

# An Experimental Investigation on the Determination of Critical Micelle Concentration (CMC) Of Various Surfactants Using the Surface Tension Method

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## Abstract

*This study primarily focuses on the experimental investigation for determining the critical micelle concentration (CMC) of various surfactants that are commonly employed to enhance the stability of nanoparticles in base fluids. In this context, three surfactants belonging to the anionic category—Sodium Dodecyl Sulfate (SDS), Sodium Lauryl Sulfate (SLS), and the bio-surfactant Rhamnolipid—were selected, along with one non-ionic polymer, Polyvinylpyrrolidone (PVP), which is used as a surfactant. The CMC of each surfactant was determined through precise surface tension measurements, conducted across a wide range of concentrations. The CMC is identified as the concentration at which surfactant molecules begin to form micelles in the solution, and is characterized by a noticeable inflection point in the surface tension versus concentration curve. A clear trend was observed wherein the surface tension decreases significantly with the initial addition of surfactant, up to a certain concentration. Beyond this critical point (the CMC), further addition of surfactant does not result in any substantial change in surface tension, indicating micelle formation. The findings of this research offer valuable insight into the micellization behavior of these surfactants and their potential applications in industries such as pharmaceuticals, cosmetics, detergents, and nanotechnology, where control over interfacial properties is essential for product stability and performance.*

**Keywords:** CMC, surfactant, surface tension, rhamnolipids, heat transfer enhancement

## INTRODUCTION

In today's world, conserving available energy sources and improving the efficiency of thermal devices are critical needs. A common solution to both challenges is to enhance heat transfer rates. To enhance heat transfer performance, current research is increasingly focused on the utilization of nanofluids. However, one major issue faced is the stability of nanofluids in base solutions [1]. A

prevalent approach to addressing this stability problem is the mixing of surface active agents with nanofluids, which helps to stabilize the nanoparticles in the base fluids. Surfactants are widely utilized in numerous industrial applications due to their ability to reduce surface tension and facilitate the formation of micelles. The CMC is a pivotal parameter that signifies the concentration which molecules of surfactant aggregate to form micelles, marking the transition from individual molecule behaviour to collective assembly [2]. Determining the CMC is crucial for optimizing surfactant usage in formulations and enhancing the efficiency of various processes. This study focuses on an experimental investigation to find the CMC of various surfactants using the surface tension method.

