Investigation of the Surface Tension of Saltwater Solutions to Better Understand Sea Salt Aerosols

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Introduction

•Aerosols are tiny particles in the atmosphere that range in size from a few nanometers to hundreds of micrometers.[1]

•The formation of clouds depends on the activation of aerosol particles, referred to as cloud condensation nuclei (CCN).[1]

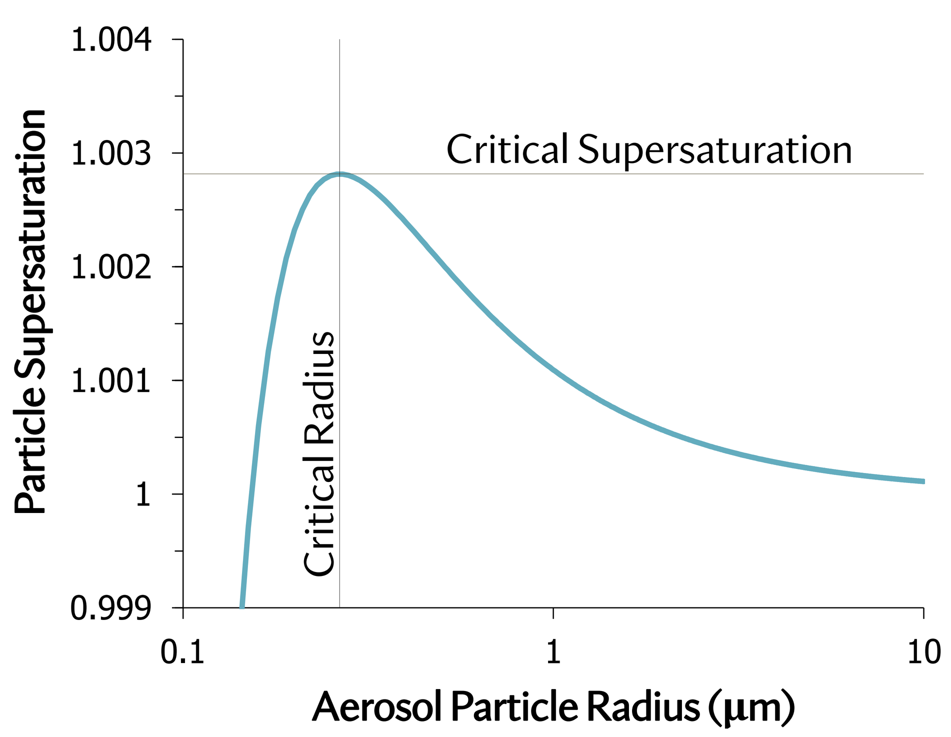
•Activation occurs once particles grow to the critical radius and the ambient supersaturation is above the critical supersaturation. Köhler curves can be used to predict these values (shown below).[2]

•Cloud formation is important to understand because clouds scatter incoming radiation. This reduces the amount of solar radiation that reaches the earth and causes a cooling effect, thus helping to counteract global warming.[1]

•Understanding cloud formation allows for more accurate climate models to be produced. Currently, aerosol-cloud interactions are not well understood.[3]

•Sea salt aerosols are relevant because they contribute to up to 65% of CCN in the high southern latitudes and up to 30% elsewhere.[4] Sea salt aerosol production occurs at the air-sea interface when rising bubbles burst, such as when waves break.[1]

•Some work has examined the impact of surface tension on the CCN activation efficiency of sea salt aerosols, but results are mixed. Additionally, studies use different stand-ins for ocean water including NaCl, seawater with the biological material removed, filtered seawater, and pure seawater.[5,6,7,8,9]



Goal: To further the understanding of the impact of surface tension on the CCN activation efficiency of sea salt aerosols by comparing the surface tension of NaCl, commercially available evaporated sea salt with the biological material removed, and natural evaporated sea salt solutions.

Du Nüoy Tensiometer

Information obtained from CSC Scientific Company, INC. *DuNouy Tensiometers*. Fairfax, Va. https://cdn2.hubspot.net/hub/75757/docs/tensiometer_manual.pdf (accessed April 13, 2022).

