Interaction of Evaporating Multicomponent Microdroplets with Humid Environments

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Introduction

Evaporation and **condensation** of **multicomponent microdroplets** or **liquid aerosols** are important in a broad range of **respiratory drug delivery applications**, such as:

- design of solid dosage forms of spray dried particles in cosolvent systems
- study of trajectory and deposition of propellant droplets in a humid environment such as the mouth and respiratory tract

In this work, a semi-analytical/numerical model and a single-particle levitation method have been used to study the drying kinetics of multi-solvent droplets. An *in silico* model is advantageous to **lower costs** and **reduce risks** in early stages of design of inhalable microparticles.

in silico Model

❖ Evaporation rate, κ, is defined as [1]:

$$\kappa = -\frac{\mathrm{d}d^2}{\mathrm{d}t}$$

❖ The evaporation rate is time-varying in a cosolvent droplet and is obtained from the total change in mass of the droplet:

$$\kappa = \frac{2d^2}{3\rho}\frac{\mathrm{d}\rho}{\mathrm{d}t} - \frac{4}{\rho\pi d}\frac{\mathrm{d}m}{\mathrm{d}t}$$

❖ The total change in mass of the droplet is obtained by the superposition of evaporation rates of each volatile component based on the Maxwell's relation [2]:

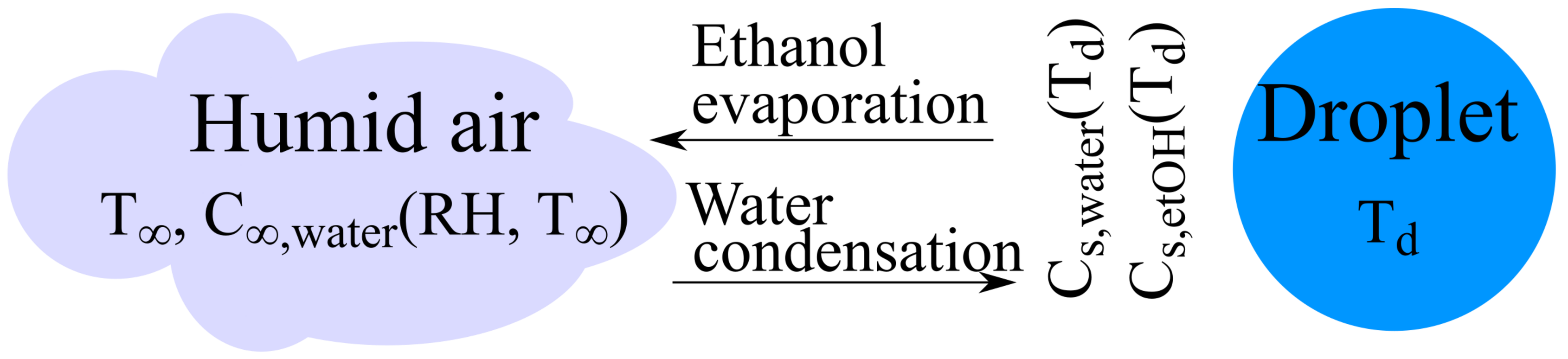
$$\frac{\mathrm{d}m}{\mathrm{d}t} = -2\pi d \sum_{i}^{n_{\text{solvents}}} D_{\mathrm{v},i}\left(C_{\mathrm{s},i} - C_{\infty,i}\right)$$

❖ The energy equation is calculated in a similar manner:

$$-\sum_i L_i D_{\mathrm{v},i}\left(C_{\mathrm{s},i} - C_{\infty,i}\right) - K_{\mathrm{air}}\left(T_d - T_\infty\right) = \frac{\rho c_{\mathrm{p}} d^2}{12}\frac{\mathrm{d}T_{\mathrm{d}}}{\mathrm{d}t}$$

❖ The simultaneous solution of these equations with the appropriate boundary conditions, results in the size history of the droplets during evaporation or condensation or both.

❖ **Assumptions and Boundary Conditions:**



- ✓ No radial bulk motion of the gas (**no Stefan flow**)
- ✓ Stationary droplets or droplets moving under creeping conditions (**spherical symmetry**)
- ✓ Infinite solvent diffusivity and infinite thermal conductivity inside the droplet (**well-mixed droplets**)

