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Effect of Different Concentrations of Detergent on Surface Tension of Water

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ABSTRACT

This research work investigated the effect of different concentrations of detergent on the surface tension of water using the capillary rise method. In the experiment, a clean capillary tube was mounted vertically in a beaker containing detergent solution of varying concentrations (0 g - 70 g). The height of the liquid column rising inside the tube was carefully measured, and the surface tension values were calculated. At zero (0) concentration, all the detergent samples exhibited similar surface tension values. However, as the concentration of detergent increased, significant variations were observed among the samples. Samples C and E (0.0015, 0.0021, 0.0015, 0.0015, 0.0013, 0.0011, 0.0007, 0.0007 and 0.0015, 0.0021, 0.0012, 0.0010, 0.0009, 0.0007, 0.0006, 0.0006 N/m) consistently recorded the lowest surface tension values across different concentrations, making them the most effective detergents for reducing surface tension. On the other hand, Samples A and B (0.00150, 0.00338, 0.00330, 0.00312, 0.00153, 0.00204, 0.00100, 0.00065, and 0.0015, 0.0032, 0.0018, 0.0013, 0.0013, 0.0012, 0.0012, 0.0010 N/m) generally exh1ibited the highest surface tension values among the detergent tested. The findings clearly demonstrate that detergent concentration plays a major role in reducing surface tension, although the effectiveness is highly dependent on the chemical composition of the detergent. These results support the understanding that detergents act as surfa1ctants by disrupting hydrogen bonding in water, thereby weakening intermolecular forces. The practical implication of this study is that certain detergents (such as Samples C and E) are better suited for applications where lowering surface tension is essential, such as in cleaning, wetting, and industrial processes.

1. Introduction

Water is nearly colorless chemical substance that is the main constituent of Earth's hydrosphere which is tasteless, transparent, odorless and a fluid of all known living organisms. It is composed of two hydrogen atoms and one oxygen atom, forming the chemical formula H_2O (Gleick, 2010). Water is a vital substance that supports numerous biological, chemical, and physical processes. It covers about 71% of the Earth's surface and is essential for sustaining ecosystems, industrial processes, and human life (Gleick, 2010). Water can exist in three physical states: liquid, solid (ice), and gas (vapor) form (Chaplin, 2001).

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Surface tension is a physical property resulting from the cohesive forces between water molecules. These intermolecular attractions cause the liquid surface to behave like a stretched elastic membrane. Pure water has a relatively high surface tension because of strong hydrogen bonding among its molecules. Surface tension influences many natural and industrial processes, including droplet formation, capillary action, and cleaning. Understanding the surface tension of water provides a basis for studying how detergents modify the behavior of water in cleaning applications. Atkins and de Paula (2018). Intermolecular forces, particularly hydrogen bonding in water, are responsible for the high surface tension of water. The introduction of detergent molecules weakens these cohesive forces by interfering with hydrogen bond interactions at the liquid surface. Studying intermolecular forces provides a theoretical basis for understanding how detergents alter the physical properties of water. (Brown. *et al*., 2018).

Water occurs in different forms depending on its composition, origin, and intended use. The main categories include:

Pure water, which consists of:
(a) **Distilled water** – Produced through distillation, a process that removes impurities and dissolved minerals (Gleick, 2010). (b) **Deionized water** – Water that has had its ions removed through ion-exchange methods, making it ideal for laboratory and industrial applications (Atkins & de Paula, 2010).

Natural water, which includes: (a) **Rainwater** – Precipitation from the atmosphere, generally regarded as pure but capable of absorbing contaminants from the air (Trenberth et al., 2007).
(b) **Surface water** – Water found in rivers, lakes, and oceans, which can be affected by pollution from human activities (Gleick, 2010). Hard water – Contains high levels of calcium and magnesium ions, leading to scale formation in pipes (Sawyer *et al.,* 2003). Soft Water – Low in mineral content, often treated to remove hardness, making it ideal for household use (Atkins & de Paula, 2010). Saltwater (Seawater) – High salinity due to dissolved salts, unsuitable for drinking without desalination (Millero, 2013).

