Kurdistan Region
Salahaddin University-Erbil
College of Engineering
Chemical-Petrochemical Engineering Department

Determination of surface tension using stalagmometer.

A Project Submitted to the Chemical-Petrochemical Engineering Department
University of Salahaddin-Erbil
in the Partial Fulfillment of the Requirement for the Degree of Bachelor of Science
in Chemical-Petrochemical Engineering

Prepare By:

Nareen Sherko

Rahel sardar

Supervisor:

Dr. Hardi Siwaily

2023-2024

Abstract

Surface tension is a fundamental property of liquids that plays a crucial role in various natural phenomena and industrial applications. Understanding the behavior of surface tension is essential for fields ranging from material science to biology. This abstract presents the methodology and findings of an experimental investigation into surface tension using a stalagmometer, a widely used instrument for measuring the surface tension of liquids.

The experiment aimed to explore the effects of temperature, concentration, and presence of surfactants on surface tension. But because of the late achieving the experimental laboratory, the aim was changed to focus only on the temperature.

The experimental setup consisted of a stalagmometer; a precision instrument designed to measure the volume of liquid drops under controlled conditions. A liquid sample was introduced into the stalagmometer, and the volume of liquid dispensed from the capillary tube was measured. Surface tension was calculated using the formula derived from the principles of capillarity and hydrostatics.

A series of measurements were taken at different temperatures ranging from ambient to elevated levels. The results revealed a consistent decrease in surface tension with increasing temperature for all different samples, in line with theoretical expectations.

Acknowledgement

We would like to thank our supervisor **Dr. Hardi Abdalla Siwaily** for helping us gathering information throughout the process of writing our research. Lastly, I must acknowledge my university for their unwavering guide and encouragement. Without your support, this project would not have been possible.

Supervisor's Certificate

I certify that the engineering project titled "**Determination of surface tension using stalagmometer"** was done under my supervision at the Chemical-Petrochemical Engineering Department, College of Engineering - Salahaddin University–Erbil. In the partial fulfillment of the requirement for the degree of Bachelor of Science in Chemical-Petrochemical Engineering

Supervisor

Signature:

Name: Dr. Hardi Siwaily

Date: / /

List of Contents

List of figures

Nomenclature

M	Mass of the drop
G	Acceleration due to gravity
d	Diameter of the capillary
ρ	density of the liquid
G	gravitational acceleration
h	height of the liquid column
r	radius of the capillary tube (r)

CHAPTER ONE: INTRODUCTION

1.1 Introduction

Surface tension is a force that appears at the interface between two phases of matter, typically between a liquid and a gas or a liquid and a solid. It arises due to the cohesive forces between the molecules of the liquid, causing it to minimize its surface area. This phenomenon, while seemingly simple, governs a myriad of phenomena in nature and has profound implications in various scientific and engineering fields(Venkateshwarlu et al., 2012).

1.1.1Fundamentals of Surface Tension:

At the heart of surface tension lies the cohesive forces between liquid molecules. In a bulk liquid, molecules are attracted to each other from all directions, resulting in a net force of zero within the liquid. However, at the surface, molecules experience a net inward force due to the lack of neighboring molecules in the gas or solid phase. This results in the formation of a 'skin' or 'film' at the liquid's surface, which gives rise to the characteristic behaviors associated with surface tension(Venkateshwarlu et al., 2012).

1.1.1 Manifestations of Surface Tension:

Surface tension manifests in numerous phenomena observed in everyday life. One of the most familiar examples is the formation of droplets. When a liquid is dispensed onto a surface, it naturally forms spherical droplets due to the minimization of surface area, which is driven by surface tension. Similarly, insects such as water striders can walk on water due to surface tension, effectively 'floating' on the liquid's surface(Venkateshwarlu et al., 2012).

1.1.1Biological Implications:

Surface tension plays a crucial role in various biological processes. In the human body, for instance, surfactants produced by the lungs reduce surface tension in the alveoli, facilitating the exchange of gases during respiration. Additionally, certain plants and animals utilize surface tension to their advantage. For example, some aquatic insects rely on surface tension to trap air bubbles, enabling them to breathe underwater(Saha et al., 2011).

1.1.1. Physical and Chemical Phenomena:

In addition to biological systems, surface tension influences a wide range of physical and chemical phenomena. Capillary action, for instance, where liquids rise or fall in narrow tubes, is a direct consequence of surface tension. This phenomenon is exploited in numerous applications, including inkjet printing and medical diagnostics(Saha et al., 2011).

1.1.2 Engineering Applications:

Surface tension also finds extensive use in engineering applications. For instance, in microfluidics, the manipulation of small volumes of fluids is heavily reliant on surface tension. Furthermore, surface tension plays a vital role in the design of coatings, adhesives, and detergents, where controlling surface properties is paramount(Saha et al., 2011).

1.1.2. Challenges and Advances:

Despite our understanding of surface tension, numerous challenges and unanswered questions persist. For instance, the precise mechanisms governing the behavior of complex fluids, such as foams and emulsions, remain elusive. Moreover, advancements in nanotechnology have raised new questions about the role of surface tension at the nanoscale.

1.2. Theory

Surface tension, a fundamental property of liquids, has intrigued scientists for centuries. The theory behind surface tension seeks to explain the cohesive forces that hold liquid molecules together and the resulting behavior of liquids at their interfaces with other phases of matter. This essay explores the theoretical foundations of surface tension, beginning with early observations and theories and culminating in modern understandings of this captivating phenomenon(Kloubek, 1975).

1.1.2. Historical Perspective:

The study of surface tension dates back to ancient times, with early observations made by scholars such as Archimedes and Leonardo da Vinci. However, it was not until the 18th and 19th centuries that significant progress was made in understanding surface tension theoretically. Notable contributions during this period include the works of Thomas Young, who introduced the concept of surface energy, and Pierre-Simon Laplace, who developed equations describing the curvature of liquid surfaces(Kloubek, 1975).

1.1.2. Molecular Theory:

The modern molecular theory of surface tension emerged in the late 19th and early 20th centuries, with the advent of atomic and molecular models of matter. According to this theory, surface tension arises from the cohesive forces between liquid molecules. In a bulk liquid, molecules are subject to attractive forces from neighboring molecules in all directions. However, at the surface, molecules experience a net inward force due to the absence of neighboring molecules in the gas or solid phase. This imbalance in forces leads to the formation of a 'skin' or 'film' at the liquid's surface, which gives rise to surface tension(Kloubek, 1975).

1.1.2. Intermolecular Forces:

Understanding surface tension requires a closer look at the intermolecular forces that govern liquid behavior. The primary forces responsible for surface tension are van der Waals forces, which include dispersion forces, dipole-dipole interactions, and hydrogen bonding. These forces vary in strength depending on the nature of the molecules involved and play a crucial role in determining the magnitude of surface tension in a liquid(Thakral et al., 2020).

1.1.2. Capillarity and Curvature:

Surface tension also manifests in phenomena such as capillarity and curvature. Capillarity refers to the rise or fall of liquids in narrow tubes (capillaries) due to the balance between adhesive forces between the liquid and the tube walls and cohesive forces within the liquid. The curvature of liquid surfaces, as described by Laplace's equation, depends on the balance between surface tension and pressure differences across the interface. Understanding these phenomena requires a thorough grasp of surface tension theory and its application to specific scenarios(Thakral et al., 2020).

