4.79*
25	260			<u>2.89</u>	**3.47**	**5.78**	**3.66**
27	210				**2.80**	**4.67**	**2.96**

Top table: Tapered tips

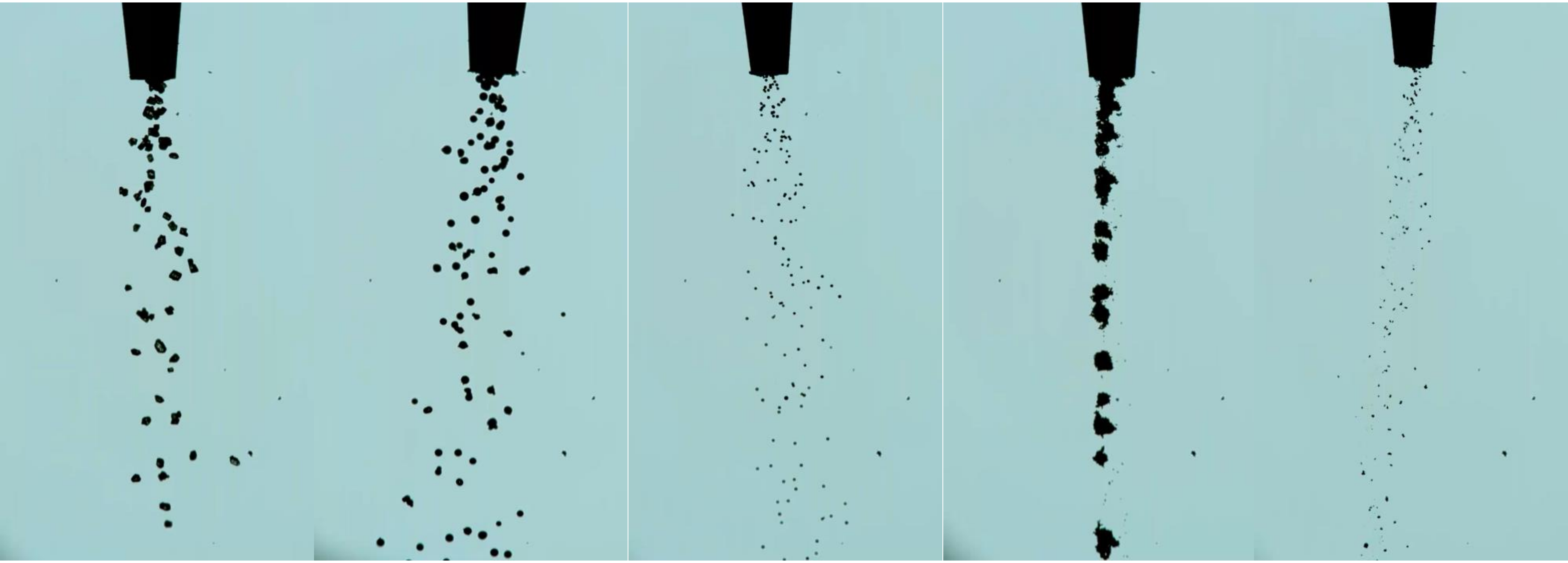
Bottom table: Blunt-end tips

ID/d_{90} used in tables based on [4]