Drinking water (potable water) is water that has been treated to comply with safety standards for human consumption,(WHO,2017).
Wastewater refers to used water that contains pollutants from household, industrial, or agricultural activities (Metcalf & Eddy, 2014).
Boiler feed water is water that has undergone specialized treatment for use in industrial boilers to minimize scaling and corrosion (Veil, 2011).A detergent is a substance used for cleaning that eliminates dirt, grease, and stains by reducing surface tension and dispersing impurities in water. Unlike soap, detergents are synthetically formulated to perform effectively in both hard and soft water (Myers, 2006). Detergents can be classified into several types. **Anionic detergents**, commonly used in household laundry and dishwashing products, are known for their ability to produce foam1 (e.g., sodium lauryl sulfate) (Rosen & Kunjappu, 2012). Cationic detergents are typically applied as fabric

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softeners and disinfectants (e.g., benzalkonium chloride) (Myers, 2006). Nonionic detergents are particularly effective at removing oily stains and are often found in dishwashing liquids (e.g., alcohol ethoxylates) (Smulders, 2002).

Surface tension is important in many natural and practical processes. For example, it enables capillary action in plants, allowing water to move through xylem vessels and transport nutrients (Taiz & Zeiger, 2010). It also plays a role in lung function, where surfactants in the alveoli reduce surface tension and prevent collapse during breathing (Weibel, 2017). Additionally, insect locomotion relies on surface tension, allowing insects like water striders to walk on water without sinking (Bush & Hu, 2006).

In engineering and materials science, surface tension has several important applications. In metal processing, it affects processes such as welding, soldering, and casting by determining the behavior of molten metal (Glicksman, 2011). In nanotechnology, surface tension is crucial for the stability and self-assembly of nanoparticles and thin films (Whitesides & Grzybowski, 2002).

In everyday life, surface tension has several practical applications. For instance, it enables the formation of soap bubbles, where surfactants lower the tension to allow the bubbles to expand and remain stable (Rosen & Kunjappu, 2012). It also influences raindrop formation, giving water droplets their shape in clouds prior to precipitation (Pruppacher & Klett, 2010). Additionally, the way cooking oils spread over surfaces is governed by surface tension, which affects food preparation and frying processes (McClements, 2015).

Surfactants reduce surface tension by interfering with the cohesive forces between molecules. They contain both hydrophilic (water-attracting) and hydrophobic (water-repelling) components, which disrupt hydrogen bonding in water (Rosen & Kunjappu, 2012). Examples include detergents and soaps, which are used for cleaning and emulsification; shampoos and conditioners, which lower surface tension to improve spreading; and wetting agents, which enhance water penetration into surfaces, such as in agricultural applications.

.. In addition, agitation through stirring or shaking disrupts the organized arrangement of molecules, temporarily decreasing surface tension, a principle applied in foaming and aeration processes (Israelachvili, 2011).

Numerous studies have shown that increasing detergent concentration leads to a progressive decrease in the surface tension of water. At low concentrations, the reduction is rapid because surfactant molecules quickly occupy available surface sites. As concentration increases further, the rate of decrease slows until a nearly constant value is reached. This relationship demonstrates that detergent concentration1 is a key factor influencing the extent of surface tension reduction and cleaning efficiency. Myers, D. (2020). Several experimental techniques are used to determine the surface tension of liquids, including the drop-count method, capillary rise method, Du Noüy ring method, and Wilhelmy plate method. In many school and undergraduate laboratory experiments, the drop-count method is commonly employed

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because it is simple, inexpensive, and sufficiently accurate for comparing the effects of different detergent concentrations on water. Adamson, A. W., and Gast, A. P. (1997).