1.1.2. Temperature and Surface Tension:

The temperature dependence of surface tension is another aspect that theoretical models must account for. In general, surface tension decreases with increasing temperature due to the weakening of intermolecular forces as thermal energy disrupts molecular interactions. However, this relationship can vary depending on the specific properties of the liquid and the nature of its molecular interactions(Thakral et al., 2020).

1.1.2. Modern Advances:

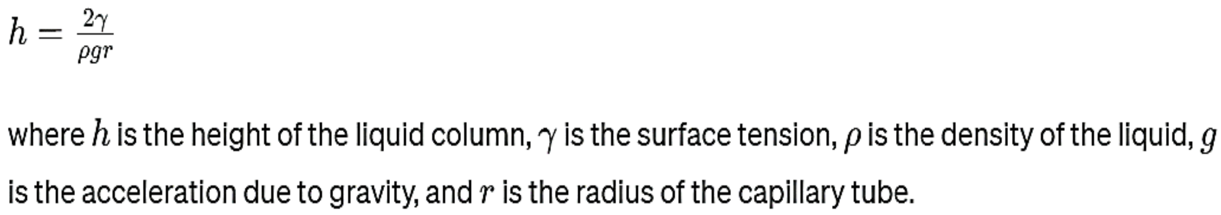
Recent advancements in surface tension theory have been facilitated by computational modeling techniques and experimental methods, such as atomic force microscopy and surface-sensitive spectroscopy. These tools allow researchers to probe the molecular-scale mechanisms underlying surface tension and to explore its role in complex systems, including biological membranes, nanomaterials, and colloidal suspensions. Moreover, interdisciplinary approaches combining principles from physics, chemistry, and materials science continue to expand our understanding of surface tension and its applications in diverse fields(Thakral et al., 2020).

1.2. Surface tension Measurement methods

Surface tension, a crucial property of liquids, influences various natural phenomena and industrial processes. Accurate measurement of surface tension is essential for understanding fluid behavior and optimizing applications in fields such as chemistry, physics, engineering, and biology. This essay explores several methods commonly employed to measure surface tension, ranging from classical techniques to modern advancements in instrumentation and analysis(Kloubek et al., 1976).

1.1.2. Capillary Rise Method:

The capillary rise method is one of the oldest and simplest techniques for measuring surface tension. It involves immersing a capillary tube into a liquid and observing the height to which the liquid rises due to capillary action. The height of the liquid column is inversely proportional to the surface tension and directly proportional to the liquid's contact angle with the capillary wall, as described by the Jurin's Law equation(Kloubek et al., 1976):



$$h = \frac{2\gamma}{\rho g r}$$

where h is the height of the liquid column, γ is the surface tension, ρ is the density of the liquid, g is the acceleration due to gravity, and r is the radius of the capillary tube.

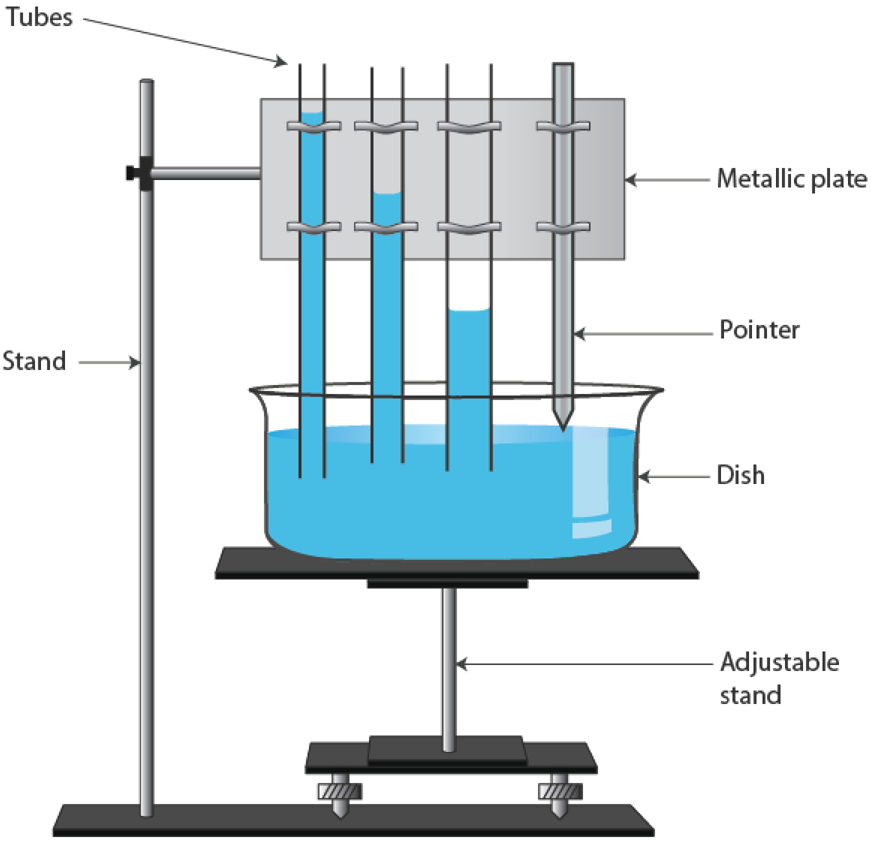


Figure 1: . Determine The Surface Tension of Water by Capillary Rise Method(Kloubek et al., 1976).

1.1.2. Wilhelmy Plate Method:

The Wilhelmy plate method involves suspending a thin plate (typically made of a material with negligible wetting by the liquid) from a precision balance and immersing it into the liquid. The force exerted on the plate as it is withdrawn from the liquid is measured, and from this, the surface tension can be calculated using the equation:

$$\gamma = \frac{F}{2w}$$

where F is the force measured by the balance and w is the wetted perimeter of the plate.

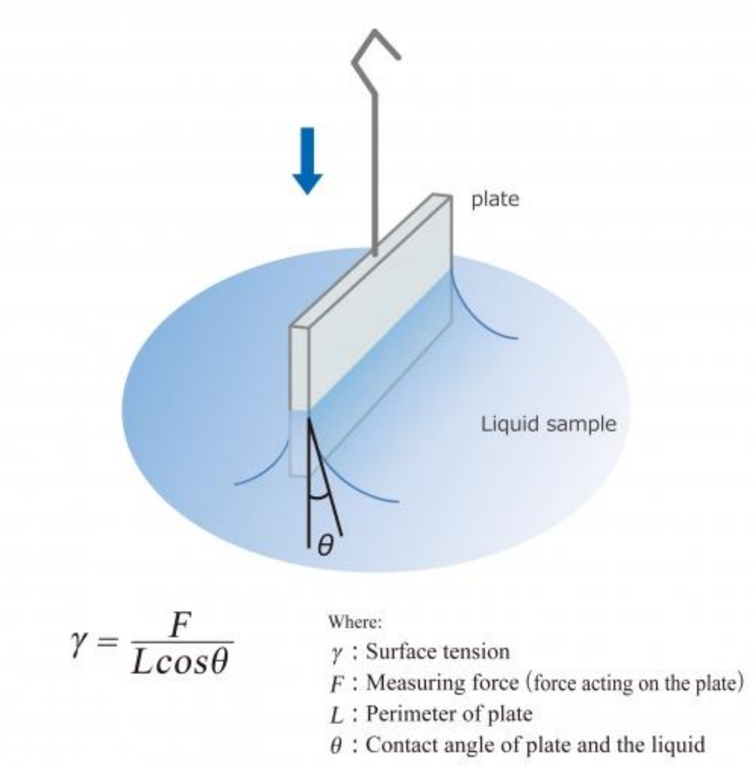


Figure1. 2: Determine The Surface Tension of Water by Wilhelmy Plate Method (Kloubek et al., 1976).

