Responsive Aerosol: A Design Framework for Aerosol with Required Properties

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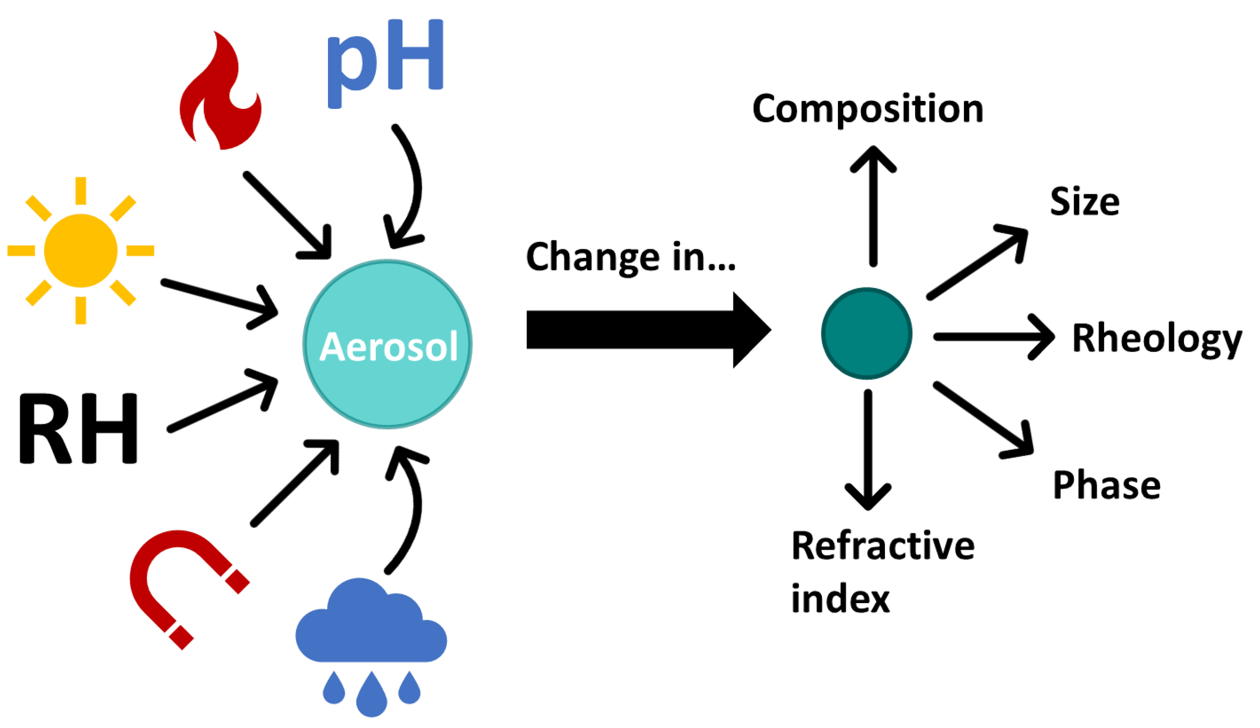
1. Background

Responsive aerosol

- Aerosols are responsive by nature, which provides an opportunity to design aerosol to have a desired response to a specified stimuli:



- Initially hydrogels are being used as the test system to explore aerosol with responsive properties.
- Hydrogels are three-dimensional polymeric networks that have hydrophilic groups attached to the polymeric backbone and can therefore swell to retain large amounts of water.
- Poly(N-isopropylacrylamide) (**pNIPAM**) and **Poloxamer-407**, both thermoresponsive hydrogels (Fig. 1), have been studied in the bulk phase and as single droplets.
- Both polymers exhibit a measurable response to temperature, moving from a solution to gel state as temperature is increased (Fig. 1).

