Exhalation, Inhalation Dynamics of Aerosol and Airborne Disease Transmission

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Highlighted Summary

Understanding the impact that airborne transport has on pathogens and the influence of environmental conditions on pathogen survival can inform the implementation of strategies to mitigate the spread of diseases such as COVID-19. However, from the point of generation to exhalation and inhalation dynamic of aerosol is poorly understood.

Two complimentary instruments are used to measure the (A) aerosol microphysical dynamics of respiratory aerosol surrogates and (B) the droplet pH change (chemical composition) change (alkaline) over time.

The results showed the composition-dependent drying and hygroscopicity profile will impact the viral survival (Langford data) and deposition efficiency through phase transition, size and pH evolution of respiratory aerosols. The CO_2 partitioning in respiratory aerosol phase is also very novel from this work.

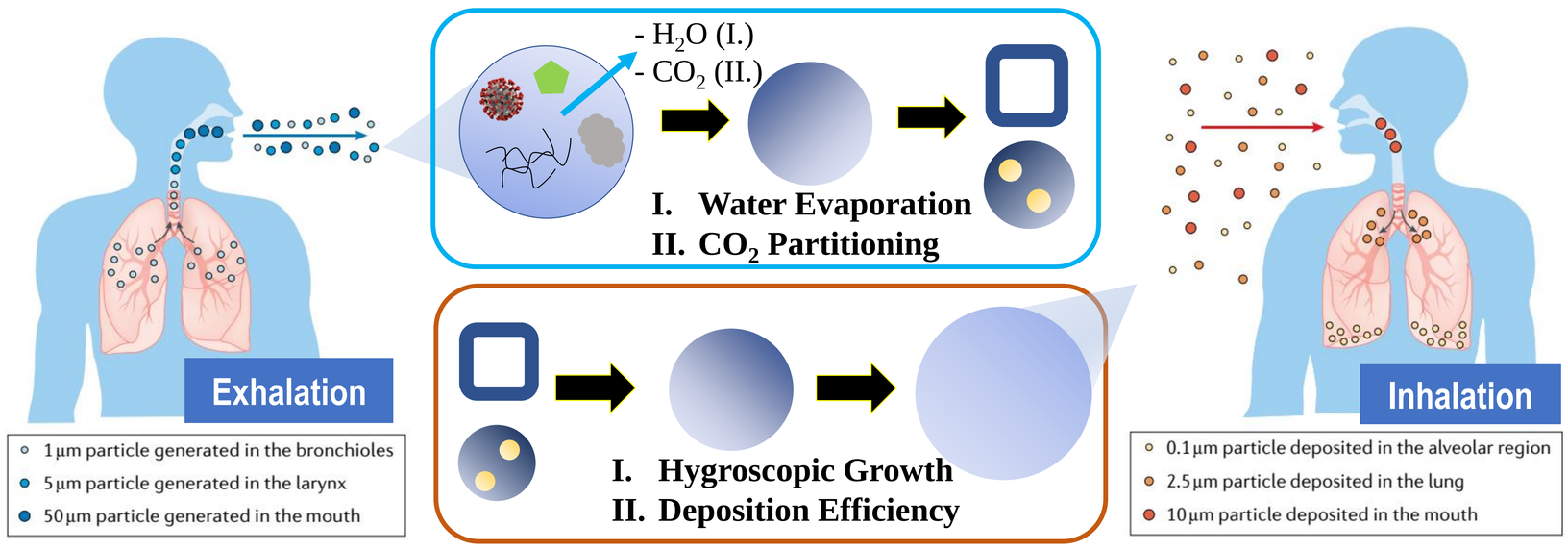


Figure 1: Diagram of the PhD Topic – Droplet Dynamics during Exhalation and Inhalation Processes

Human respiratory tract figures are from: http://dx.doi.org/10.1038/s42254-021-00307-4

Experimental Approaches to Study Respiratory Aerosol Dynamics

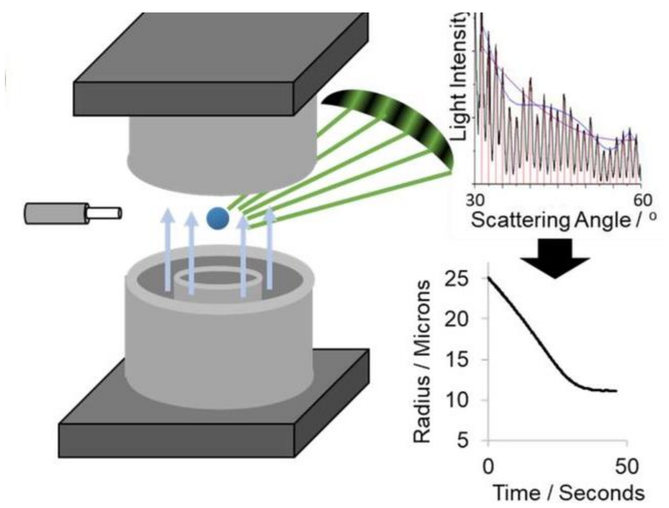


Figure 2: Comparative Kinetics Electrodynamic Balance (CK-EDB)