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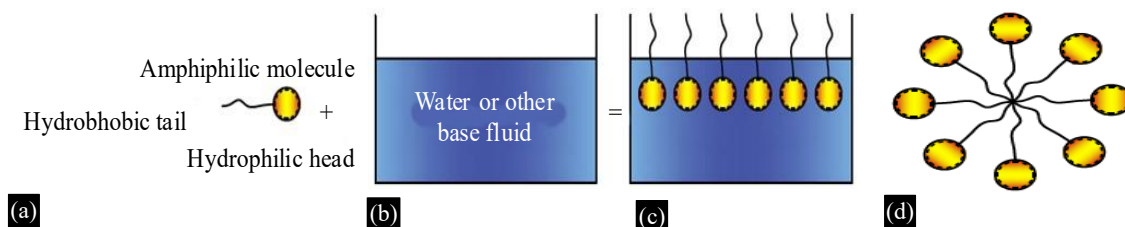
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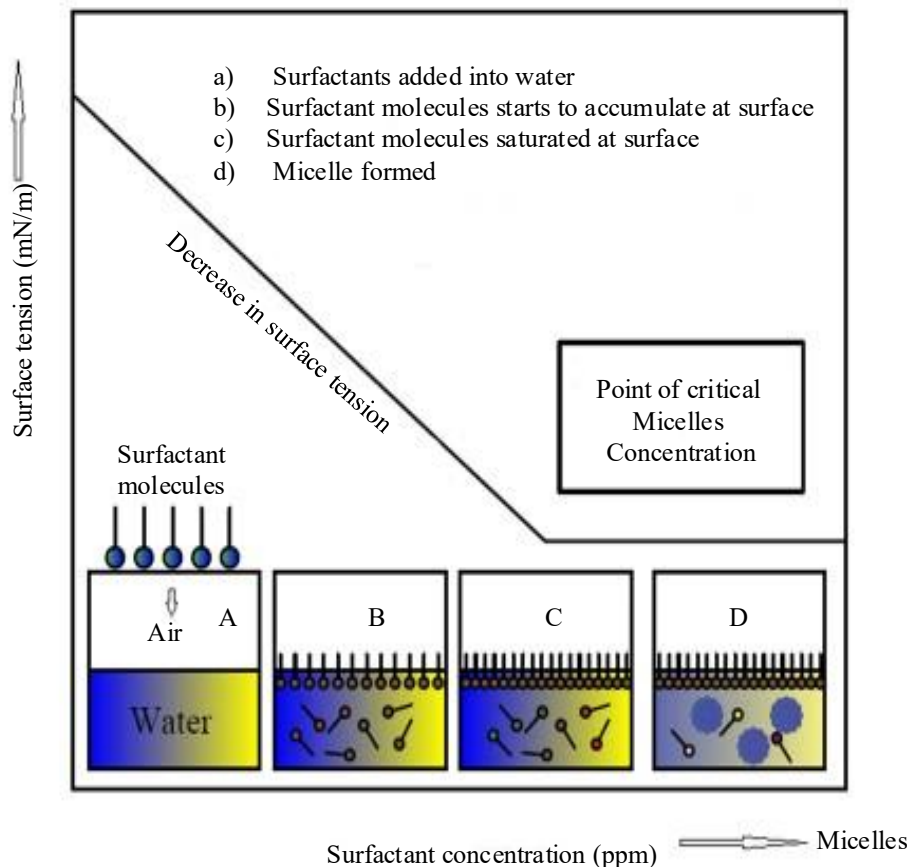
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Surfactants are organic amphiphilic long-chain molecules consists of two parts: a hydrophobic "tail" that despises water and a hydrophilic "head" that loves water. When surfactants are dissolved in a base fluid or nanofluids (NFs) at varying concentrations, the hydrophilic component is attracted to the liquid-vapour interface, orienting the head towards the water and the tail towards the vapour. This orientation alters the surface charge and its relative activities [3], affects the hydrogen potential (pH) [4], and reduces the surface energy of nanoparticles (NPs). The behaviour of surfactant molecules in a base fluid is depicted in Figure 1. The addition of surfactants decreases the interfacial tension, a process that continues with increasing surfactant concentration. But eventually, the surface gets saturated with molecules of surfactant, and further addition of surfactants no longer affects the interfacial tension. At this saturation point, surfactants begin to aggregate and form clusters known as micelles, and the concentration at which this occurs is referred to as the Critical Micelle Concentration (CMC) [5]. The structure and size of these micelles vary, taking forms such as spherical, cylindrical, rod-shaped, or plate-shaped. Several factors, including the surfactant's structure, type, temperature, and solution concentration, influence the CMC value and micelle structure.



**Figure 1.** a) Surfactant molecule with its amphiphilic nature b) Base fluid c) Surfactant molecules Attracted at liquid-vapour interface d) Micelles are formed in aqueous liquid at high concentration.



**Figure 2.** Rise in surfactant concentration in liquid effect on surface tension and formation of micelles.

The molecules' hydrophilic portion is polar and ionizable. In addition, there are four categories of polarizable surfactants: anionic, non-ionic, cationic, and Zwitterionic [6]. Because of these properties, when surfactants are added to a base liquid in small quantities they naturally gravitate toward the bubble surfaces for adsorption. The majority of other physical characteristics and the saturation temperature of base liquids are unaffected by surfactants at low concentrations, but they do have an impact on surface tension and viscosity [7]. Determining the highest surfactant concentration that should be introduced into the base liquid is therefore crucial. In pool/forced boiling, this concentration—referred to as the CMC—prevents micelle formation and hence improves heat transfer [8]. The dissolved surfactants directly impacted on the boiling heat transfer coefficient because it affects the bubble dynamics and nucleation site activation.