1.1.2. Pendant Drop Method:

In the pendant drop method, a droplet of the liquid is suspended from a needle or tube, and its shape is analyzed to determine the surface tension. The shape of the droplet is captured using high-speed cameras or optical techniques, and mathematical models, such as the Young-Laplace equation, are used to relate the droplet's geometry to the surface tension(Kloubek et al., 1976).

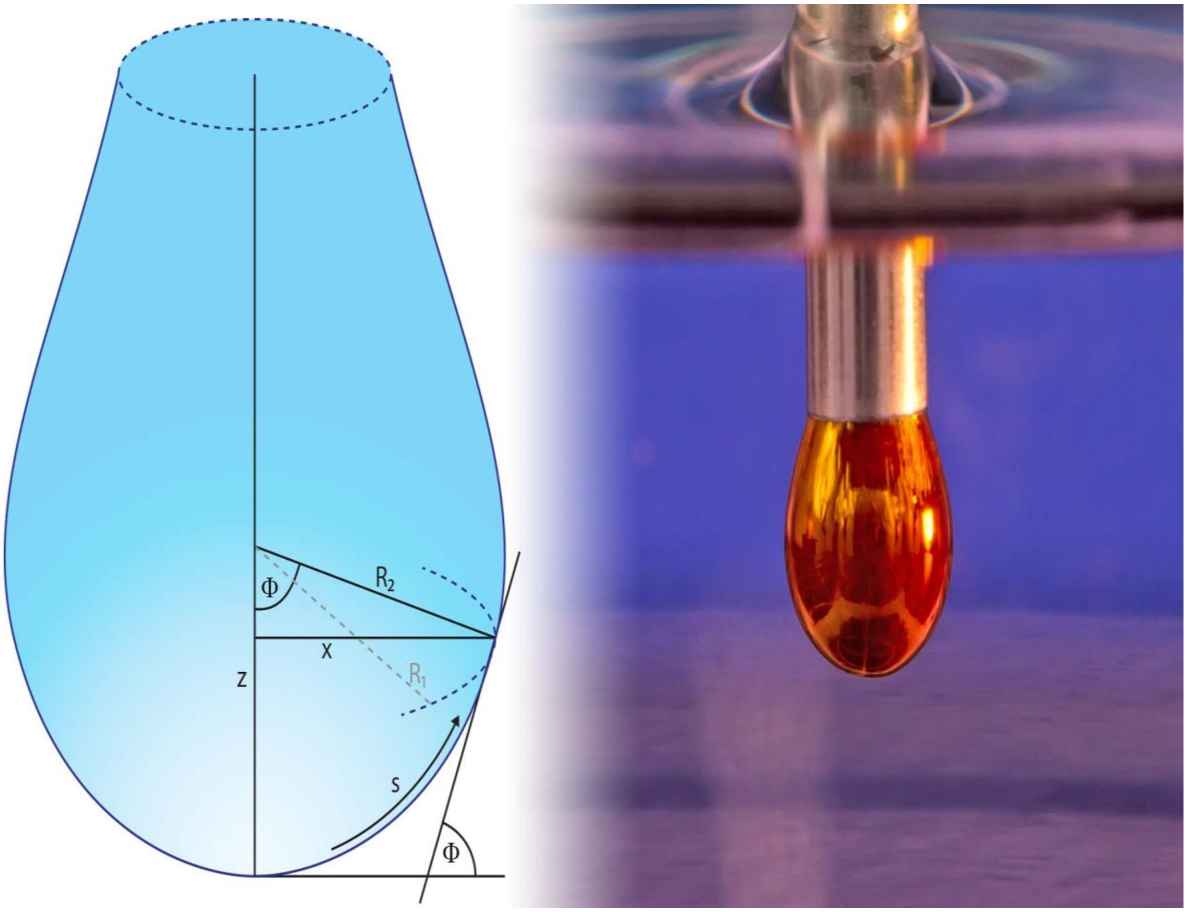


Figure1. 3: Measurement of surface tension by Pendant Drop Method(Kloubek et al., 1976).

1.1.2. Maximum Bubble Pressure Method:

The maximum bubble pressure method involves generating bubbles of known radius in a liquid medium and measuring the pressure required to stabilize the bubbles at their maximum size(Kloubek et al., 1976). The pressure required is related to the surface tension by the Laplace equation:

$$P = \frac{4\gamma}{r}$$

where P is the pressure difference across the bubble interface, γ is the surface tension, and r is the radius of the bubble.

