Development of a 3D printed wind tunnel to investigate the effects of morphology on particle resuspension

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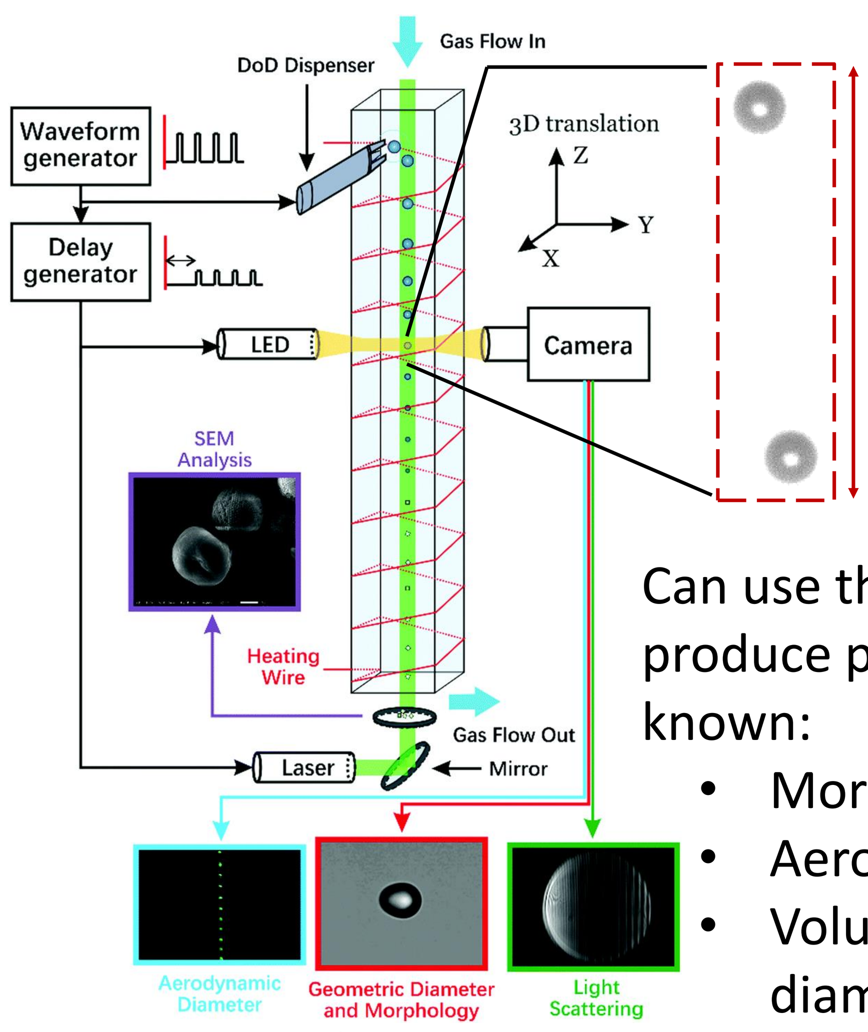
Design of a lab bench wind tunnel to accompany the Falling Droplet Column apparatus, producing particles of uniform aerodynamic size and morphology for resuspension studies

At a Glance

Why Study Particle Resuspension?

- Particle resuspension is omnipresent in our lives, with vacuuming, driving and wind all being common detachment mechanisms for particles.
- However, rarely is resuspension accounted for in models for aerosol dispersion, as a lack of knowledge on its governing factors limits the complexity of current mechanistic resuspension models*[1]*.
- Smaller scale, 3D printed wind tunnels, could provide an accessible and flexible method for investigating particle resuspension.

The Falling Droplet Column



Δt, Δz

$$v_s = \frac{\Delta z}{\Delta t}$$

$$d_a = \sqrt{\frac{18\mu v_s}{\rho_0 g}}$$

Can use the FDC to produce particles of known:

- Morphology
- Aerodynamic size
- Volume equivalent diameter

Fig.1. Schematic of the FDC as described by Hardy et al.[2]

Using Relative Humidity to Control the Size and Morphology of Sugars Dried in the FDC

As sugar solutions dry in lower RH conditions (<20% for sucrose, <50% for raffinose) they form particles with a viscous outer shell and void centre. RH can be used to control the quantity of water that remains in the particle and allows for varied surface plasticity and morphology in the cases of sucrose and raffinose particles, respectively.