Color Key
Free flow
Arching
Forced arch
<u>Clogging</u>
Unreliable

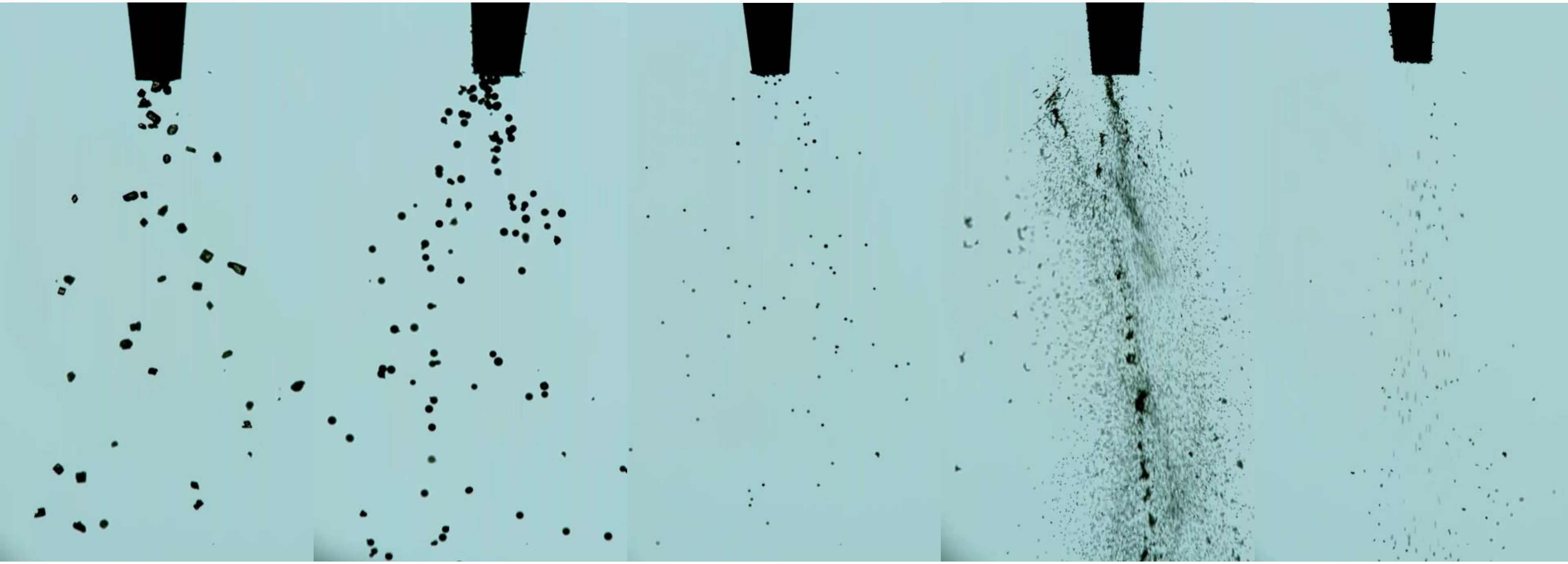
[4] Xu, S.; Sun, H.; Cai, Y.; Geng, X.; Studying the orifice jamming of a polydispersed particle system via coupled CFD-DEM. Powder Tech. 2020, 368, 308-322.

Flow Behavior of Different Materials at 1.9V (~200Hz)