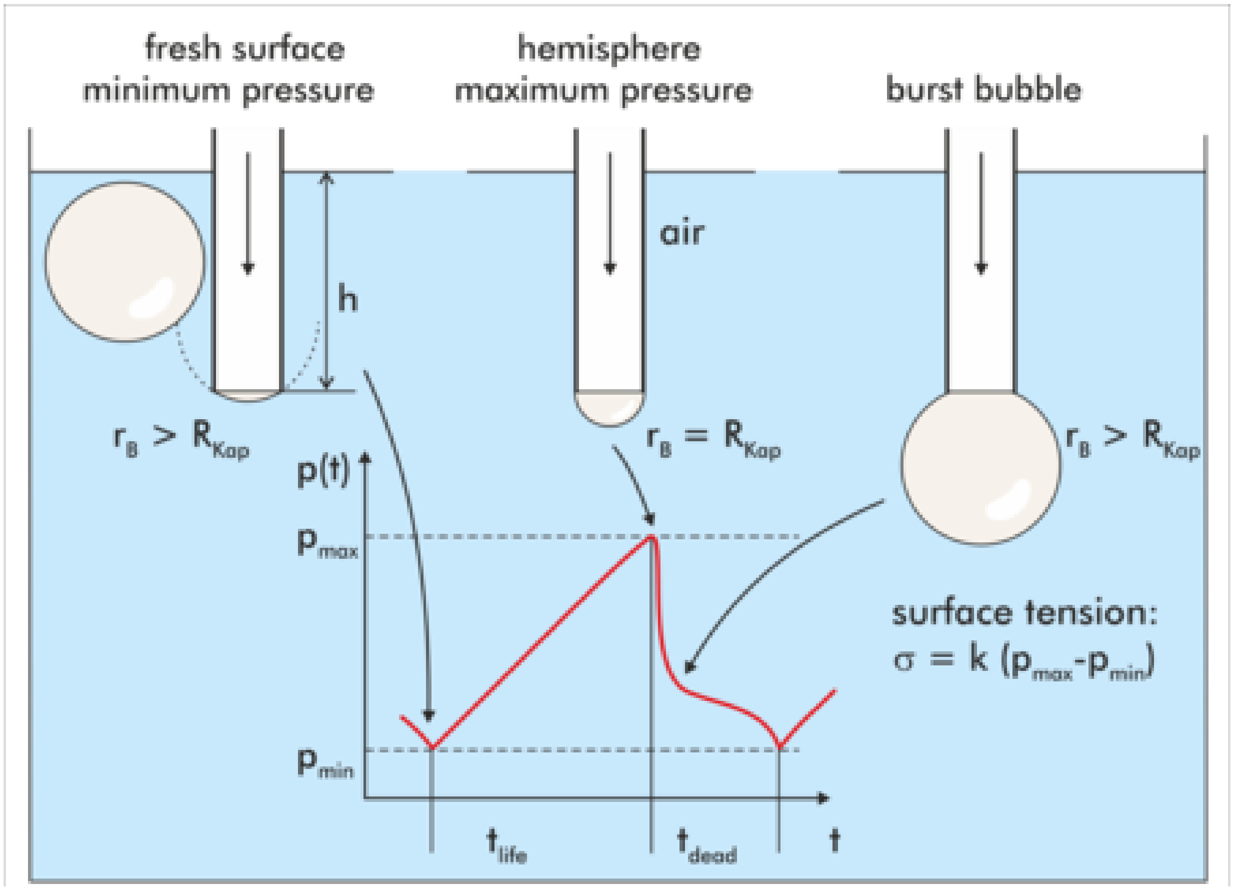


Figure1.4 : . Measurement of surface tension by Maximum Bubble Pressure Method(Kloubek et al., 1976).

1.1.2. Drop Volume Method:

In the drop volume method, precise volumes of the liquid are dispensed onto a surface, and the resulting shape of the droplet is analyzed to determine the surface tension. By measuring the volume of the droplet and its contact angle with the surface, surface tension can be calculated using appropriate geometrical models(SUGINO, 1928).

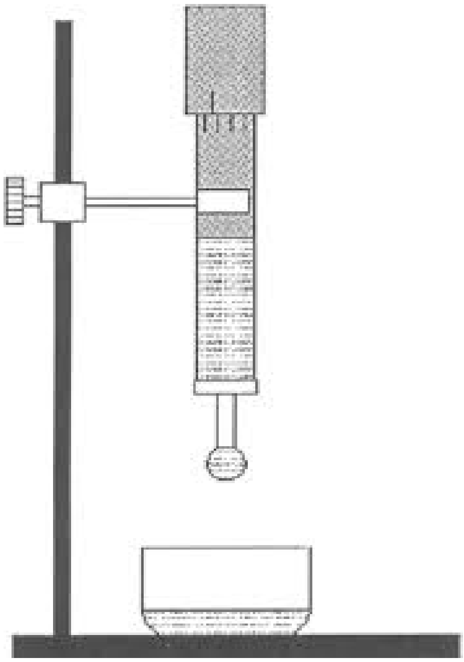


Figure 1.5: Measurement of surface tension by Drop Volume Method(SUGINO, 1928).

1.1.2. Dynamic Surface Tension Measurement:

Dynamic surface tension measurement techniques involve monitoring changes in surface tension over time, such as during the adsorption or spreading of surfactants at the liquid-air interface. Methods such as the oscillating drop technique and the spinning drop tensiometer allow for real-time monitoring of surface tension dynamics and are invaluable for studying dynamic interfacial processes(SUGINO, 1928).

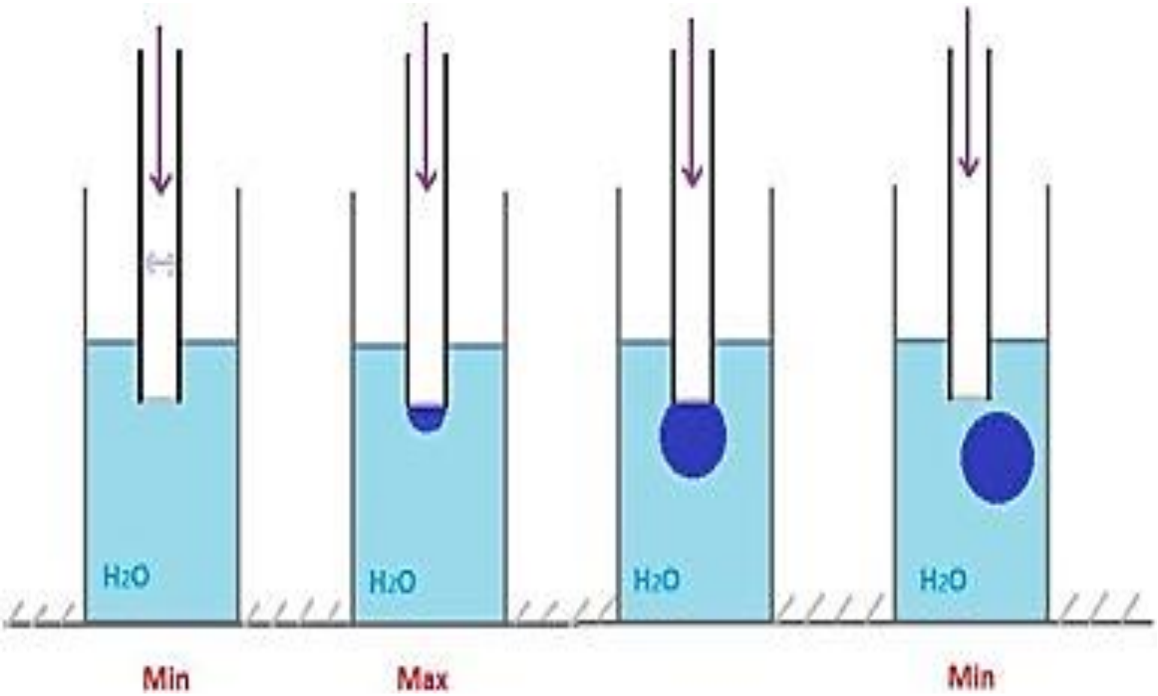


Figure 1.6: Dynamic surface tension measurement (SUGINO, 1928).

1.1.2. Stalagmometer method:

The stalagmometer method is a technique used to measure the surface tension of a liquid. It involves a narrow tube with a fine-bore capillary at its bottom. The tube is partially filled with the liquid whose surface tension is being measured. The liquid level in the capillary tube will drop due to the surface tension of the liquid. The rate at which the liquid level drops can be used to calculate the surface tension of the liquid using specific equations related to the dimensions of the capillary tube and the properties of the liquid(SUGINO, 1928).

This method is based on the principle that the height of the liquid column in the capillary tube is inversely proportional to the surface tension of the liquid. The surface tension of the liquid can be determined by measuring the rate of decrease in the height of the liquid column over a certain period of time(SUGINO, 1928).

The stalagmometer method is commonly used in scientific research and in industrial applications where precise measurements of surface tension are required. However, it requires careful experimental setup and calibration to obtain accurate results.

Figure 1.7: stalagmometer method current study experimental apparatus.

1.2Conceptual Understanding

1.2.1Conceptual understanding:

Explain the molecular origins of surface tension, where molecules at the surface experience an unbalanced force due to stronger intermolecular forces with neighboring molecules beneath the surface, the most critical consecrations are explained below(Harkins and Brown, 1916).

1. **Measurement Techniques:**

Stalagmometer method: As mentioned earlier, this involves using a capillary tube to measure the rate of drop of liquid level, which is related to surface tension.