Hydrogels

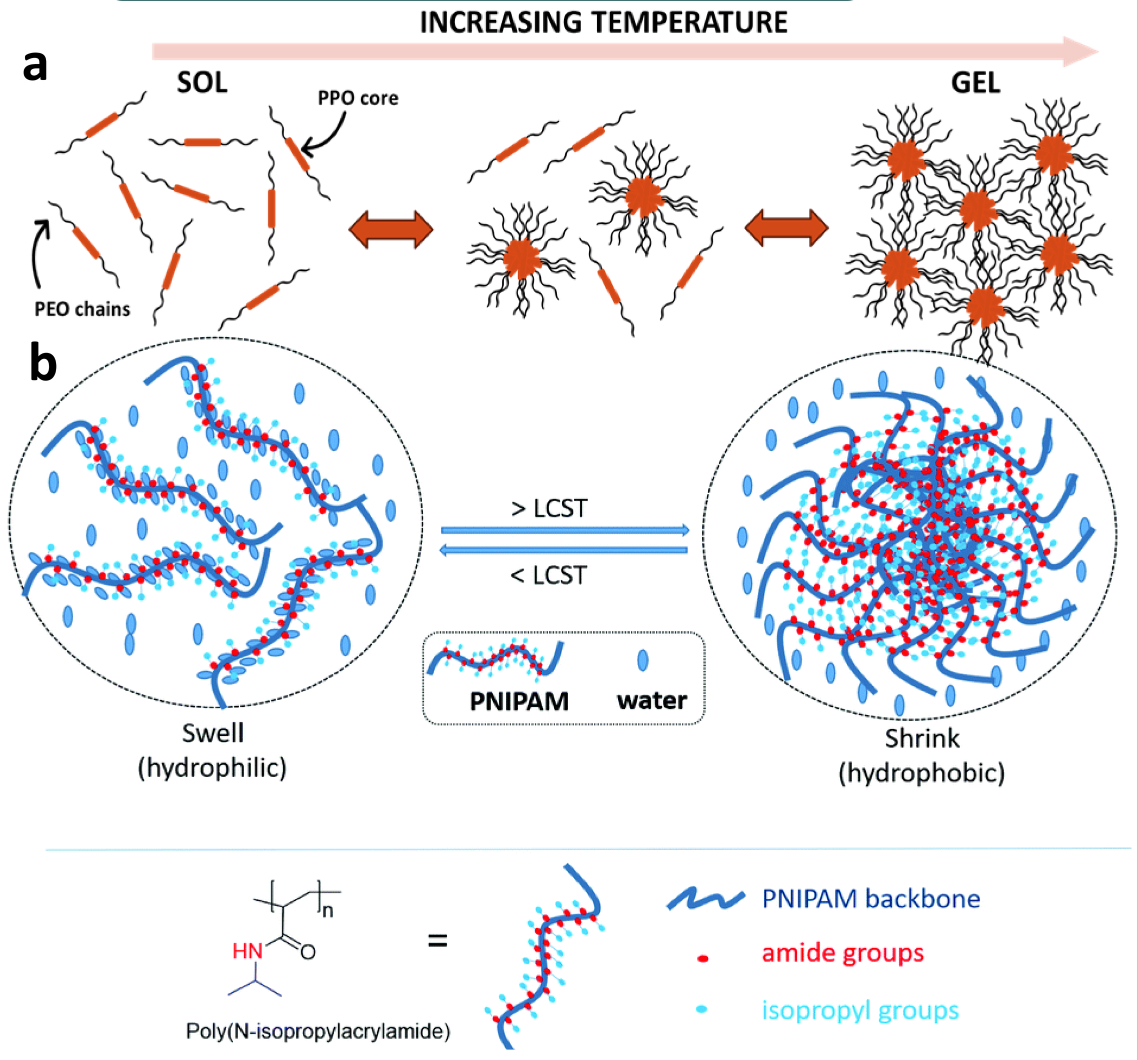


Figure 1—a) Solution to gel transition of P-407 b) Swollen and collapsed state of pNIPAM below and above the lower critical solution temperature (LCST). Figure taken from Doberenz et al.

2. Motivation

The ability to design an aerosol to have a required response to its environment has potential applications in many areas. For example, the aerosol could be used to report on changes in temperature, pH, or RH in the environment, and they could also be designed for controlled release of an API in aerosol drug delivery.

3. Aims

Characterise changes in an aerosol's properties in response to an external stimulus using two hydrogel systems.

Build a framework to allow the design of aerosol that have a desired response to stimuli.

Create a model to understand how changes in the environment can be detected from the corresponding change in size and rheology of the aerosol and to allow a prediction of one from the other.