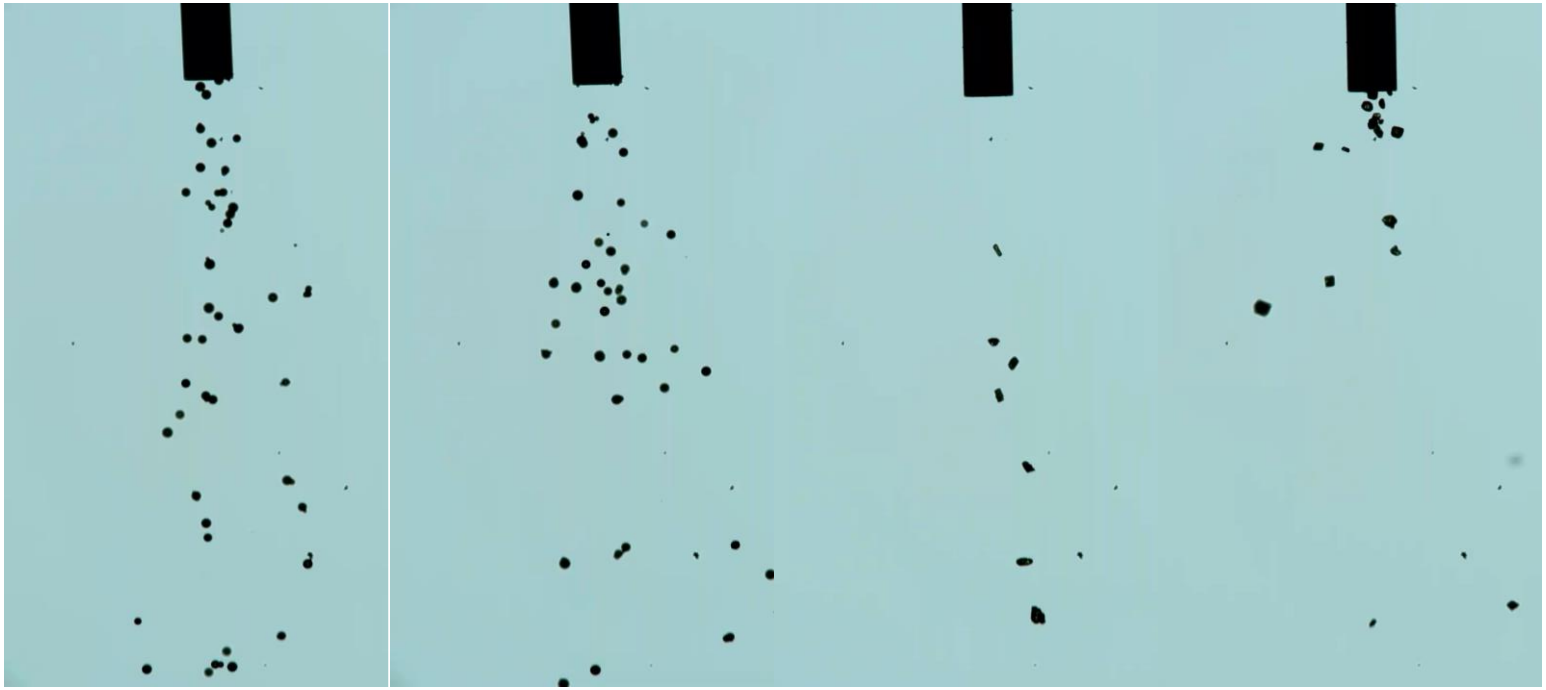
150-212 µm Granulated Sugar $1.6\ g/cm^3$	150-212 µm	53-75 µm Soda Lime Microspheres $2.5\ g/cm^3$	13-45 µm	42-71 µm SLS PA12 $1.0\ g/cm^3$

Flow Behavior of Different Materials at 3.1V (~300Hz)



150-212 µm Granulated Sugar 1.6 g/cm^3	150-212 µm	53-75 µm Soda Lime Microspheres 2.5 g/cm^3	13-45 µm	42-71 µm SLS PA12 1.0 g/cm^3