There are various techniques available to measure the CMC of surfactants, including interfacial tension, self-diffusion, conductivity, surfactant-selective electrodes, turbidity, fluorescence methods, and osmotic pressure [6]. In these methods, the CMC is determined by plotting the measured values against the surfactant concentration. Figure 2 illustrates the change in ST with increasing surfactant concentration and indicates the concentration at which micelles form. The surface tension method is a reliable and precise technique that measures the reduction in surface tension as surfactant concentration increases, enabling the identification of the CMC point [9]. By systematically varying the concentration of different surfactants and measuring their corresponding surface tension, aim to establish a comprehensive understanding of their micelle formation behaviour.

Surfactants can affect the dynamics and production of bubbles during boiling heat transfer. Enhancement of nucleate boiling heat transfer can result from their ability to alter the shape, the size, the rate of bubble formation and departure characteristics of bubbles. Surface tension gradients can cause surfactants to cause Marangoni convection. The fluid's mixing can be improved by this convection, increasing the rates of heat transfer [10].

The aim of this study is to precisely ascertain the CMC for a range of surfactants, this can change the viscosity and thermal conductivity ( $k$ ) of the fluid [13]. Micelles have the capacity to increase a fluid's thermal conductivity which improves heat transmission. Also, CMC providing insights into their effectiveness and potential applications. It is anticipated that the study's conclusions would have a big impact on industries such as pharmaceuticals, cosmetics, and detergents, where surfactants play a critical role in product performance and stability.

The primary objective of studying various surfactants and their effects on flow boiling is to enhance the heat transfer rate. This enhancement is crucial for numerous industrial applications, including cooling systems, chemical processing, and energy production. One effective approach to achieving improved heat transfer involves the use of surfactants, which can alter the thermophysical properties of fluids to boost their thermal performance. A thorough understanding of surfactant properties is essential for optimizing their use in heat transfer systems. By reducing surface tension, surfactants enhance surface wetting, thereby improving the interaction between the fluid and the heat transfer surface, leading to improved contact and, consequently, more efficient heat transfer.

## **MATERIAL AND METHODS**

### **Materials**

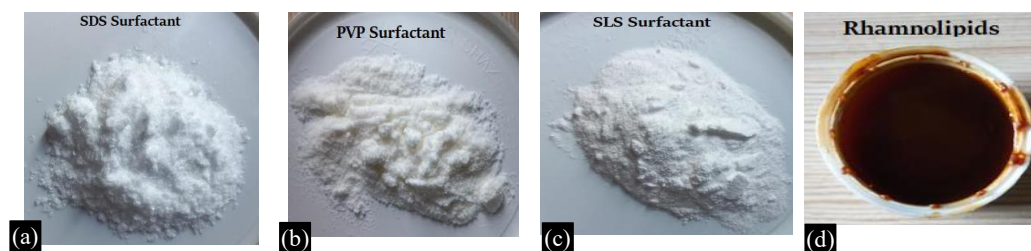
Distilled water is used as the foundation fluid in this investigation to prepare a range of solutions containing distinct surfactants. The study of critical micelle concentration (CMC) determination involved the selection of two types of surfactants: anionic and non-ionic. Because of their demonstrated ability to improve the characteristics of nanofluids, the non-ionic polymer Polyvinylpyrrolidone (PVP) used as a surfactant and the anionic surfactants Sodium Lauryl Sulfate (SLS) and Sodium Dodecyl Sulfate (SDS) were chosen. This study also investigates Rhamnolipid, a recently discovered non-toxic anionic surfactant. It is produced from microorganism (*Pseudomonas Aeruginosa*) and it is biodegradable. The specifications of all these surfactants are listed in Table 1.