4. Research Methodology

BULK PHASE:

- **A rheometer was used** to measure viscoelastic properties and a **bubble pressure tensiometer** was used to measure dynamic surface tension.

DROPLET PHASE:

Comparative-kinetic electrodynamic balance will be used to measure the size change of the droplets with respect to temperature and RH.

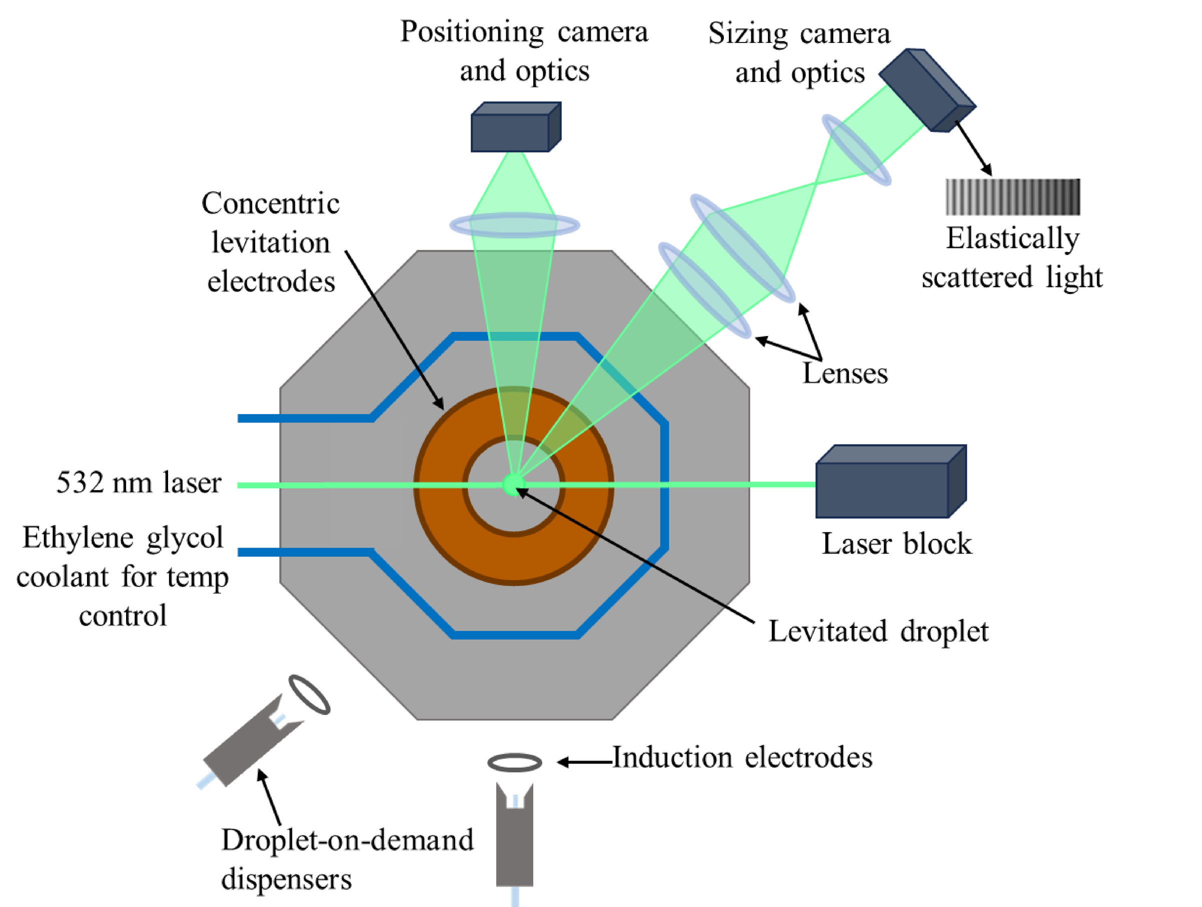
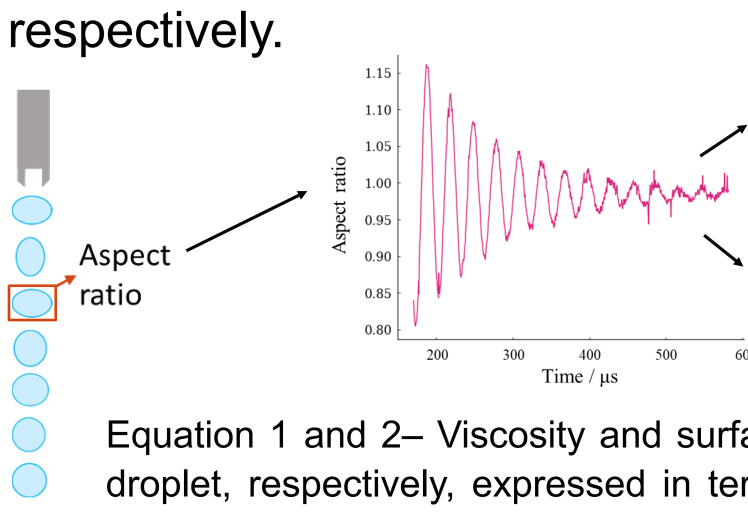