Effect of Blunt-End Tips

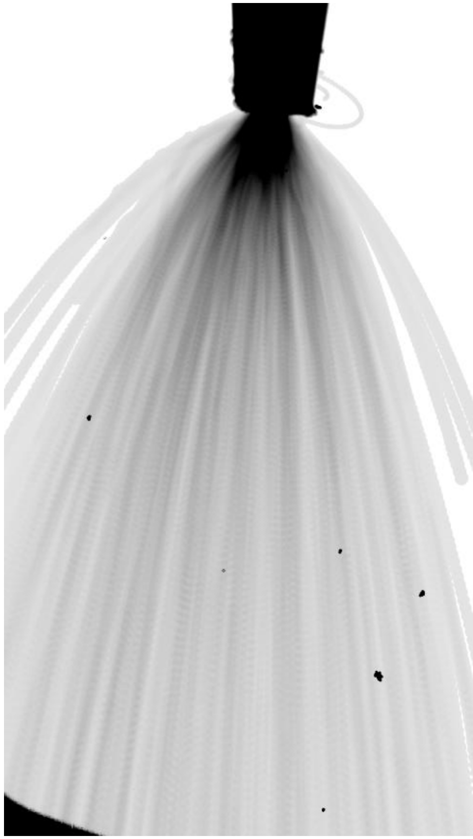


1.9V 3.1V
Soda Lime Microspheres
150-212 µm

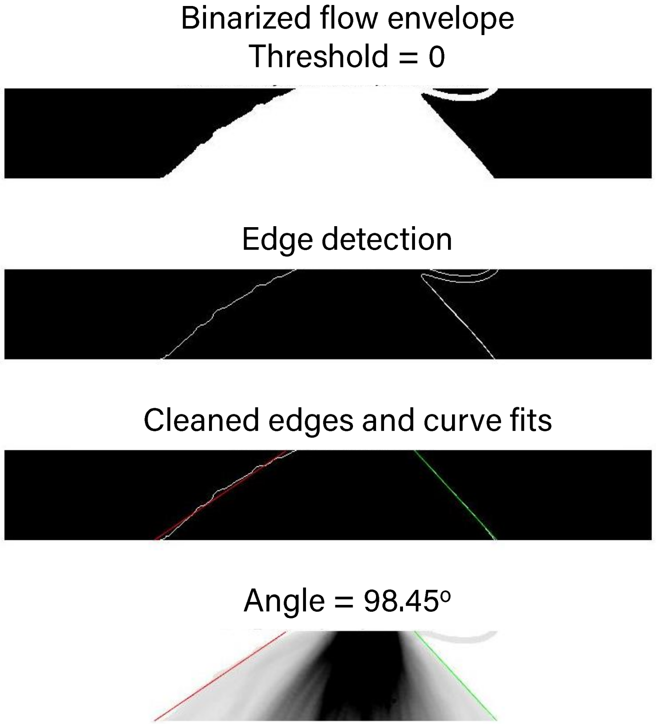
1.9V 3.1V
Granulated Sugar
150-212 µm

Particle Deposition Video Analysis

- Process video into long-exposure, heatmap image
- Cone angle calculation
  - Binarize image, thresholding can filter out particle traces
  - Extract left and right edges from the first millimeter of the spray pattern
  - Fit lines to the edges
  - Calculate the angle between the lines



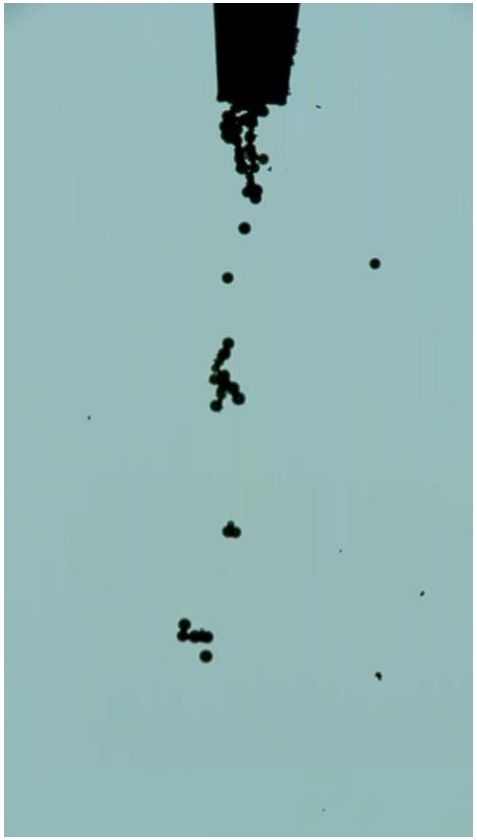
Heatmap of 3.1V 150-212 μm soda lime video



Cone angle demonstration

Electrostatically Affected Deposition

- Improper grounding of wires changed flow
- Particles agglomerate into bonded chains at nozzle tip until a group is heavy enough to break away
- Deposition speed significantly reduced
- Particles can stick to the outer surface of the nozzle
- Future work will look at
  - Dependence on materials
  - Dependence on particle size
  - Quantifying the electrostatic discharge



2.5V, 150-212 µm soda lime, charged flow

Conclusions

- Free-flowing, coarse powders had limited compatible tip sizes for toggleable arching. Typically, a range of approximately $3 < ID/d_{90} < 5$ is useable
- Fine, cohesive powders demonstrate desirable arching behavior for a wide range diameter ratios, which is helpful for more precise flow rates and localized deposition
- Sugar needed larger orifices to controllably arch compared to spheres, while the deposition pattern (cone angle) didn't seem too affected by shape
- The particle flow behavior of fine particles was cyclic and subject to drift, whereas it was more uniform for the coarse particles
- Blunt-end tips demonstrated less dependence on voltage, but more dependence on particle shape
- Electrostatic charge dramatically changes deposition pattern and flow rate

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Thank you!

Questions?