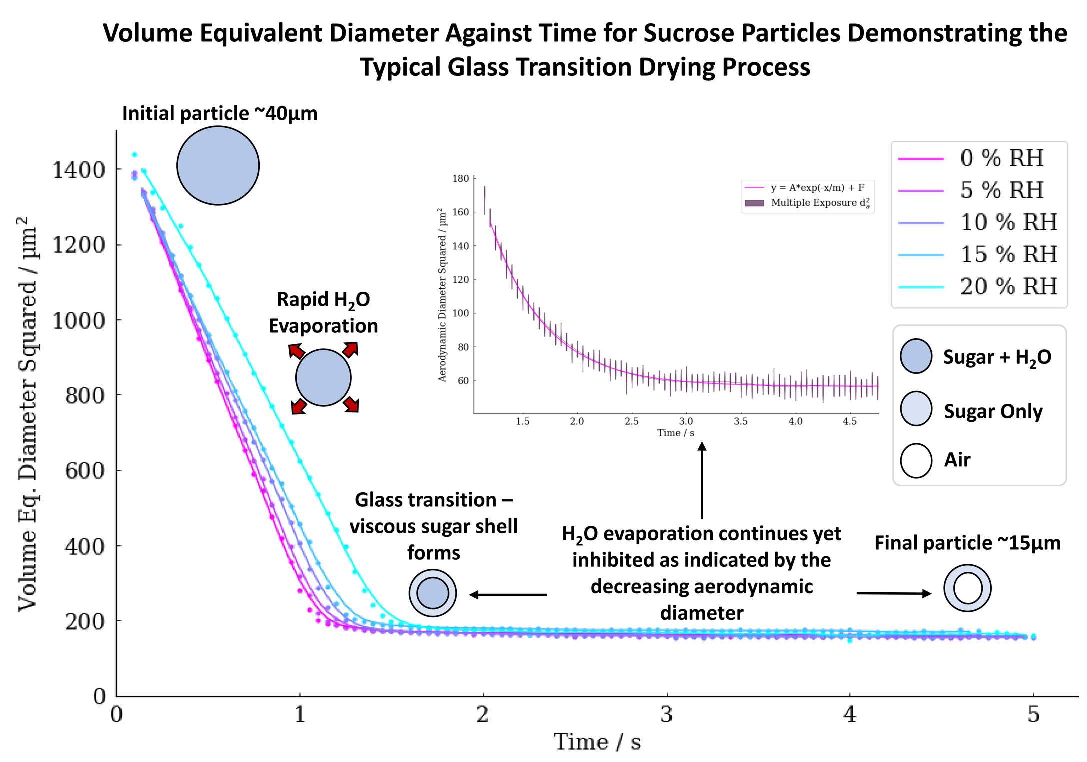


Fig.2. Graph displaying the typical sugar drying process.

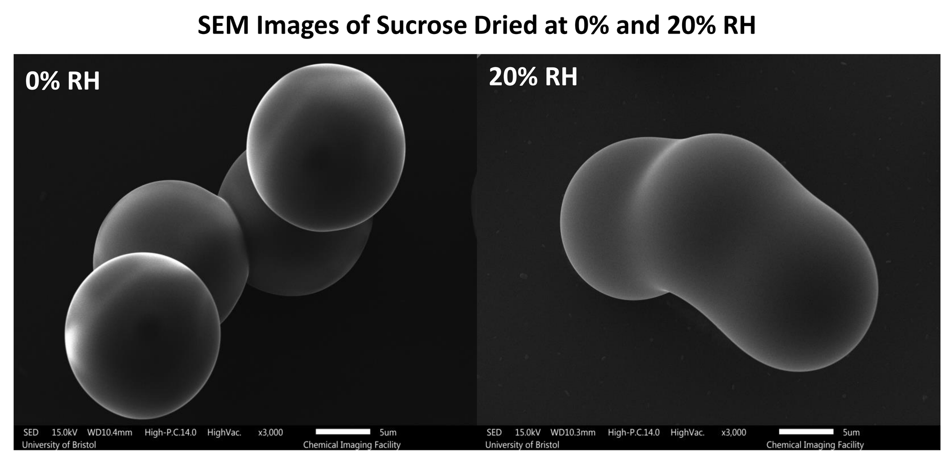


Fig.3. Sucrose dried in higher RH conditions is more likely to agglomerate with nearby particles suggesting that the increased water content reduces surface rigidity.

