Surface Tension of Surfactant-Containing, Finite Volume Droplets

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This display describes key results from a recent paper: Bzdek et al., PNAS, 2020
Surface Tension Is Key for Cloud Droplet Activation

• Surface tension influences critical supersaturation

• Surfactants are key components of aerosol composition (e.g. Gerard, EST, 2016; Kroflic, EST, 2018; Facchini, Nature, 1999)

• Surface-bulk partitioning of surface active molecules alters the Köhler curve (e.g. Sorjamaa, ACP, 2004; Petters and Petters, JGR, 2016)

• Potentially large surfactant effects on cloud droplet number concentration (Prisle, GRL, 2012)
Direct Surface Tension Measurements of Picolitre Droplets

- Study coalescence of two optically trapped droplets (part a)
- Resulting shape oscillations recorded (part b); frequency ($\omega$) extracted
- Droplet’s Raman spectrum gives size ($a$) and composition (part c)
- Combined, obtain precise measurements of droplet surface tension (part d; see equation)
- More information: Bzdek et al., Chem. Sci., 2016; Bzdek et al., PNAS, 2020
Droplet Surface Tension Not Equivalent to Bulk Value

• Droplets containing Triton (surfactant) have surface tensions (red symbols) lower than that of water but higher than that of the solutions that produced them (black line).

• As surface-to-volume ratio changes, surface tension changes.

• Partitioning model calculations (coloured lines) confirm observation is due to droplets’ high surface-to-volume ratios.

• See Bzdek et al., PNAS, 2020 for more details.
Potentially Significant Climate Impacts

- Accurately accounting for surface-bulk partitioning allows predictions of evolving surface tension during hygroscopic growth...

- …which alters activation parameters (e.g. critical radius, critical supersaturation) as the initial surfactant concentration is varied

Table 1. Parameters for droplets with initial composition (at 0.05-μm radius) indicated in Fig. 5A

<table>
<thead>
<tr>
<th>[Triton X-100]_{tot,init}, mM</th>
<th>R_0, μm</th>
<th>SS_0, %</th>
<th>γ_0, mN·m⁻¹</th>
<th>ΔN_d/N_d,est</th>
<th>IRE_{est}, W·m⁻²</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.076</td>
<td>0.91</td>
<td>67</td>
<td>0.054</td>
<td>-0.22</td>
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<tr>
<td>1</td>
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<td>0.89</td>
<td>67</td>
<td>0.088</td>
<td>-0.48</td>
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<tr>
<td>10</td>
<td>0.085</td>
<td>0.82</td>
<td>64</td>
<td>0.32</td>
<td>-1.6</td>
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<tr>
<td>100</td>
<td>0.12</td>
<td>0.57</td>
<td>55</td>
<td>0.99</td>
<td>-4.9</td>
</tr>
<tr>
<td>1,000</td>
<td>0.15</td>
<td>0.25</td>
<td>34</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

R_0: critical radius, SS_0: critical supersaturation, γ_0: surface tension at activation, ΔN_d/N_d,est: estimated fractional change in N_d, IRE_{est}: estimated IRE when compared to the reference case.
Key Conclusions

• Surfactants can significantly reduce aerosol droplet surface tension below the value for water, but surface tension reduction is size dependent and does not correspond exactly to the macroscopic solution value

• Independent monolayer partitioning model confirms size-dependent surface tension arises from high surface-to-volume ratios in finite-sized droplets

• Predictions of aerosol hygroscopic growth using the model are consistent with a reduction in critical supersaturation for activation, potentially substantially increasing cloud droplet number concentration and modifying radiative cooling relative to current estimates assuming a water surface tension

• Improved constraints on identities, properties, and concentrations of atmospheric aerosol surfactants is required

• Further reading: Bzdek et al., PNAS, 2020; Malila and Prisle, JAMES, 2018

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