Determination of Aqueous Surfactant Solution Surface Tensions with a Surface Tensiometer

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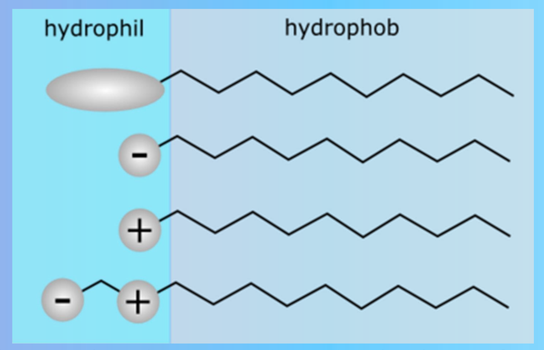
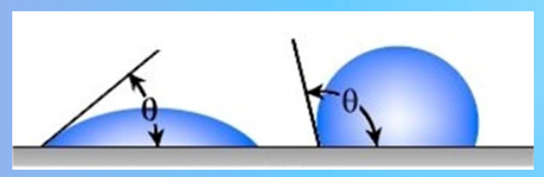
OBJECTIVE:
Surfactant solutions are used in engineering systems for improving boiling heat transfer. The purpose of this research is to determine the surface tensions of surfactant solutions and to investigate the effect of concentration on surface tension.

BACKGROUND:
Surfactants are compounds that lower the surface tension between two liquids or between a liquid and a solid. Surfactants may act as detergents, wetting agents, emulsifiers, foaming agents, and dispersants. They can be classified as nonionic, anionic, cationic, and amphoteric [1].



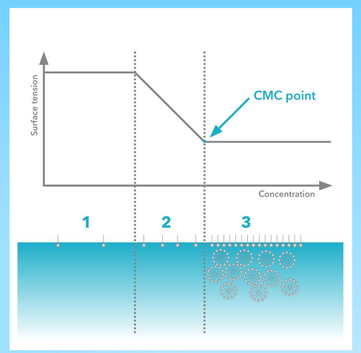
(From top to bottom) Nonionic, anionic, cationic, and amphoteric surfactant molecule

SURFACE TENSION:
Surface tension is the energy, or work, required to increase a liquid's surface area due to intermolecular forces [2]. Liquids with higher surface tension tend to pull on the surrounding liquid molecules more strongly than those with lower surface tension.



Low surface tension (left) and high surface tension (right) [3]

CRITICAL MICELLE CONCENTRATION (CMC):
The proportion of molecules present at the surface of a liquid in the bulk of a liquid depends on their concentration. At low concentrations, surfactant molecules stay at the surface of the liquid. As the surface becomes crowded with surfactant, additional molecules collect as micelles. This concentration is called CMC, which can be determined by measuring surface tension [4].



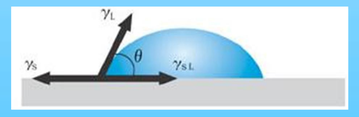
Graph indicating CMC point [5]

SURFACTANT:
Sodium lauryl sulfate (SLS) is an anionic surfactant, used as a foaming and cleaning agent in detergent, wetting agent in textiles, cosmetic emulsifier, and sometimes in toothpaste. It is synonymously called sodium dodecyl sulfate (SDS).

EXPERIMENTAL TEST SETUP:

BZY-101 Automatic Surface Tensiometer

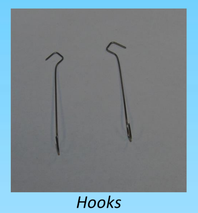
A surface tensiometer that utilizes the Wilhelmy plate method was used to measure surface tension. The Wilhelmy plate was immersed into the water or surfactant solution, so that the plate was under surface tension. The surface tensiometer would sense the pulling force on the plate from the solution to obtain a measurement.