### Preparation of Solution

To prepare the solution, first calculate the mass of the surfactant with the help of weighing machine at Pimpri Chinchwad college of Engineering, Pune needed for the desired surfactant concentration using the provided equation 1:

Surfactant concentration,

$$\text{ppm} = \frac{\text{mass of surfactant}}{\text{mass of solvent}} * 10^6 \quad (1)$$



**Figure 3.** Photograph of surfactants (a) SDS (b) PVP (c) SLS (d) rhamnolipids

**Table 1.** Used surfactant with its chemical properties.

Name of the surfactant	SDS	SLS	PVP	RHL
	Sodium dodecyl sulfate	sodium lauryl sulfate	Polyvinylpyrrolidone	Rhamnolipids
Molecular Formula	$C_{12}H_{25}NaO_4S$ [11]	$CH_3(CH_2)_{11}OSO_3$ [12]	$(C_6H_9NO)_n$ [11]	$C_{32}H_{58}O_{13}$ [12]
Structure				
Ionic nature	anionic	anionic	Non-ionic	anionic
Appearance	White Crystalline powder	White powder	Yellowish powder	Brown liquid
Manufacturer	HIMEDIA	Thermo Fisher Scientific India Pvt. Ltd. Mumbai	HIMEDIA	Altinbio Scientific Pvt Ltd, Mumbai
Molecular Weight	288.38 (g/mol)	288.38 (g/mol)	40000 (g/mol)	650.89 (g/mol)
CAS No.	151-21-3	151-21-3	9003-39-8	--



**Figure 4.** Magnetic stirrer.

Next, the surfactant is mixed into the distilled water and stirred at 700 rpm for 1 hour using a magnetic stirrer manufactured by Remi Sales and Engineering Ltd. as shown in Figure 4. In this experiment, the concentrations of SDS, SLS, and PVP surfactants varied from 0 ppm to 3500 ppm, while the concentration of the bio-surfactant Rhamnolipids ranged from 0 ppm to 600 ppm. All samples were prepared in 100 ml of distilled water.

### Measurement of Surface Tension

Using a KOCOUR™ Stalagmometer (2.5 ml, appropriate for low viscosity liquids) at atmospheric pressure, and at a room temperature  $24 \pm 1$  °C, the surface tension of each solution was determined using Yuan and Herold's Drop Count Method [14]. This technique depends on the force balance of the drops as they detach from the liquid-dispensing capillary tube. Equation 2 is used to calculate Surface tension by this method.

Weight of the drop = Force required to balance the weight of the drop

$mg = \text{surface tension} \times \text{Perimeter of capillary tube}$

$mg = \gamma \times 2\pi r$

$$\gamma = \frac{mg}{2\pi r} \quad (2)$$

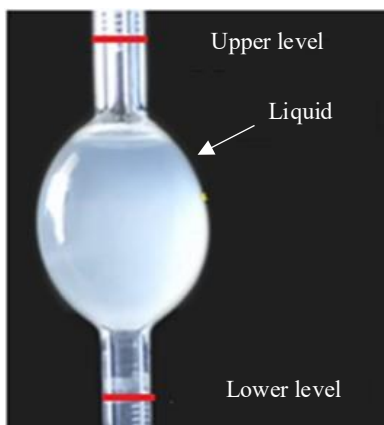
With this approach, a rubber cork is used to draw the test sample into the stalagmometer above the upper mark. The liquid is permitted to pass through the capillary tube within the stalagmometer after the lower meniscus has been adjusted to the upper mark. Drops of liquid start to fall out of the glass tube. As the sample moves from the higher mark to the lower mark, as shown in the Figure 5, count the number of drops. This method is repeated for 3 times and then take the average of bubble count. One can calculate the surface tension using the equation 3 where water is taken as a reference liquid.