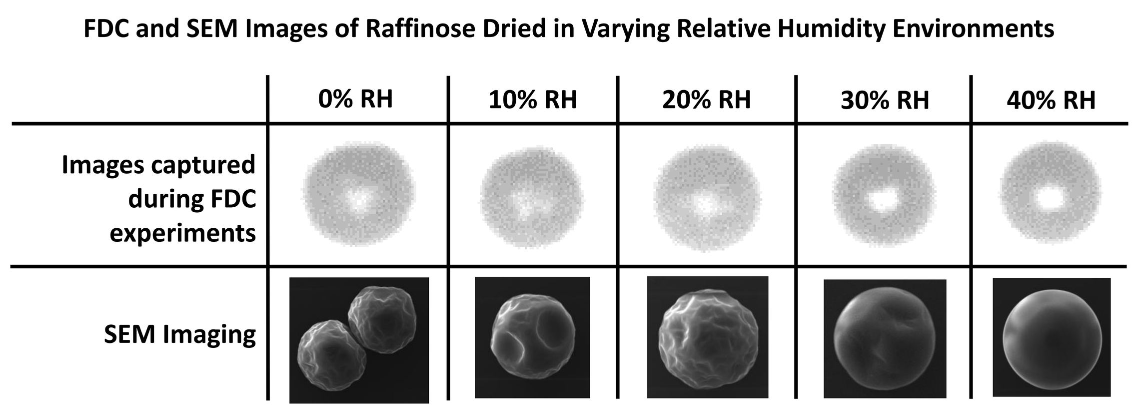


Fig.4. When dried in low RH environments (<30% RH) the surface of raffinose crumples, forming non spherical particles, before transitioning towards sphericity in the 20% - 40% RH range. The FDC hence offers the capability to tune raffinose morphology for resuspension experiments.

Wind Tunnel Design and Construction

An open design, driven by nitrogen gas through a 100 l/min mass flow controller, was adopted.

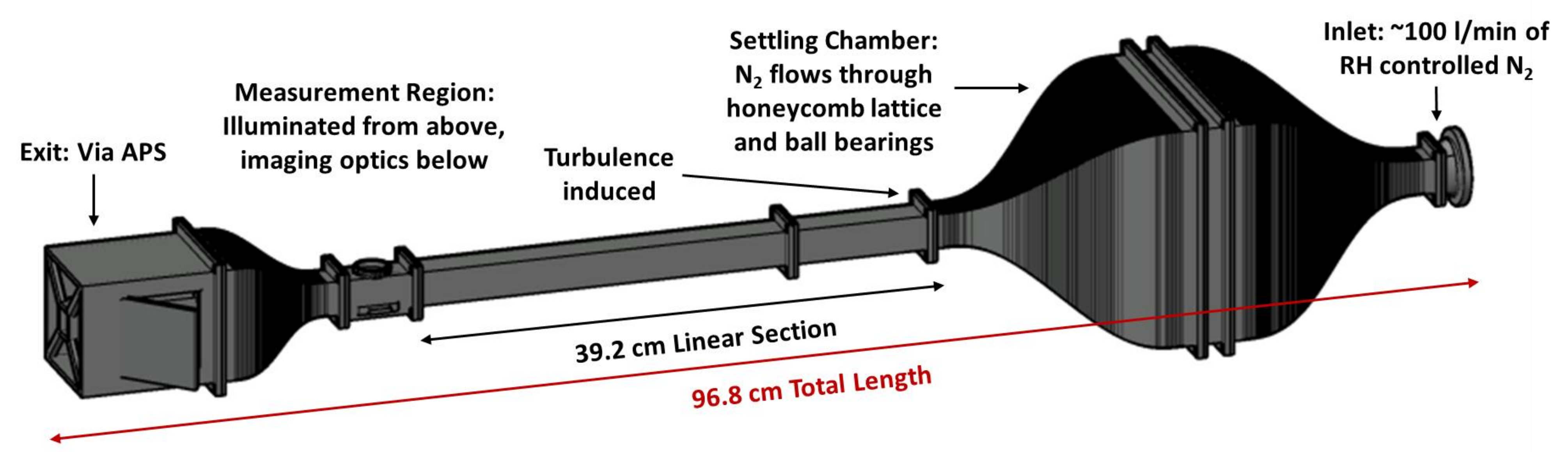


Fig.5. Schematic of the wind tunnel, measuring below 1 m in length with a largest cross section of 16 cm x 16 cm. The measurement region and main tunnel have a cross section of 2 cm x 2 cm.

Key Design Features:

- Particles must reside within the laminar boundary layer of a fully developed turbulent flow*[1]*. Hence the gas passes through a settling chamber, to ensure the flow is laminar before turbulence is induced. The long linear section allows the turbulent flow to fully develop prior to interacting with the particles.
- The measurement region is designed to be removed and attached to the FDC during particle production, limiting the potential for particles to be exposed to the lab environment.
- The tunnel is split into sections for ease of 3D printing and to allow for design updates.