CK-EDB is able to provide:

- **Size revolution** (till equilibration) and **phase** information by collecting the elastic scattering light pattens by positioning a CCD camera from a droplet under the controlled relative humidity and temperature, and $CO_{2(g)}$ level in the near future (under construction).
- None-destructive **single-particle** technique
- **Hygroscopicity** study

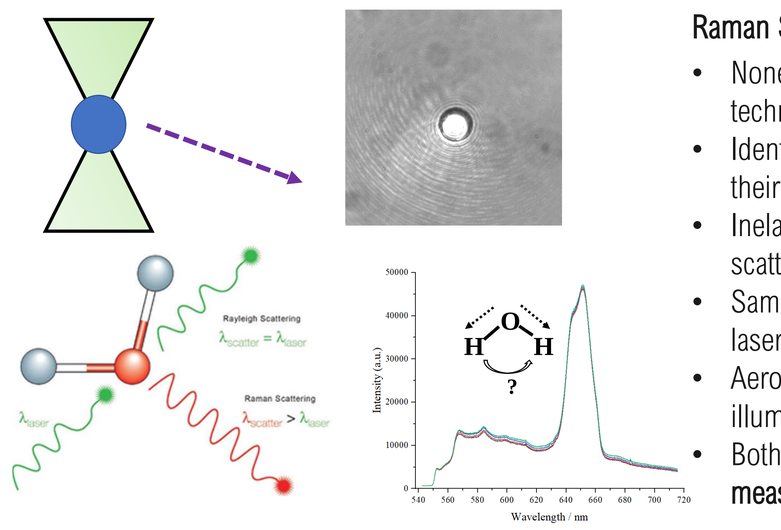


Figure 3: Aerosol Optical Tweezers (AOT-100)

Raman Spectroscopy:

- None-destructive **chemical analysis** technique
- Identification of molecules based on their **vibrational fingerprint.**
- Inelastic scattering of photons (Raman scattering)
- Sample is illuminated with a 532 nm laser beam
- Aerosol is imaged under brightfield illumination using a CCD camera
- Both **bulk** and **aerosol phase measurement** can be done.

The EDB and Raman system hold the potential to estimate droplet acidity. By changing the conditions in these systems, we can explore in great detail how aerosol dynamics changes as a function of environmental conditions, and interpret the viral survival data in aerosol phase consequently.

Respiratory Aerosol Microphysics

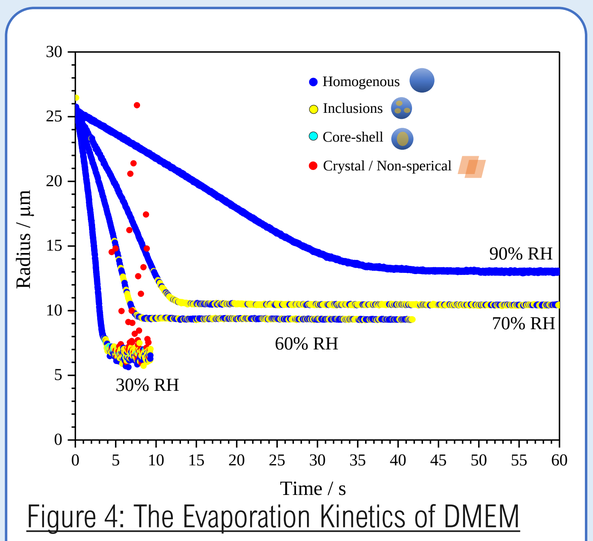


Figure 4: The Evaporation Kinetics of DMEM

The evaporation kinetics and phase change of Dulbecco's Modified Eagle Medium (DMEM) was measured with the CK-EDB. DMEM is a cell culture medium containing range of organic compounds (e.g., glucose) and inorganic salts (e.g, NaCl, $NaHCO_3$) at concentrations approximate to those in saliva.