2. Materials and Method

The materials used are narrow tube, 500 cm^3 beaker, traveling microscope, pin (pointer), retort stand and different detergent. The capillary rise method was used in determining surface tension by measuring the height to which a liquid rises in a narrow tube due to capillary action. (Atkins *et al.,* 2010). A clean capillary tube was mounted in a 500 cm^3 beaker vertically containing each detergent solution of six different brands. The height of the liquid column rising inside the tube was measured using a microscope scale of the traveling microscope. The inner radius of the capillary was measured using a travelling microscope. Then the surface tension was calculated using the formula:

$$\Upsilon = r\left(\frac{h+r}{3}\right)2\rho g cos\theta \quad (1)$$

At θ= 0°

$$\Upsilon = r\left(\frac{h+r}{3}\right)2\rho g \quad (.2)$$

where:

h= height of the liquid column.

r= internal radius of the capillary tube.

ρ = density of the water.

g = acceleration due to gravity.

Assumption: Contact angle is assumed to be zero (complete wetting).

3. Results and Discussion

Table 3.1: Sample A: Variation of concentration of the detergents with surface tension

S/NO	Mass (g)	Height (m)	Υ (N/m)
1.	0	0.00821	0.00150
2.	10	0.0197	0.00338
3.	20	0.0192	0.00330
4.	30	0.0181	0.00312

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5.	40	0.0083	0.00153
6.	50	0.0115	0.00204
7.	60	0.0051	0.00100
8.	70	0.0029	0.00065

Table 3.1 shows the surface tension of the liquid (distilled water) is 0.00150 N/m. From the table we can see clearly, when 10g of detergent was added in the liquid the value of the surface tension shut up to 0.0038 N/m. There is a wide gap in the drop of the surface tension between 30g-40g and the subsequent values followed the normal expectation (increase in concentration decreases surface tension).

Table 3.2: Sample B: Variation of concentration of the detergent with surface tension

S/NO	Mass (g)	Height (m)	ϒ (N/m)
1.	0	0.0083	0.0015
2.	10	0.0188	0.0032
3.	20	0.0102	0.0018
4.	30	0.0070	0.0013
5.	40	0.0069	0.0013
6.	50	0.0065	0.0012
7.	60	0.0062	0.0012
8.	70	0.0052	0.0010

Table 3.2 Show the surface tension of the liquid is 0.0015 N/m when the 10 g of detergent was added the value of the surface tension is 0.0032 N/m. There is a wide gap in the drop of the surface tension between 10 g - 20 g and the subsequent followed the normal expectation.

Table 3.3: Sample C: Variation of concentration of the detergent with surface tension

S/NO	Mass (g)	Height (m)	ϒ (N/m)
1.	0	0.0082	0.0015
2.	10	0.0117	0.0021
3.	20	0.0081	0.0015
	30	0.0080	0.0015
4.	40	0.0068	0.0013
5.	50	0.0057	0.0011
6.	60	0.0035	0.0007

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7.	70	0.0033	0.0007

Table 3.3: Show the surface tension of the liquid is 0.0015 N/m. When the 10 g of detergent was added the value of the surface tension is 0.0021 N/m. The drop of the surface tension between 10 g-70 g followed the normal expectation.

Table 3.4: Sample D: Variation of concentration of the detergent with surface tension

S/NO	Mass (g)	Height (m)	ϓ (N/m)
1.	0	0.0083	0.0015
2.	10	0.0135	0.0024
3.	20	0.0190	0.0033
4.	30	0.0166	0.0029
5.	40	0.0130	0.0023
6.	50	0.0082	0.0015
7.	60	0.0059	0.0011
8.	70	0.0009	0.0003

Table 3.4: Show that the surface tension of the liquid is 0.0015 N/m. When the 10 g of detergent was added the value of the surface tension is 0.0024 N/m. There is an increment in the value of surface tension when 10 g of detergent was added to make it 20 g the value rise to 0.0033 N/m. And the subsequent followed the normal expectation.

Table 3.5: Sample E: Variation of concentration of the detergent with surface tension

S/NO	Mass (g)	Height (m)	ϓ (N/m)
1.	0	0.0082	0.0015
2.	10	0.0116	0.0021
3.	20	0.0063	0.0012
4.	30	0.0051	0.0010
5.	40	0.0044	0.0009
6.	50	0.0030	0.0007
7.	60	0.00217	0.0006
8.	70	0.0025	0.0006

Table 3.5: Show that the surface tension of the liquid is 0.0015 N/m. When the 10 g of detergent was added the value of the surface tension is 0.0021 N/m. There is a wide gap in the drop of the surface tension between 10 g-20 g and the subsequent followed the normal expectation.