•The Du Nüoy tensiometer is an instrument used for measuring the surface tension of liquids.

•Has a graduated dial with a vernier scale that allows for the force to be read to 0.1 dyne/cm.

•A fine torsion wire applies the force needed to pull the platinum-iridium ring from the surface of the liquid (known as the Ring Method).

Correction factor F is given by:

$$(F-a)^2 = \frac{4b}{(\pi R)^2}\left(\frac{P}{\rho_{liq}-\rho_{vap}}\right) + (0.04534 - 1.679\frac{r}{R})$$

Where ρ_{liq} and ρ_{vap} = densities of the liquid and vapor respectively; R = radius of the ring; r = radius of the wire from which the ring is composed; P = measured surface tension; and a and b are universal constants for all rings. The corrected surface tension is found by multiplying the measured value by F.

Experimental

Validation of Method

Compared the surface tensions of the following to standard accepted values and literature values:

HPLC Grade Water[10]	0.66-1.38% error
NaCl Solutions (40g/kg & 80g/kg)[11]	0.78-1.52% error
Methanol[12]	4.58-6.25% error
Methanol/Water Solutions[13]	2.69-7.41% error
Olive Oil[14] & Canola Oil[14]	1.14-5.17% error

Water-based solutions had the best agreement. It was determined that volatile solutions should not be used with this method. The oils had a large range of percent error due to the lack of a universally accepted surface tension.

Cleaning Procedures

•Measurements were found to be extremely sensitive to trace contamination.

•The surface tension of HPLC grade water was measured before every trial to ensure the error was ~1%. If not, all glassware and the ring were rinsed with DI water, cleaned with glassware soap, and rinsed with HPLC water.

•Accuracy improved with less cleaning after purchasing new glassware and covering glassware while not in use.

Saltwater Solution Trials

•NaCl solutions were made using Certified ACS crystalline NaCl from Fisher Chemical; Saltwater solutions without biological material were made using Hain Pure Foods Sea Salt; Natural saltwater solutions were made using evaporated seawater collected from the coastal zone of the NH coast.

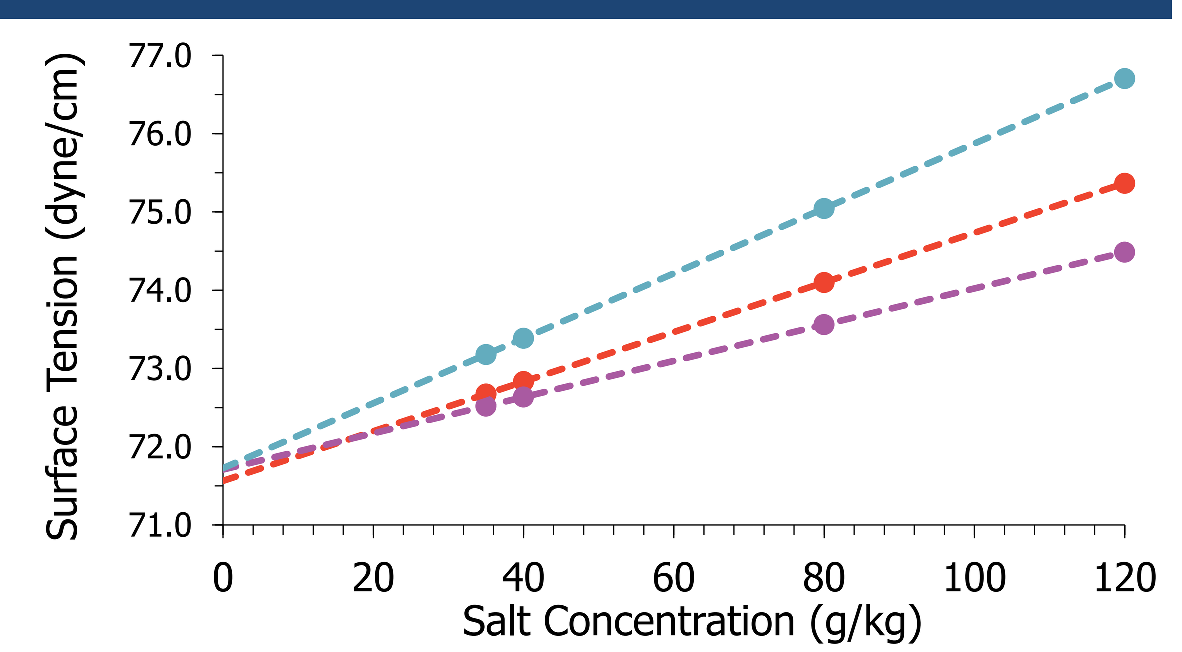
•Surface tension was measured of 35 g/kg, 40 g/kg, 80 g/kg, and 120 g/kg solutions. Measurements were taken 6 times per trial, with 3 overall trials. Natural solutions only had one 120 g/kg trial due to lack of available salt.