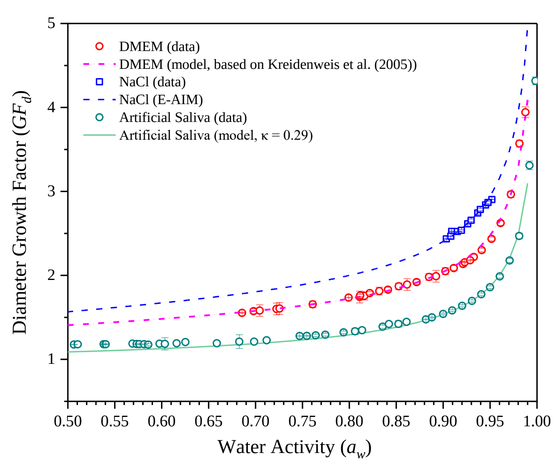


Figure 5: Hygroscopicity of DMEM

The DMEM is less hygroscopic than NaCl, which will affect the size after being inhaled and consequently the deposition and infection site in the human respiratory tract.
Artificial saliva data is from published data in this group: https://doi.org/10.1021/acscentsci.0c01522

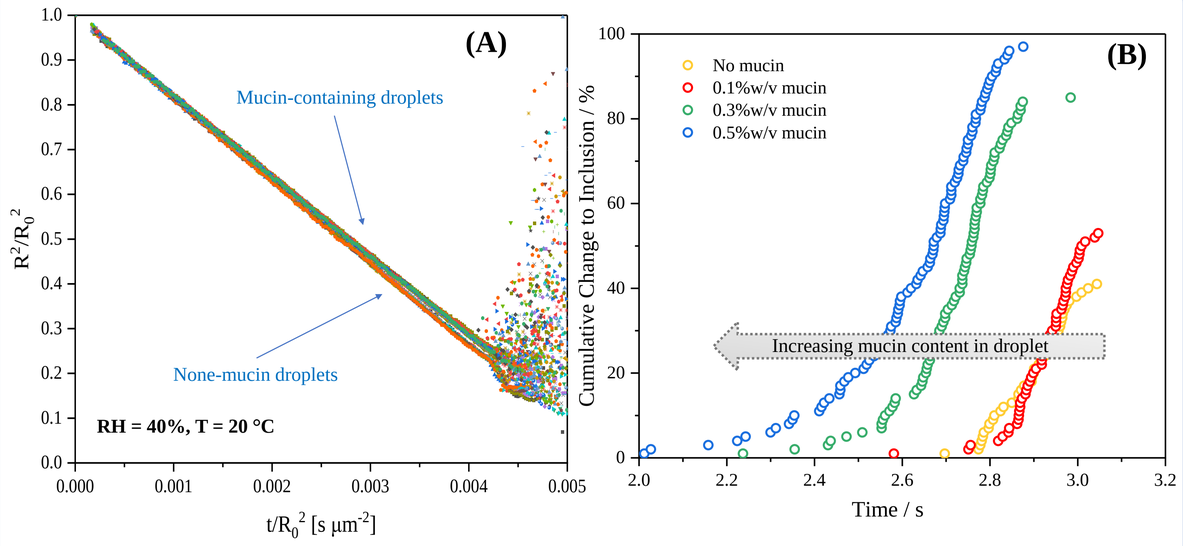


Figure 6: Mucin-Containing Droplet (A) Evaporation Kinetics and (B) Phase Change

Clinically-relevant concentration of mucin (0.01, 0.03 and 0.05 %w/v) was added to the complete DMEM with 10% Fetal Bovine Serum (FBS) matrix and compared with the complete DMEM+10% FBS. The drying kinetics of droplets has no (statistically) significant difference.

However, the inclusion body forming happens earlier as the increase of mucin concentration, indicating a higher probability for virus to survival within a mucin-rich droplets, which is normally generated by an infectious individual.

This measurement also matches the bioaerosol survival study done by Alexander et al. (2022, under review).