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Definitions:

- Sample A → Rafa Detergent, Sample B → Klin Dete1rgent, Sample C → Viva Plus Detergent, Sample D → Visa Fresh Detergent, Sample E → Good Mama Detergent

Table 4.6: Summary of the estimated surface tension (γ) for each detergent and the combined statistics (mean, standard deviation, median) at each mass level. The mean γ decreases as more detergent is added, indicating increased surfactant activity at the air–water interface.

Table 3.6: Summary Statistics of the Estimated Surface Tension

Mass (g)	**Mean γ (N/m)**	**Std Dev (N/m)**	**Median γ (N/m)**
0.0	0.001582	0.000238	0.001500
10.0	0.002636	0.000613	0.002400
20.0	0.002219	0.001007	0.001800
30.0	0.001964	0.000974	0.001500
40.0	0.001466	0.000518	0.001300
50.0	0.001308	0.000499	0.001200
60.0	0.000920	0.000259	0.001000
70.0	0.000650	0.000250	0.000650

For example, at Mass = 0 g the mean γ ≈ 0.00158 N/m, while at Mass = 70 g the mean γ ≈ 0.00066 N/m. This confirms a consistent reduction in γ with detergent addition.

3.2 Graphical Presentation of Results1

Figure 1 shows γ vs mass for each detergent. Figure 2 provides a grouped bar chart comparing the detergents at each mass value. Figure 2 plots the mean γ against mass with error bars (±1 standard deviation).

Surface tension (΄Υ) Vs Mass for each detergent

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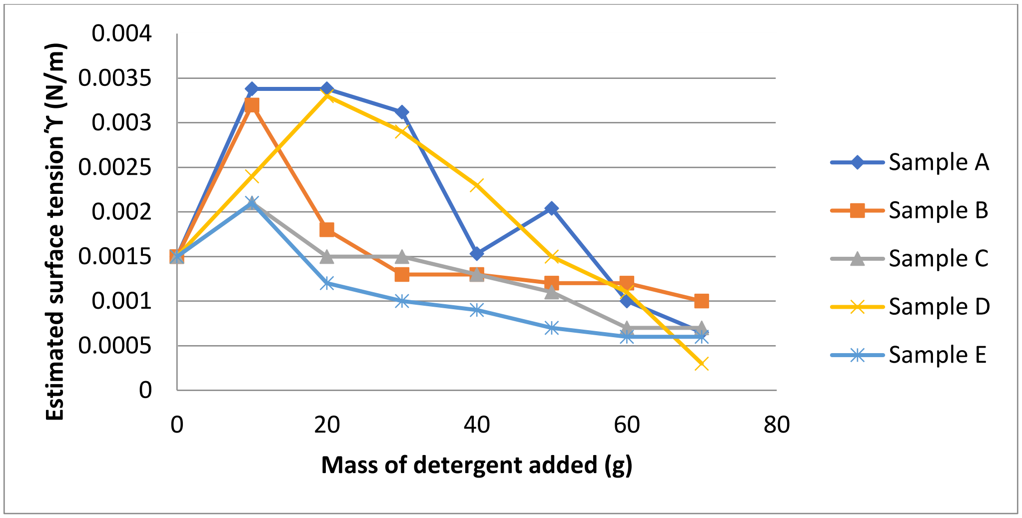

Figure 1: γ vs Mass for each detergent.