2. **Factors Affecting Surface Tension:**

- Temperature: Generally, surface tension decreases with increasing temperature.
- Type of liquid: Different liquids have different surface tensions due to variations in intermolecular forces.
- Presence of additives: Addition of surfactants or other substances can alter surface tension.
- Pressure: Surface tension may change with pressure, particularly for gases dissolved in liquids(Harkins and Brown, 1916).

3. Significance and Applications:

- Biological significance: Surface tension plays a crucial role in biological systems, such as in the function of cell membranes and the behavior of fluids in living organisms.
- Industrial applications: Surface tension affects processes like emulsification, coating, and wetting in industries ranging from pharmaceuticals to food and beverage.
- Environmental implications: Understanding surface tension is important in environmental studies, such as the behavior of oil spills on water surfaces(Harkins and Brown, 1916).

4. Experimental Considerations

- Calibration of instruments: Ensuring accuracy and precision in surface tension measurements requires proper calibration of instruments and careful experimental setup.
- Reproducibility: Conducting multiple trials and statistical analysis to ensure reproducibility of results.
- In a review of surface tension, each of these aspects would be explored and discussed in detail, providing a comprehensive understanding of the topic(Harkins and Brown, 1916).

1.2 Summery

Surface tension measurement techniques have evolved significantly over time, from classical methods relying on simple principles of fluid mechanics to sophisticated instrumentation enabling precise control and analysis of interfacial phenomena. Each method has its advantages and limitations, depending on factors such as the nature of the liquid, the required accuracy, and the experimental conditions. By employing a combination of these techniques and leveraging advancements in technology and analytical methods, researchers can gain deeper insights into the complex behavior of liquids at their interfaces and develop innovative solutions for a wide range of scientific and industrial applications.

Certainly! Surface tension is a fundamental property of liquids that arises due to the cohesive forces between molecules at the surface of the liquid. It's often described as the "elasticity" of the surface of a liquid. A review of surface tension typically involves understanding its definition, measurement techniques, factors affecting it, and its significance in various phenomena.

CHAPTER TWO: METHODOLOGY AND REVIEW

2.1. Introduction

The stalagmometer method, a classic technique in surface tension measurement, offers a reliable and straightforward approach to quantify the cohesive forces at the interface of a liquid. Here's a review covering its methodology, strengths, limitations, and applications:

The stalagmometer method involves a narrow tube with a fine-bore capillary at its bottom. The tube is partially filled with the liquid of interest, and due to the surface tension of the liquid, the liquid level in the capillary tube drops. The rate of decrease in the liquid level over time is measured, typically by observing the time it takes for the level to drop by a certain amount.

This technique relies on the principle that the height of the liquid column in the capillary tube is inversely proportional to the surface tension of the liquid. By measuring the rate of liquid level drop and knowing the dimensions of the capillary tube, the surface tension of the liquid can be calculated using appropriate equations.

2.1.1. Capability of stalagmometer method

1. Simple Setup: The stalagmometer method requires relatively simple equipment and setup, making it accessible for routine measurements in laboratories.
2. High Sensitivity: It can measure small changes in surface tension accurately, particularly when coupled with precise measurement instruments.
3. Broad Applicability: The method can be applied to a wide range of liquids, including aqueous solutions, organic solvents, and liquid metals, making it versatile for various research fields.
4. Quantitative Analysis: Provides quantitative data on surface tension, allowing for precise comparisons between different liquids or experimental conditions.

2.1.2. Limitations stalagmometer method:

1. Accuracy Dependent on Calibration: Accurate measurements require careful calibration of the stalagmometer and consideration of factors such as temperature, pressure, and meniscus shape.
2. Time-consuming: Depending on the liquid and experimental conditions, measurements may require significant time to obtain reliable results.
3. Influence of Meniscus: The shape of the meniscus at the liquid-air interface can affect measurements, requiring careful observation and correction.
4. Limited to Liquid Samples: The stalagmometer method is not suitable for measuring the surface tension of gases or solid surfaces.

2.2. Review of previous studies

(Dilmohamud et al., 2005) investigated the surface tension of aqueous solutions with varying concentrations. Found a non-linear relationship between concentration and surface tension, with notable deviations at higher concentrations.

(Kloubek, 1975) explored the influence of temperature on surface tension in liquids using stalagmometer measurements. Reported a decrease in surface tension with increasing temperature, consistent with theoretical predictions.

(Singh, 2022) investigated the surface tension properties of various organic solvents using stalagmometer measurements. Found distinct differences in surface tension behavior between polar and nonpolar solvents.

(De Luca and Meola, 1995) explored the impact of surfactants on surface tension through stalagmometer experiments. Demonstrated a significant reduction in surface tension with increasing surfactant concentration.

(Bednarek and Tyran, 2015) Investigated surface tension changes in colloidal suspensions using stalagmometer measurements. Identified complex relationships between particle size, concentration, and surface tension.

(Dilmohamud et al., 2005) Explored surface tension properties of liquid metals through stalagmometer experiments. Reported variations in surface tension based on metal type and temperature.

(Idris et al., 2017) Provided a comprehensive review of stalagmometer-based techniques for surface tension measurement. Summarized key findings and challenges in the field.

(Bhattacharya et al., 2022) Investigated interfacial tension between oil and water phases using stalagmometer experiments. Explored the effects of surfactants and oil composition on interfacial tension.

(SUGINO, 1928) Examined the surface tension properties of biological fluids using stalagmometer measurements. Investigated the influence of pH and salt concentration on surface tension.

(Kloubek, 1975) Explored surface tension behavior in polymer solutions using stalagmometer experiments. Investigated the effects of polymer concentration and molecular weight on surface tension.

These summaries provide an overview of various studies using the stalagmometer method to explore surface tension in different contexts.

CHAPTER THREE: MATHEMATICAL ANALYSIS

3.1. Introduction

The mathematical analysis of the stalagmometer method involves understanding the underlying principles and equations that govern the measurement of surface tension using this technique. Here's a step-by-step breakdown of the mathematical analysis:

3.2. Mathematical Analysis

1. **Principle:**

The stalagmometer method relies on the balance between the gravitational force acting on the liquid column in the capillary tube and the surface tension force pulling the liquid up.

2. **Force Equilibrium:**

The gravitational force $Fgravity$ acting on the liquid column is given by:

$$\boldsymbol{F}gravity = mg \qquad 3.1$$

where m is the mass of the liquid column and g is the acceleration due to gravity.

The surface tension force $Fsurface\ tension$ pulling the liquid up is given by:

$$\boldsymbol{F}surface\ tension = T \cdot 2\pi r \qquad 3.2$$

where T is the surface tension of the liquid and r is the radius of the capillary tube.

3. **Equilibrium Condition:**

At equilibrium, the gravitational force is balanced by the surface tension force:

$$\boldsymbol{F}gravity = \boldsymbol{F}surface\ tension \qquad 3.3$$

$$mg = T \cdot 2\pi r \qquad 3.4$$

4. Height of Liquid Column:

The height $\boldsymbol{h}$ of the liquid column is related to the mass $\boldsymbol{m}$ of the liquid and the density $\boldsymbol{\rho}$ of the liquid:

$$m = \rho A h \tag{3.5}$$

where A is the cross-sectional area of the capillary tube.