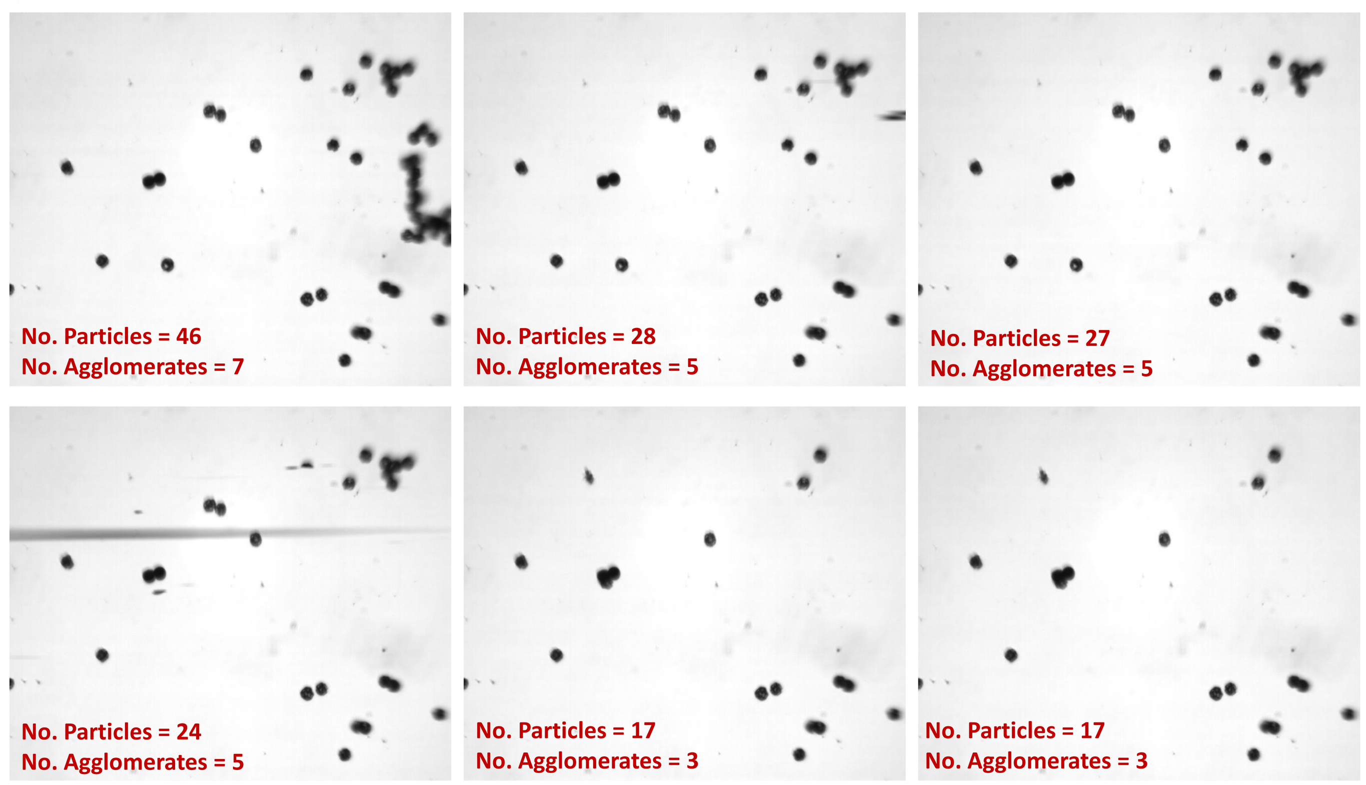


Fig.6. Six consecutive frames from a resuspension event captured with an 18fps camera. 63% of the visible particles (NaCl crystals created in the FDC at 0% RH with a ~15 µm diameter) were removed from the surface whilst the gas flow was accelerating to the maximum 100 l/min flow rate.

Future Work

SHORT TERM

- Optimising tunnel design via flow experiments and CFD.
- Add autonomy to the experiment with LabView.
- Establish a calibration method.

LONG TERM

- Investigate the relationship between morphology and rates of resuspension.
- Incorporate this knowledge into an existing ideal model.

References

[1] J. C. Vincent, et al., "Towards a predictive capability for the resuspension of particles through extension and experimental validation of the Biasi implementation of the 'Rock'n'Roll' model," *J. Aerosol Sci.*, vol. 137, no. July, p. 105435, 2019, doi: 10.1016/j.jaerosci.2019.105435.

[2] D. A. Hardy et al., "High time resolution measurements of droplet evaporation kinetics and particle crystallisation," Phys. Chem. Chem. Phys., vol. 23, no. 34, pp. 18568–18579, 2021, doi: 10.1039/d1cp02840e.