Young Equation

$$\gamma_S = \gamma_L \cos\theta + \gamma_{SL}$$

where
γ_S = solid surface tension (mN/m)
γ_L = liquid surface tension (mN/m)
γ_{SL} = solid/liquid boundary tension (mN/m)
θ= contact angle (degrees or radians)



Hooks

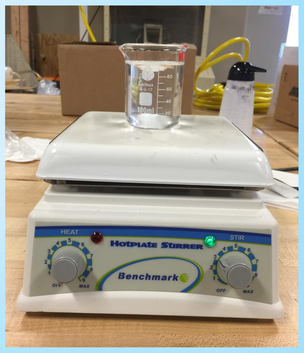
Calibration poise

A calibration poise, which was attached to a hook, was used to calibrate the surface tensiometer before the tests were performed.

Each concentration of surfactant was measured in parts per million (PPM)

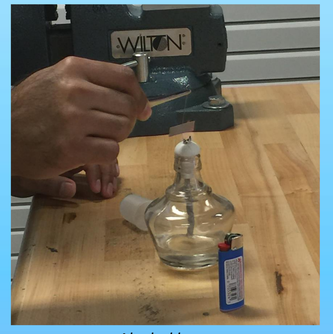
$$PPM = 1{,}000{,}000\frac{m_c}{m_s}$$

where
m_c = mass of component (kg)
m_s = mass of solution (kg)



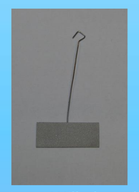
Hot plate

A magnetic stirrer and hot plate was used to ensure that the surfactant was thoroughly mixed with the water.



Alcohol lamp

Tweezers

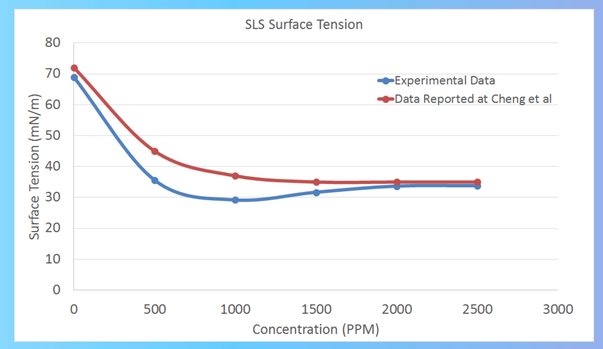


Platinum Wilhelmy plate

When handling the Wilhelmy plate, a pair of tweezers was used to ensure that the plate did not get damaged nor contaminated. After each test, the plate was rinsed with distilled water. When the plate was dry, an alcohol lamp was used to burn the plate, which completed the cleansing process.

RESULTS AND COMPARISON:
Surface tension measurements were obtained for distilled water and SLS. Since the data for SLS exists in literature, the experimental data was compared to data reported at Cheng et al [6].

PPM	H_2O Mass (g)	SLS Mass (g)	Initial Surface Tension (mN/m)	Surface Tension After 2 min. (mN/m)	Repeatability (mN/m)	Mean Surface Tension (mN/m)
0	100	0	68.9	69	68.9	68.9
500	100	0.05	36.5	35.1	35.1	35.6
1000	100	0.10	29.7	28.9	28.9	29.2
1500	100	0.15	31.6	31.7	31.7	31.7
2000	100	0.20	33.8	33.6	33.6	33.7
2500	100	0.25	33.9	33.7	33.8	33.8



Comparison of the results

As shown in the plot, CMC is reached when the SLS solution is at a concentration of 2000 PPM. To verify the consistency in measurements, the percentage differences were determined

$$\%diff. = \left|\frac{\gamma_{exp} - \gamma_{data}}{\frac{\gamma_{exp} + \gamma_{data}}{2}}\right| * 100\%$$

where
γ_{exp} = experimental surface tension (mN/m)
γ_{data} = reported surface tension data at Cheng et al (mN/m)

PPM	Experimental Surface Tension (mN/m)	Reported Surface Tension Data at Cheng et al (mN/m)	Percentage Difference
0	68.9	72.0	4.40%
500	35.6	45.0	23.3%
1000	29.2	37.0	23.6%
1500	31.7	35.0	9.90%
2000	33.7	35.0	3.78%
2500	33.8	35.0	3.49%

FUTURE WORK:
The surface tensions of ECOSURF™ EH-14 and SA-9 will be tested. (Not reported in the literature)

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