Figure 2—A schematic representation of a CK-EDB from a view looking down into the instrument.

Stroboscopic Imaging used to determine the surface tension and viscosity of the droplets phase from the droplet oscillation frequency and decay, respectively.



$$\mu = \frac{\rho a^2}{\tau_l (l-1)(2l+1)} \quad [1]$$

$$\sigma = \frac{a^3 \rho \omega_l^2}{l(l-1)(l+2)} \quad [2]$$

Equation 1 and 2– Viscosity and surface tension of the oscillating droplet, respectively, expressed in terms of the droplet radius, a, the fluids density, ρ, the decay time of the amplitude of the lth mode, τ_l, and the angular oscillation frequency of the lth mode, ω_l.

5. Results

Poloxamer-407 properties:

	Bulk		Droplet
Conc / wt%	σ_0 / mN m^{-1}	σ_{eqm} / mN m^{-1}	σ_0 / mN m^{-1}
0.5	61.1	42.5	61.4
1.0	60.1	41.0	60.5
1.5	59.4	40.6	59.2
2.0	59.1	40.1	59.3
2.5	58.1	39.3	58.5

Table 1—Surface tensions of Poloxamer-407 in bulk and droplet phase.

Bulk rheology studies:

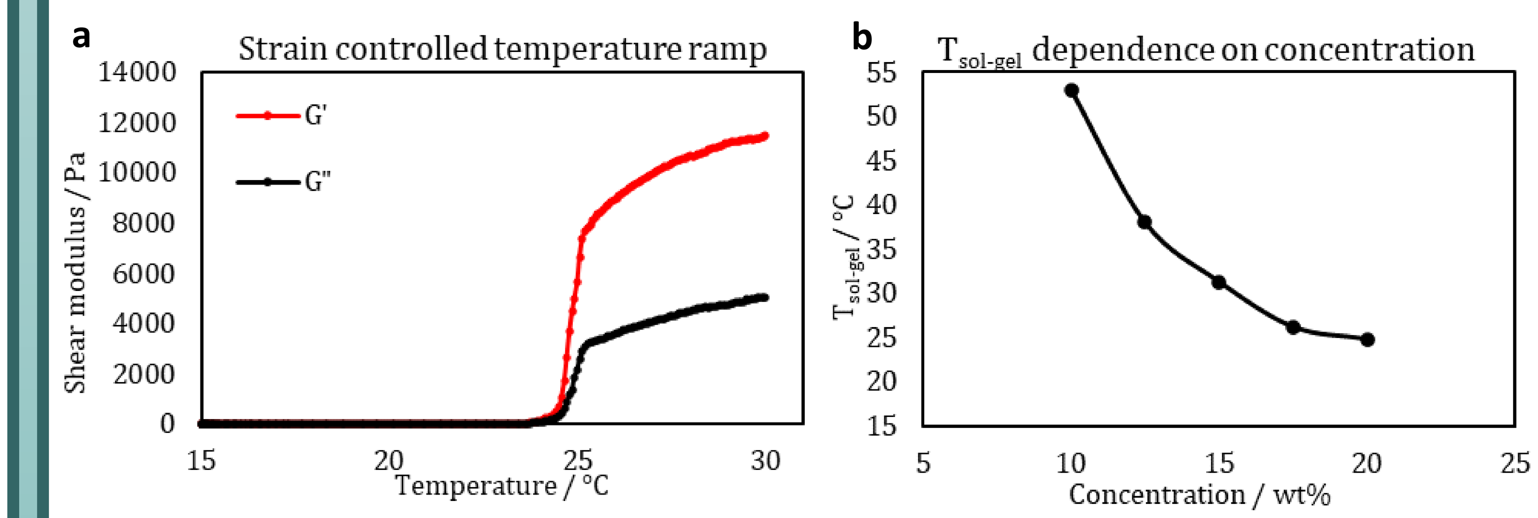


Figure 3- a) Example of a sol-gel transition of 20 wt% Poloxamer 407 exhibited by the extreme increase in storage and loss moduli. G' is the storage modulus (elastic component), and G" is the loss modulus (viscous component). In this case the sol-gel transition temperature is 24.5 °C. b) Sol-gel transition temperature of poloxamer 407 as a function of concentration. Each data point was found by plotting a strain controlled temperature ramp at varying concentrations.

Single droplet studies:

Temperature ramp on levitated droplets of poloxamer 407 and pNIPAM using the CK-EDB:

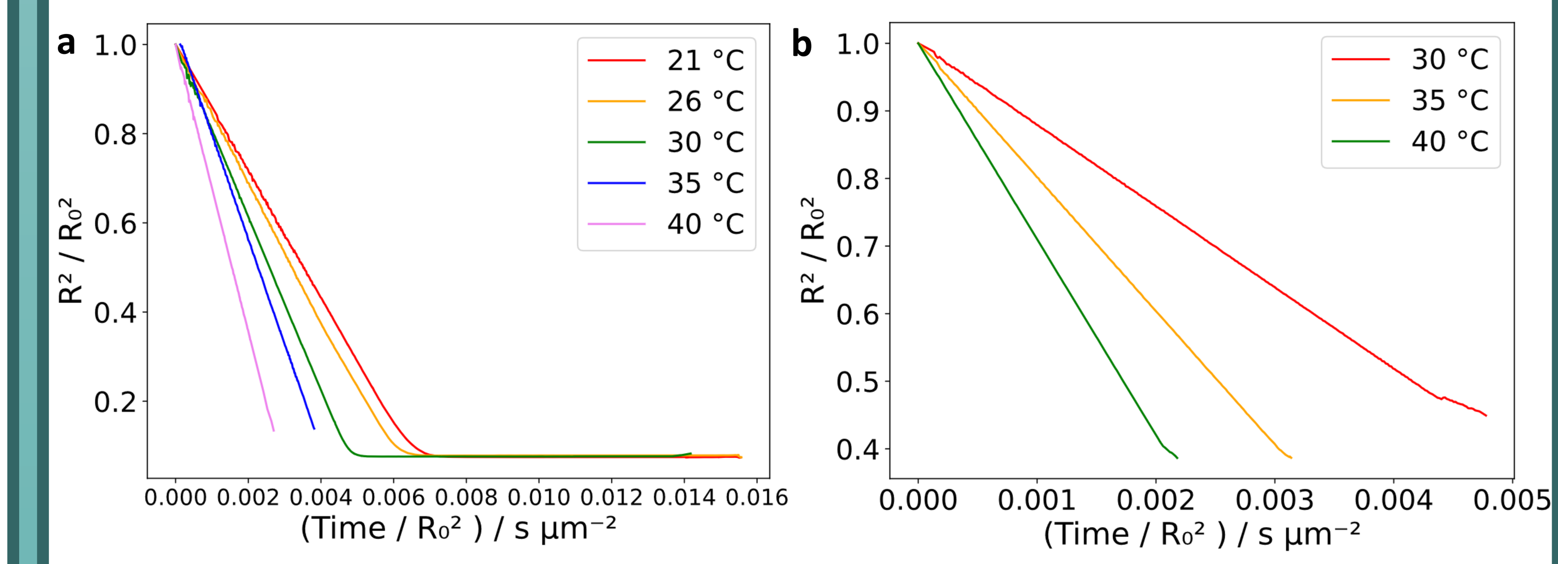


Figure 4—Normalised evaporation curves at different temperatures measured using the CK-EDB. a) 2.5 wt% Poloxamer 407 b) 0.2 wt% pNIPAM

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