Surface Tension of sample

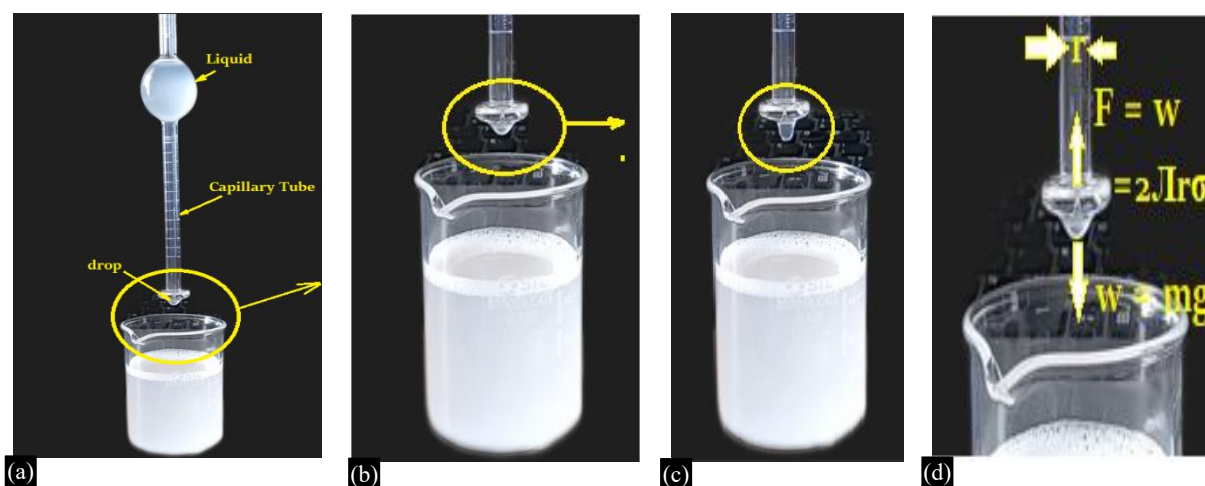
$$(\gamma_1) = \frac{n_2 \cdot d_1 \cdot \gamma_2}{n_1 \cdot d_2} \quad (3)$$

In the above expression,  $n_1$  and  $n_2$  are the number of drops of the test fluid and water, respectively, as measured using the stalagmometer.  $\gamma_2$  denotes the surface tension of the reference fluid, water.  $d_1$  and  $d_2$  are the densities of the test sample and reference liquid, respectively, measured using a 25 ml gravity bottle.

The Stalagmometer concept and force balancing on drops are shown in Figure 6, where the surface tension force is supposed to balance the drop's weight.



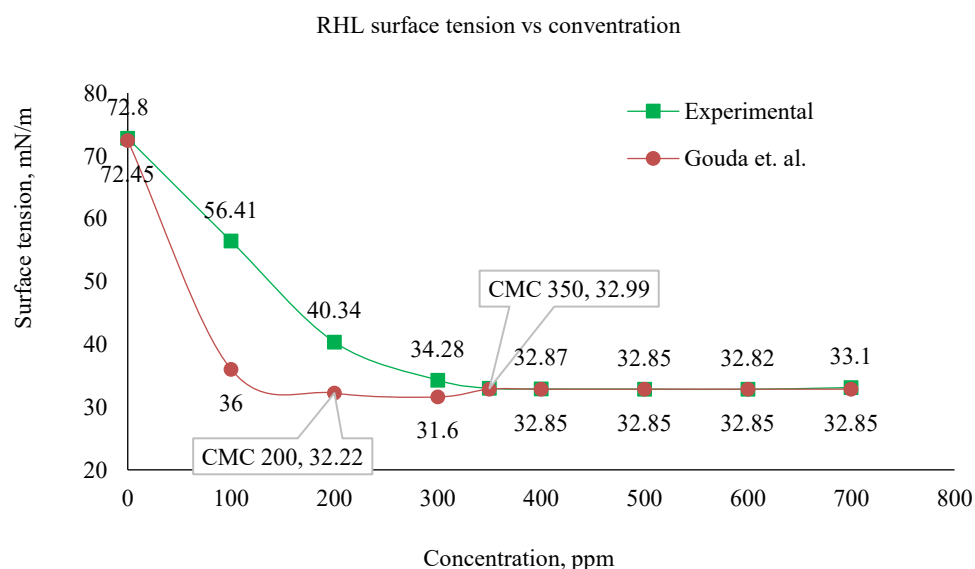
**Figure 5.** Level in between drops are counted.