Experimental Method

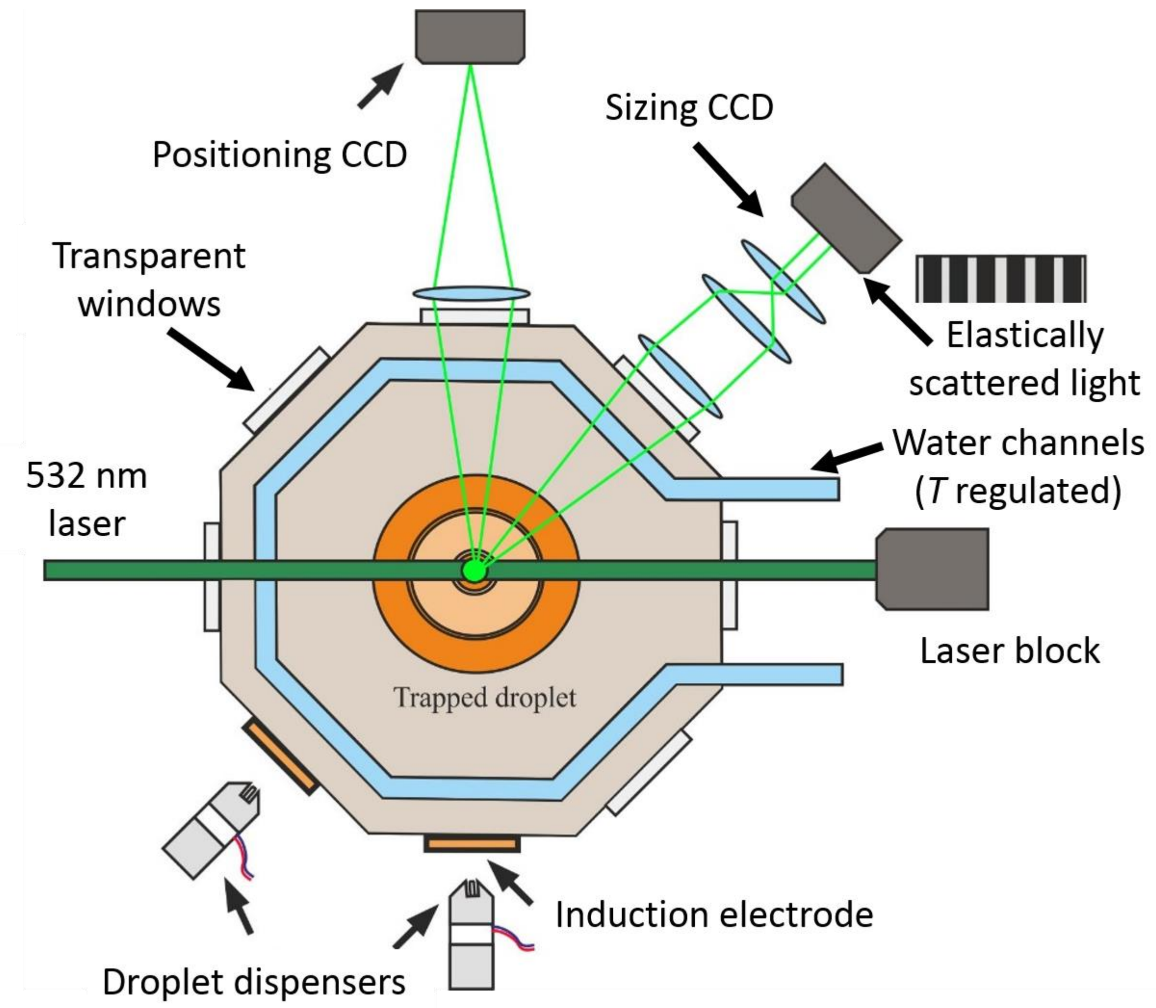
❖ Why Single Particle Levitation?