Spectroscopic Characterisation

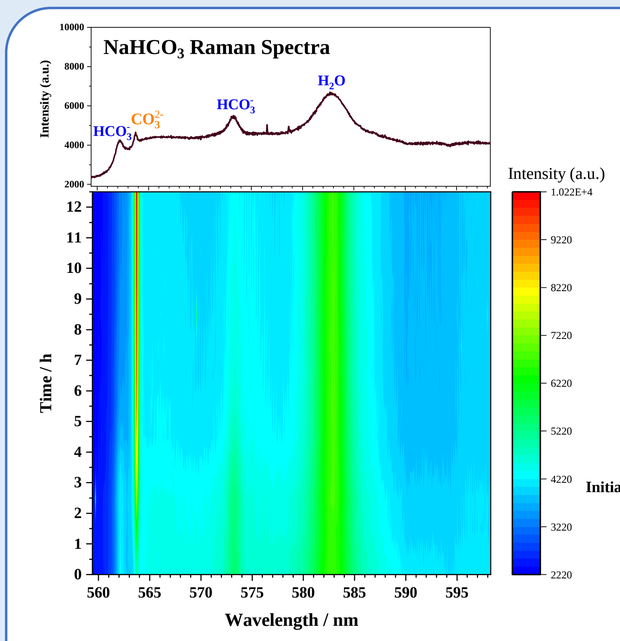
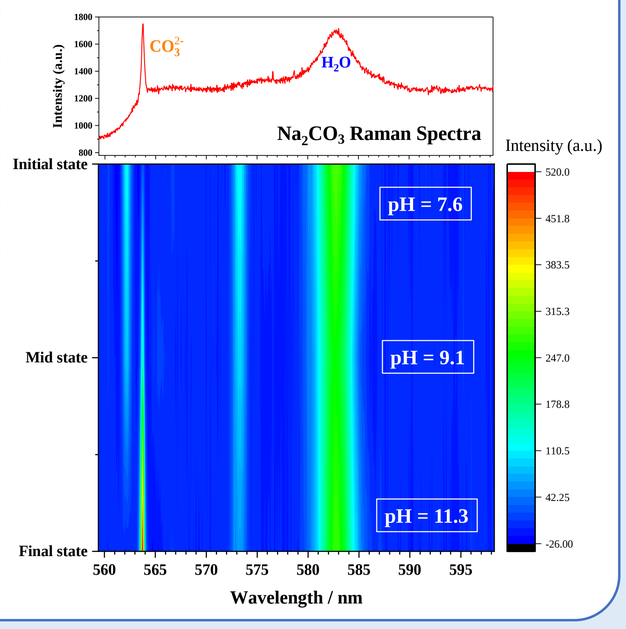


Figure 8: Simulating the pH Change in Human Saliva

Instant Raman measurement was done by simulating the initial, mid and final state of 2:1 mass ratio NaCl-$NaHCO_3$ mixing solution, providing the evidence of a significant increase in droplet pH, which could cause the loss of infectivity in the exhaled aerosol.

Figure 7: Raman Measurement of NaCl-$NaHCO_3$ Mixing Solution

2:1 mass ratio NaCl-$NaHCO_3$ mixing solution was measured by the Aerosol Optical Tweezers (AOT), the Raman spectra of $NaHCO_3$ has finally shifting to Na_2CO_3, indicating the irreversible CO_2 loss from the bicarbonate solution.



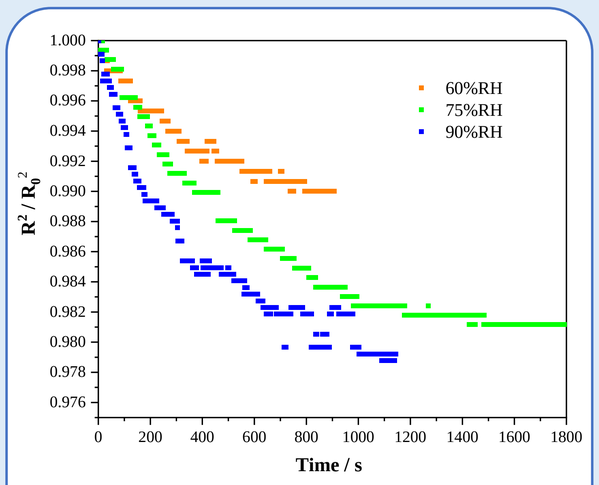


Figure 9: EDB and Raman Measurement Call-back

The exactly same solution was dispensed into EDB chamber and after water equilibrated with the RH, size loss still happen due to the fact that chemical composition changed to Na_2CO_3 and the CO_2 partial pressure on droplet can be estimated by the R-Squared Law (0.05 Pa), which matches the E-AIM calculation.

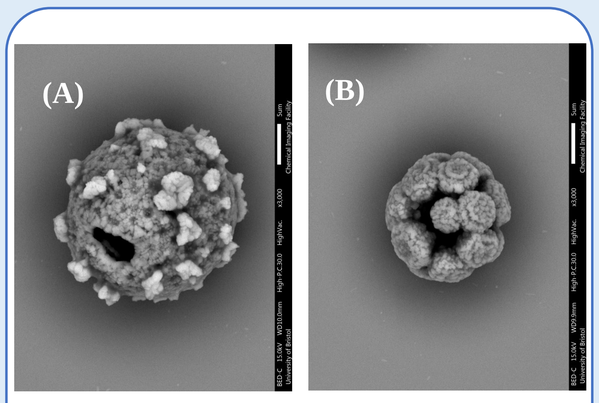


Figure 10: SEM Images and Open Questions

(A) 0.08MF NaCl-$NaHCO_3$ mixing solution drying at 0%RH, 25°C
(B) 0.08MF NaCl-$NaHCO_3$ mixing solution with tiny amount of $CaCl_2$, drying at 0%RH, 25°C

Open Questions (Next Step for Research): What role does Ca^{2+} play during drying regarding the droplet pH going towards alkaline?