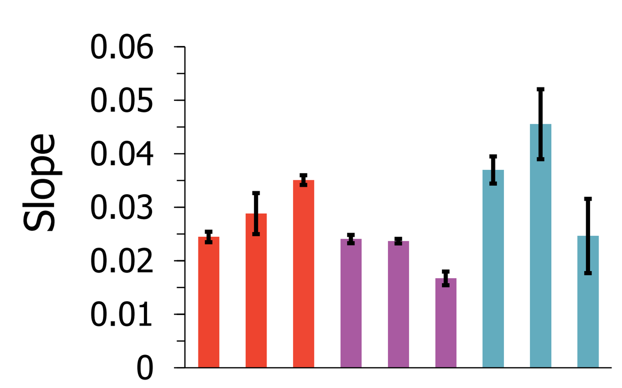
Results

Surface Tension of the 3 Solutions

•Figure to the right shows the average surface tension vs salt concentration.

•Concentrations were normalized to the above values using the linear relationship between concentration and surface tension for each trial, and then the 3 values were averaged.





•Figure to the left shows the slope plus uncertainty of the relationship between salt concentration and surface tension for all three solutions. Each bar represents one trial.

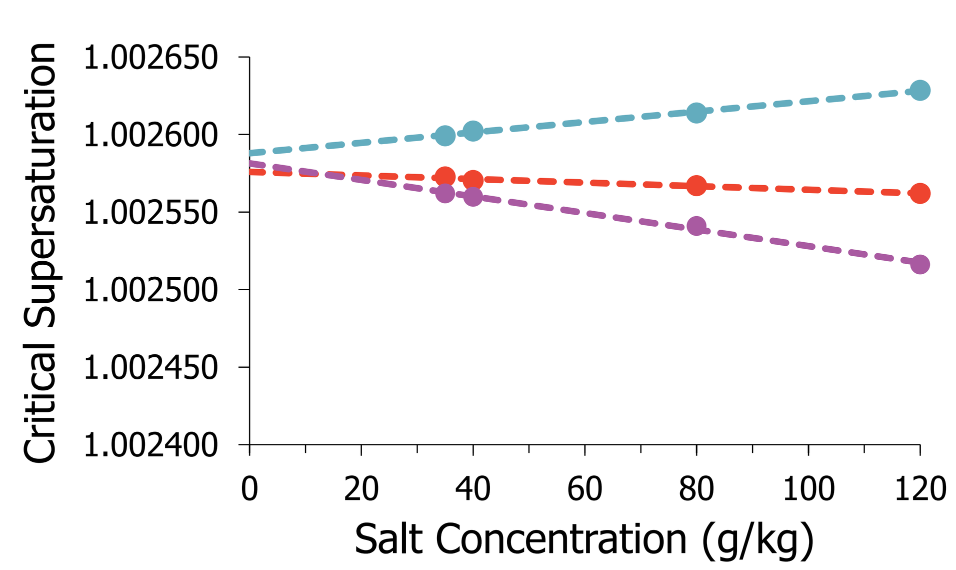
Impact of Surface Tension Data on the Köhler Curve