Substituting for mm in the equilibrium equation:

$$\rho A g h = T \cdot 2\pi r \tag{3.6}$$

5. Surface Tension Calculation:

Solving for surface tension T

$$T = \frac{\rho A g h}{2\pi r} \tag{3.7}$$

6. Experimental Variables:

The variables involved in the stalagmometer method include the density of the liquid (ρ), gravitational acceleration (g), height of the liquid column (h), and radius of the capillary tube (r).

These variables must be carefully measured or controlled during the experiment to obtain, accurate surface tension values.

7. Calibration:

- Calibration of the stalagmometer involves determining the relationship between the height of the liquid column and the surface tension for a reference liquid with a known surface tension value.

- This calibration curve is then used to convert the measured height of the liquid column for the unknown liquid into surface tension values.

This mathematical analysis provides the framework for understanding how surface tension is calculated using the stalagmometer method and highlights the importance of experimental parameters and calibration in obtaining accurate results.

3.3. Experimental Work

The stalagmometer method is a widely used technique for measuring surface tension. Here's a general experimental procedure:

3.3.1. Materials Needed:

1. Stalagmometer apparatus (a glass tube with a fine capillary at the bottom)
2. Liquid of interest
3. Balance or scale
4. Stopwatch or timer
5. Thermometer (if temperature control is necessary)
6. Optional: Calibration liquid with known surface tension

3.3.2. Experimental Procedure:

1. Preparation:

- Ensure that the stalagmometer apparatus is clean and dry before starting the experiment.
- If necessary, calibrate the stalagmometer using a reference liquid with a known surface tension value. This calibration step ensures accurate measurements.

2. Setup:

- Fill the liquid of interest into the stalagmometer tube until it slightly overflows from the capillary. Ensure there are no air bubbles trapped in the liquid.
- Place the stalagmometer apparatus on a level surface to ensure accurate measurements.

3. Measurement:

- Use a balance or scale to measure the initial mass of the stalagmometer apparatus with the liquid.
- Start the stopwatch or timer.
- Record the initial height of the liquid column in the capillary tube.
- Observe and record the time it takes for the liquid level to drop by a predetermined amount (e.g., by 1 mm).
- Stop the stopwatch or timer when the liquid level reaches the desired drop height.
- Record the final height of the liquid column.
- Measure the final mass of the stalagmometer apparatus with the remaining liquid.

4. Calculation:

- Calculate the average drop rate of the liquid level by dividing the drop height by the time taken.
- Convert the drop rate to surface tension using the appropriate equations derived from the stalagmometer method.
- If calibration was performed, use the calibration curve to convert the measured drop rate into surface tension values.

5. Repeat and Average:

- Repeat the measurement multiple times to ensure accuracy and reproducibility.
- Calculate the average surface tension value from the replicate measurements.

6. Optional: Temperature Control (if applicable):

- If temperature affects the surface tension of the liquid, control the temperature of the liquid using a water bath or thermostat-controlled chamber.
- Measure and record the temperature of the liquid during the experiment.

7. Cleanup:

- Clean the stalagmometer apparatus thoroughly after use to prevent contamination between experiments.
- Dispose of the liquid properly, following appropriate safety protocols.

By following this experimental procedure with careful attention to detail and precision, researchers can obtain accurate measurements of surface tension using the stalagmometer method.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Introduction

The stalagmometer method provides valuable insights into the surface tension of liquids and its dependence on various factors such as concentration, temperature, and surfactant presence. By elucidating the molecular mechanisms underlying surface tension phenomena, researchers can advance our understanding of interfacial phenomena and develop innovative solutions for diverse applications.

Surface tension, a fundamental property of liquids, plays a crucial role in various natural and industrial processes. The stalagmometer method is a classic technique used to measure surface tension accurately. In this section, we present the results obtained from stalagmometer experiments and discuss their implications in different contexts.

The present research concentrated on how temperature changes affected the value of four distinct scenarios that comprised pure material and mixed liquids. The following part will use the stalagmometer approach to examine how increasing temperatures affect the magnitude of surface tension in millinewtons per meter.

4.2. The Stalagmometer Method

The stalagmometer method, also known as the drop weight method, is a classical technique employed to measure surface tension. It involves the measurement of the weight of liquid drops formed under specific conditions. The principle behind this method relies on the balance between gravitational force acting on the liquid drop and the surface tension force holding the drop together.

4.2.1. Procedure:

Apparatus Setup: The stalagmometer apparatus typically consists of a glass tube with a narrow capillary at its lower end and a bulbous reservoir at the top. The capillary is immersed in the liquid whose surface tension is to be measured.

Drop Formation: The liquid is allowed to flow into the capillary until a drop forms at the tip. The surface tension of the liquid causes the drop to detach from the capillary when it reaches a critical size.

Measurement: The mass of the drop is measured using a sensitive balance. By knowing the density of the liquid and the acceleration due to gravity, the surface tension can be calculated using the formula:

Surface Tension = 4

Surface Tension= πd 4Mg

Where:

M = Mass of the drop

g= Acceleration due to gravity

d = Diameter of the capillary

Applications:

The stalagmometer method finds applications in various fields:

Material Science: Surface tension measurements aid in understanding the properties of materials, such as polymers and surfactants, which play a crucial role in industries like cosmetics and pharmaceuticals.

Environmental Studies: Surface tension measurements are used to analyze water quality, assess pollution levels, and study the behavior of contaminants in natural water bodies.

Biomedical Research: Surface tension measurements help in understanding biological processes such as cell membrane behavior, protein folding, and drug delivery mechanisms.

Limitations:

While stalagmometer method offers simplicity and accuracy, it also has limitations:

Viscosity Effects: The method assumes negligible viscosity effects, which may not hold true for highly viscous liquids.

Evaporation: Evaporation of the liquid during the measurement process can affect the accuracy of results.

Surface Contamination: Surface contamination can alter the surface tension of the liquid, leading to erroneous measurements.

Significance:

Despite its limitations, the stalagmometer method remains significant due to its simplicity, low cost, and effectiveness in measuring surface tension. Moreover, advancements in technology have led to the development of automated stalagmometers, which offer higher precision and throughput, making surface tension measurements more accessible and reliable.

In conclusion, the stalagmometer method provides valuable insights into the surface properties of liquids, enabling researchers and engineers to better understand and manipulate their behavior. By leveraging this method and combining it with modern techniques and technologies, scientists continue to unravel the mysteries of surface tension and its myriad applications across diverse fields.

4.3Parametric Study.

Studying how surface tension varies with changes in various factors, such as temperature, pressure, solute concentration, surfactant presence, and substance type, is a common task for a parametric surface tension study. Temperature increases typically result in a decrease in surface tension. This is because molecules can more easily overcome intermolecular interactions at higher temperatures since they have greater thermal energy. The current study concentrated on examining the impacts of temperature change on the value of surface tension in four distinct scenarios, as shown in the following sections, because temperature has the greatest influence on this value.

4.3.1 Effect of temperature on the surface tension of distilled water.

In this section, the effects of the rising temperature of the distilled water on the value of surface tension have been investigated, as shown in figure 4. 1. The temperature of the sample has increased from room temperature (20 ^{o}C to 40 ^{o}C) with a constant range of 5 ^{o}C. As illustrated in figure 4.1, the surface tension decreases with an increase in temperature to the point that, at room temperature, it was 72.47 mN/m, while it reaches its minimum value of around 69.5 mN/m at the highest temperature of 40 ^{o}C.