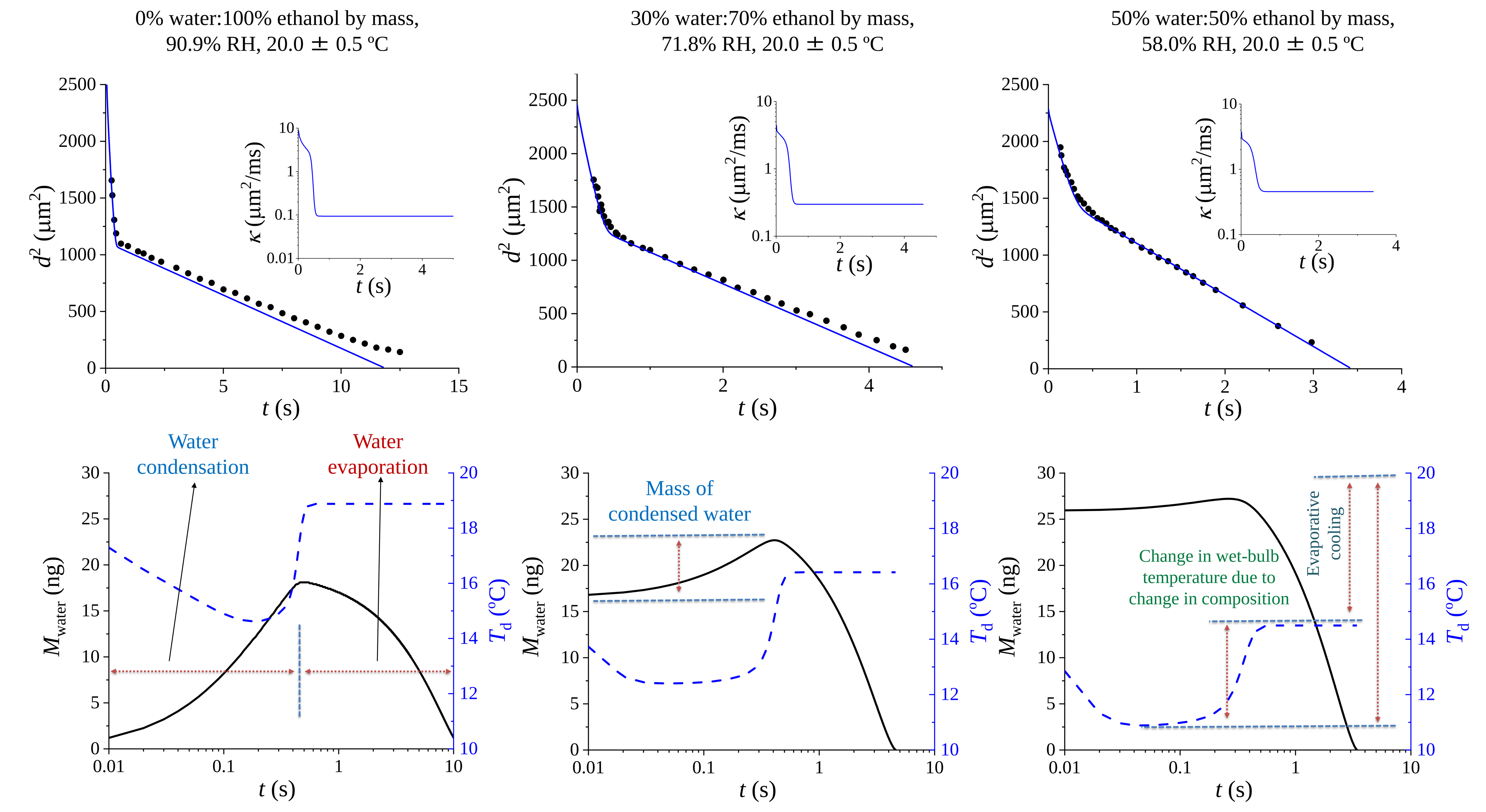
- ❑ Highly Accurate for droplets and particles with slow drying conditions
- ❑ Minimal amount of material needed
- ❑ Accurate control of ambient conditions

❖ Droplets of pure ethanol or mixtures of ethanol and water were injected into the center of an **Electrodynamic Balance**.

❖ Size history of the Droplets were obtained from elastic scattering patterns of light and **Mie Theory** [3].

❖ The humidity values inside the chamber were calculated using a comparative approach and a probe water droplet.





Size and composition history of the droplets. Plots on the top show the diameter squared vs time and inset plots show the evaporation rates. Plots on the bottom show water content (closed lines) and droplet temperatures (dashed lines) vs time.

Discussions

❖ Good agreement in the size history and the change in evaporation rates between the two methods was observed.

❖ Rapid condensation of water onto a pure ethanol droplet in humid air was observed, due to the significant decrease in droplet temperature.

❖ At higher RH values, water condenses more rapidly on the droplet and evaporates slower in the final stage at higher temperatures.

❖ Lower ethanol mass fractions results in Lower initial evaporation rates due to the lower vapor pressure near the droplet surface.

Conclusions

✓ **Humidity of the drying environment** has a significant effect on the **evaporation rate** and **composition** of **cosolvent aerosol particles**.

✓ **Condensation of water** onto evaporating aerosol droplets and particles can occur in humid environments. This is important in deposition and aerodynamic behavior of aerosolized droplets and particles in pMDIs, DPIs and nebulizers.

✓ The **change of solvent composition** will also have a substantial impact on the properties of the inhaled therapeutic particles, due to the different solubility and solution behavior of the active biologics or excipients in drying of pMDI droplets and spray drying of cosolvent formulations.

✓ Methods discussed here are excellent tools to study these phenomena and their effects in different areas pertaining to respiratory drug delivery.

References

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