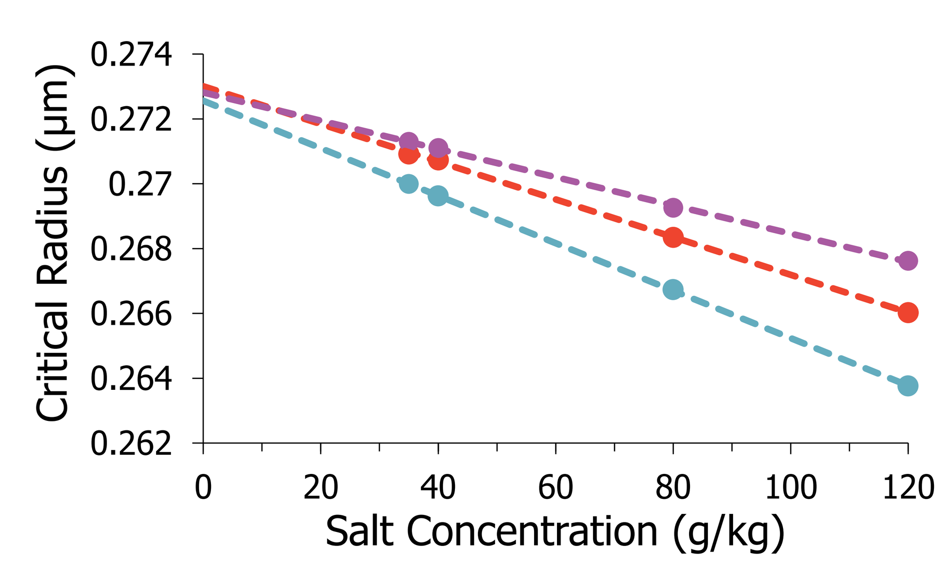
Köhler curves were calculated using:

$$S_{Köhler} = 1 + (\frac{2\sigma}{\rho_l R_v T} \div r) - (\frac{4 i m_s M_v}{3\pi \rho_l M_s} \div r^3)$$

Where σ = surface tension; ρ_l = solution density; R_v = gas constant for the solution vapor; T = air temperature; i = van't hoff factor; m_s = mass of solute; M_s = mass of solute; and r = radius.

The critical supersaturation and critical radius were determining by taking the first derivative of the equation to find the maximum point.





Key (All graphs): Actual Sea Water; NaCl; Sea Salt w/o Biological Material

Discussion

Comparison of the Surface Tensions of the Salt Solutions

•Seawater without biological material had the lowest surface tension, followed by NaCl solutions, followed by natural seawater.

•Agreement between the solutions worsened as concentration increased. This may be due to error accumulation (solutions were made by adding more salt to the previous solution) or due to the solution sitting out longer, thus allowing more time for dust and other substances in the air to accumulate.

Natural Sea Salt Solutions had the Greatest Variation in Surface Tension

•Natural seawater had the greatest variety in the slope of the relationship between concentration and surface tension.

•This is likely due to the presence of varying amounts of biological material and inorganic ions other than Na^+ and Cl^-.

Impact of Surface Tension on Critical Supersaturation and Radius

•Actual seawater needs higher supersaturation for its cloud nuclei to activate. This means actual sea salt needs the ambient supersaturation to be higher as well.

•The critical radius of actual seawater is lower than that of NaCl or seawater without biological material for all concentrations. This means that actual sea salt nuclei need to grow less and may be able to reach critical radius more quickly.

The presence of biological material, substances found in actual seawater, and ions other than Na^+ and Cl^- alter the surface tension of these solutions as well as the critical supersaturation and critical radius of cloud nuclei. However, the impacts appear to be minor.

Future Work

•The surface tension of actual seawater was expected to be lower due to the presence of biological material. A review of the literature could be done to find possible answers, as well as using X-ray crystallography to analyze actual seawater.

•The error associated with the tensiometer appears to be greater than the expected ±0.1 dyne/cm. A closer look into this error could be done.

•Test the impact of common pollutants on surface tension and Köhler curves.

Acknowledgments

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