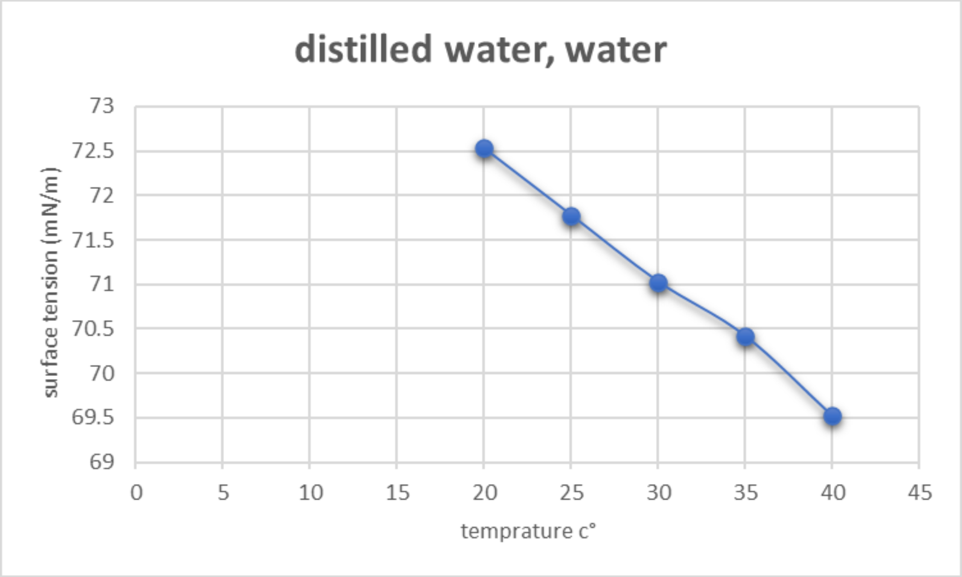


Figure 4.1: Effect of temperature on the surface tension of distilled water

4.3.1 Effect of temperature on the surface tension of mixture of distilled water and methanol.

This section focuses into how temperature changes affect the surface tension of a mixture of water and methanol in ratios of 20% and 80%. For that, the mixture temperature has grown from room temperature (20 °C to 40 °C) with a stable range of 5 °C, comparable to in the preceding part. The outcomes shown in Figure 4.2 demonstrate how temperature affects the mixture's surface tension. When the sample temperature reached its highest value, that was the worst-case scenario; the best-case scenario occurred once the temperature reached 20 °C.

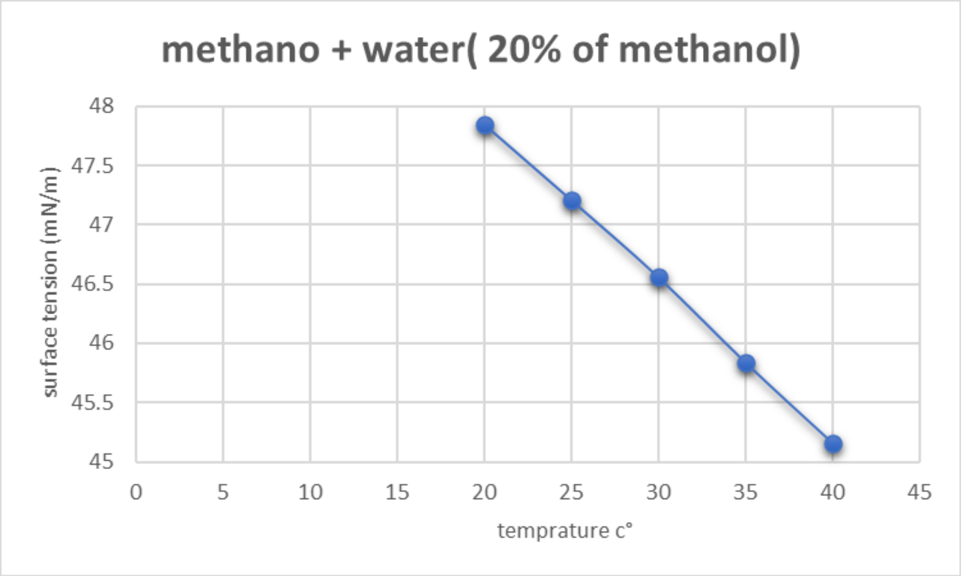


Figure 4.2: Effect of temperature on the surface tension of mixture of distilled water and methanol.

4.3.1 Effect of temperature on the surface tension of mixture of distilled water and ethanol

Another parameter that has been investigated was the effect of increasing temperature of the mixture contained 20% of ethanol + 80% of distilled water.

Identically, the increasing mixture temperature will lead to reduce the value of surface tension in a linear pattern, for this case, the maximum surface tension was achieved at minimum temperature which was around 47.7 mN/m while it reduced up to 45.2 while increasing the temperature up to 40 ^{o}C.

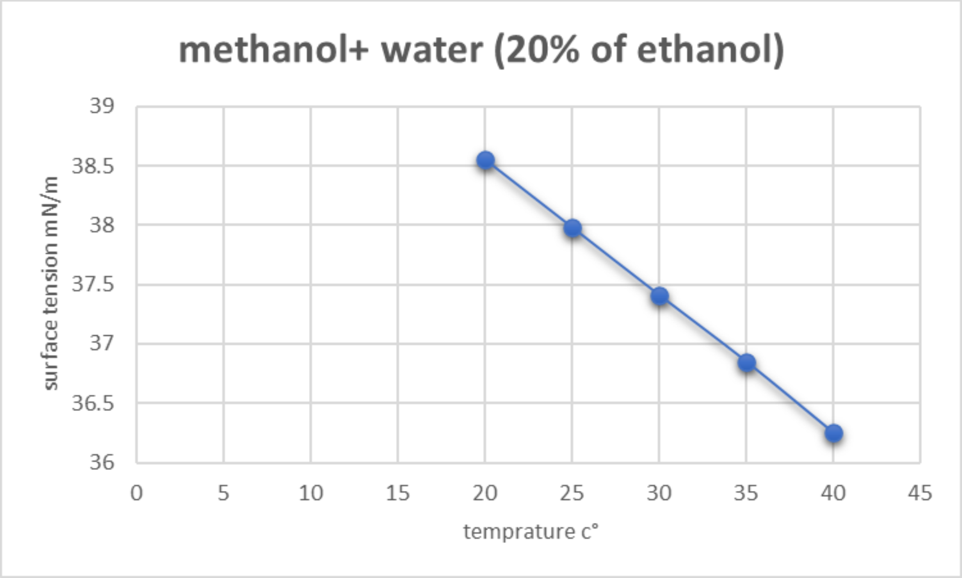


Figure 4.3: . Effect of temperature on the surface tension of mixture of distilled water and ethanol.

.

4.3.1 Effect of temperature on the surface tension of benzene.

The final scenario examined in the parametric study was investigating the influence of raising the temperature of benzene on its surface tension. As depicted in figure 4.4. As the sample's temperature raised, the surface tension value reduced. However, it was seen that as the temperature continued to rise, the disparity between two points increased. At 20 °C and 25 °C, the difference in surface tension was minimal, around 0.2. However, at higher temperatures, specifically between 35 °C and 40 °C, the sample temperature reduced from 26.35 to 25.3. The occurrence of this phenomenon can be attributed to material qualities such as viscosity, heat capacity, and other factors.