Grouped comparison of ϒ across detergent at each mass

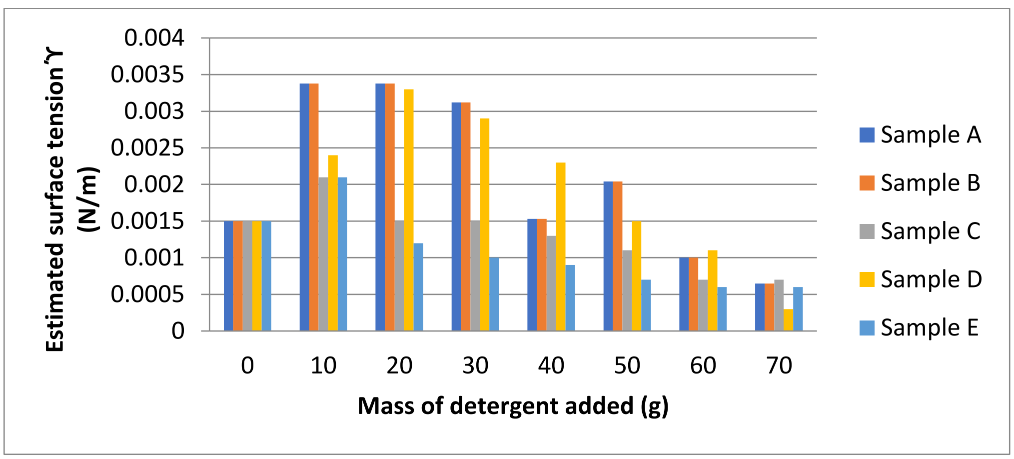

Figure 2: Grouped bar chart comparing detergents at each mass.

At zero (0) concentration all the samples has the same value of surface tension, when the concentration of the detergent was increased to 10g, we can see that Sample A has 0.00338 N/m and B 0.0032 N/m which are the highest values of the surface tension and for that are not good to be recommend as a detergent that can reduced the value of surface tension while Sample C and E have 0.0021 N/m and 0.0021 N/m as the lowest values of the surface tension at the same concentration, so they are good to be recommended as detergent to be considered when reducing surface tension of a liquid. At 20g we can see that Sample A has 0.0033 N/m and sample B 0.0018 N/m which are the higher values of the surface tension, while sample C and E have 0.0015 N/m and 0.0012 N/m as the lowest values of the surface tension. At 30g we can see that Sample A has 0.0031 N/m and B 0.0013 N/m which are the highest values of the

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surface tension while sample C and E have 0.0015 N/m and 0.0010 N/m as the lowest values of the surface tension. At 40 g we can see that Sample D has 0.0023 N/m, sample A has 0.0015 N/m and sample B has 0.0013 N/m respectively, which are the highest values of the surface tension, while sample C and E have 0.0013 N/m and 0.0009 N/m as the lowest values of the surface tension. At 50 g we can also see that Sample A has 0.0020 N/m and B 0.0012 N/m which are the highest values of the surface tension and for that are not good to be recommend as a detergent that can reduced the value of surface tension under this condition, while sample C and E have 0.0011 N/m and 0.0007 N/m as the lowest values of the surface tension, so they are good to be recommended as detergent to be considered when reducing the surface tension of the liquid. At 60 g the bar chart shows that Sample D has 0.0011 N/m while sample A and sample B have 0.0010 N/m and 0.0012 N/m which are the highest values of the surface tension, while sample C and E have 0.0007 N/m and 0.0006 N/m as the lowest values of the surface tension, so they can to be recommended as detergent to be considered when reducing the surface tension of the liquid. At 70 g we can see from the graph that Sample C has 0.0007 N/m, Sample A and sample B 0.0007 N/m and 0.0010 as samples with the highest values of the surface tension while sample D and E have 0.0003 N/m and 0.0012 N/m as the lowest values of the surface tension, so they can be recommended as detergent to be considered when reducing the surface tension of the liquid.

4. Conclusion

The experimental findings indicate that detergent concentration has a noticeable impact on the surface tension of water. As the amounts of detergent increases, the surface tension gradually decreases because hydrogen bonding and intermolecular forces in water are disrupted. However, after a certain concentration is reached, further additions of detergent do not significantly lower the surface tension, implying that the critical micelle concentration (CMC) has been achieved. The results are consistent with earlier research on surfactants, confirming that detergents function effectively as surface-active agents. Practically, the findings suggest that certain detergents (e.g., Samples C and E) are more suitable for applications that require reduced surface tension, such as cleaning, wetting, and various industrial processes.

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