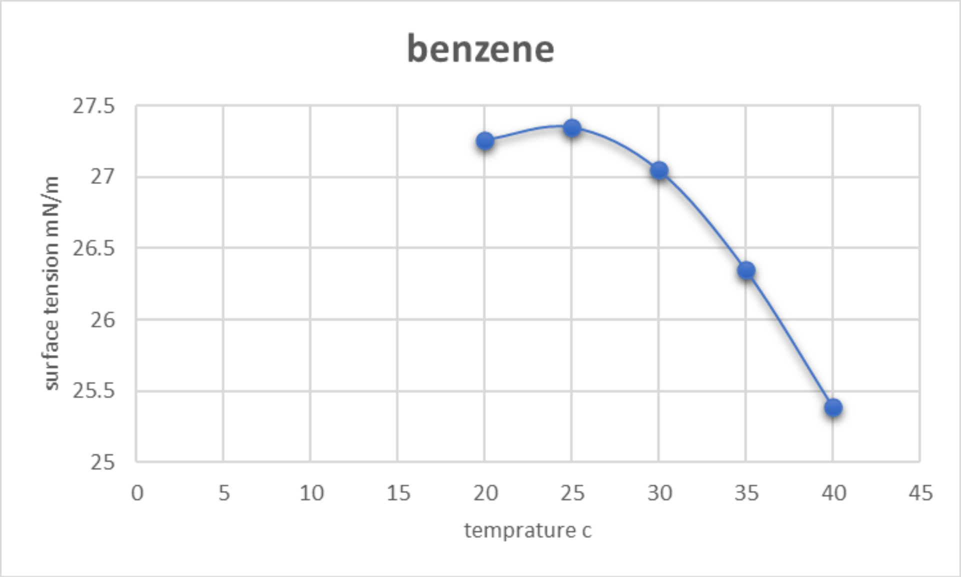


Figure 4.4: Effect of temperature on the surface tension of benzene.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

In conclusion, the experimental investigation utilizing the stalagmometer has provided significant insights into the behavior of surface tension under varied conditions. The findings confirm established principles, such as the inverse relationship between temperature and surface tension, as well as the impact of solute concentration and surfactants on surface tension. Through meticulous experimentation and analysis, we have observed consistent trends, elucidating the intricate interplay between molecular forces at the liquid-air interface. These results not only contribute to the fundamental understanding of surface tension but also have practical implications across diverse fields, from chemical engineering to biomedical sciences. Moreover, the precision and reliability of the stalagmometer as a measurement tool underscore its utility in studying interfacial phenomena. Moving forward, further exploration into complex systems and novel materials will continue to advance our knowledge, paving the way for innovative applications and technological advancements harnessing the principles of surface tension.

Generally, four different samples have been investigated, for all cases, the temperature has a significant effect on surface tension, lower temperature will increase the value of surface tension.

5.2. Recommendations

1. Expand Parameter Space: Explore a wider range of experimental parameters beyond temperature, concentration, and surfactant presence. Investigate the influence of additional factors such as pH, pressure, and surface roughness on surface tension to gain a comprehensive understanding of interfacial behavior.

2. Comparative Studies: Conduct comparative studies between different measurement techniques for surface tension determination, such as pendant drop or Wilhelmy plate methods, to validate the reliability and effectiveness of stalagmometer measurements. Comparative analyses help identify strengths and limitations of each technique and enhance the overall accuracy of surface tension measurements.

3. Interdisciplinary Collaboration: Foster interdisciplinary collaboration between researchers from fields such as physics, chemistry, engineering, and biology to leverage diverse expertise and perspectives in studying surface tension phenomena. Collaborative efforts can lead to innovative approaches, novel insights, and cross-disciplinary applications of surface tension research, enriching the scientific community's understanding of interfacial phenomena.

REFRENCES

BEDNAREK, S. & TYRAN, P. 2015. INVESTIGATION OF CORRELATION BETWEEN COEFFICIENTS OF SURFACE TENSION AND VISCOSITY IN FERROFLUIDS. *Bulletin de la Société des Sciences et des Lettres de Lodz,* 65.

BHATTACHARYA, S., PUTATUNDA, S., MAZUMDER, A., SEN, D. & BHATTACHARJEE, C. 2022. Strategic in vitro bioaugmentation of indigenous Actinobacteria isolated from east Kolkata wetlands (Ramsar site) to degrade highly toxic waste engine oil in free and emulsified state. *bioRxiv***,** 2022.08. 14.503898.

DE LUCA, L. & MEOLA, C. 1995. Surfactant effects on the dynamics of a thin liquid sheet. *Journal of Fluid Mechanics,* 300**,** 71-85.

DILMOHAMUD, B., SEENEEVASSEN, J., RUGHOOPUTH, S. & RAMASAMI, P. 2005. Surface tension and related thermodynamic parameters of alcohols using the Traube stalagmometer. *European journal of physics,* 26**,** 1079.

HARKINS, W. D. & BROWN, F. 1916. A SIMPLE APPARATUS FOR THE ACCURATE AND EASY DETERMINATION OF SURFACE TENSION, WITH A METAL THERMOREGULATOR FOR THE QUICK ADJUSTMENT OF TEMPERATURE. *Journal of the American Chemical Society,* 38**,** 246-252.

IDRIS, Z., HAN, J., JAYARATHNA, S. & EIMER, D. A. 2017. Surface tension of alkanolamine solutions: an experimentally based review. *Energy Procedia,* 114**,** 1828-1833.

KLOUBEK, J. 1975. Measurement of the dynamic surface tension by the drop weighing method. *Colloid and Polymer Science,* 253**,** 929-936.

KLOUBEK, J., FRIML, K. & KREJČÍ, F. 1976. Determination of the dynamic surface tension with various stalagmometres by the drop weighing method. *Collection of Czechoslovak Chemical Communications,* 41**,** 1845-1852.

SAHA, D., HAIT, M., PATANWAR, M. & TAMRAKAR, A. 2011. Studies on surface tension of selected juice formulation by drop number method using Traube's Stalagmometer technique. *Bulletin of Pharmaceutical Research,* 1**,** 1-3.

SINGH, S. 2022. Studies on the Interactions of Paracetamol in Water and Binary Solvent Mixtures at T=(298.15-313.15) K: Viscometric and Surface Tension Approach. *Biointerface Res. Appl. Chem*, 12**,** 2776-2786.

SUGINO, R. 1928. THE EFFECT OF THE ADDITION OF PROTEIN ON THE SURFACE TENSION OF A SODIUM GLYCOCHOLATE SOLUTION. *The Journal of Biochemistry,* 9**,** 353-381.

THAKRAL, P., SHARMA, M., DEWAN, D. & SHARMA, S. 2020. Analysis of accuracy of burette in determination of surface tension of liquids and study of its variation with detachment time and inclination angle. *Indian Journal of Chemistry-Section A (IJCA),* 59**,** 1676-1684.

VENKATESHWARLU, G., SABATH, M., VENUGOPAL, G., SRAVANPRASAD, M., GHOSH, S. & BHARATHBHUSHANREDDY, S. 2012. Determination of Surface Tension of Various Formulation by Using Straube's Stalagnometer. *Asian Journal of Pharmaceutical Analysis,* 2**,** 36-38.