**Figure 6.** Stalagmometer and force balance schematic for a drop.

## RESULTS AND DISCUSSION

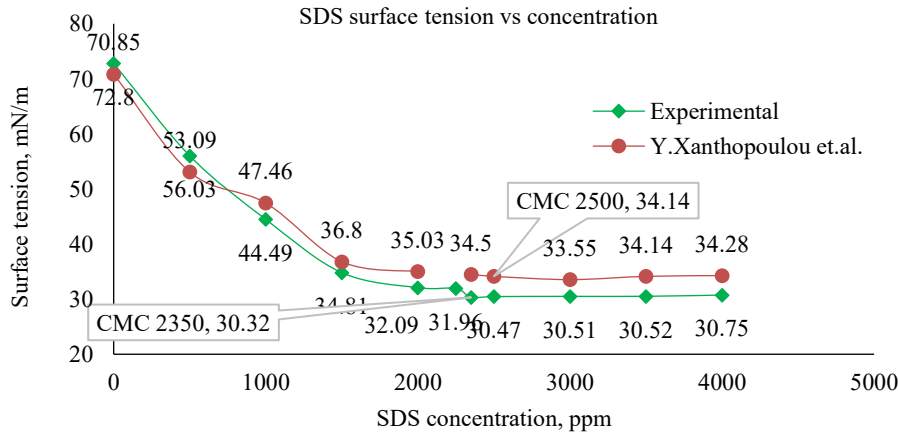
Since Rhamnolipids are bio-surfactants, they accumulate at the air-water interface and lower the surface tension of Distilled water. Rhamnolipids can position themselves at the surface and break the cohesive interactions between water molecules because of their amphiphilic nature, which is characterized by their hydrophilic and hydrophobic moieties. The result of this disturbance is a reduction in surface tension. The addition of Rhamnolipids in different concentration from 0 ppm to 600 ppm in the interval of 100 ppm resulted in a considerable reduction of the surface tension of water. According to preliminary studies, pure water has a surface tension of about 72.8 mN/m [18]. When Rhamnolipids was added to the water and thoroughly mixed, the surface tension was seen to drop to 32.99 mN/m at 350 ppm. Beyond a concentration of 350 ppm, there is no significant effect on surface tension, indicating that 350 ppm represents the critical micelle concentration (CMC) of the Rhamnolipids surfactant. This finding aligns with the results reported by Gouda et al. [12], measure the surface tension Force-Tensiometers (Make: Attension, Model: Sigma- 703D), at room temperature ( $25 \pm 1$  °C), where the surface tension of Rhamnolipids was observed to decrease to approximately 32.22 mN/m at a concentration of 200 ppm as shown in Figure 7. This significant decrease demonstrates how effective Rhamnolipids is as a surface-active material.



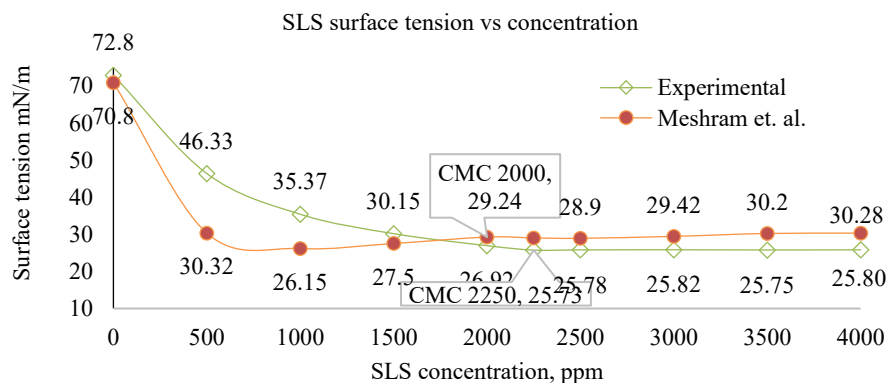
**Figure 7.** Surface tension vs. RHL concentration.

At starting the addition of SDS surfactant in water with different concentration from 0 ppm to 3500 ppm in the interval of 500 ppm resulted in a considerable decline the surface tension of water. When SDS was mixed to the water and thoroughly mixed, the surface tension decreased to 34.81 mN/m and 30.47 mN/m respectively at 2000 ppm and 2500 ppm from 72.8 mN/m at 0 ppm. Beyond a concentration of 2500 ppm, there is no significant effect on surface tension, indicating that 2500 ppm represents the CMC of the SDS surfactant. Further to find the optimum concentration of CMC performed two other experiments at 2250 ppm and 2350 ppm. It is found that the surface tension at 2350 ppm is near about same 30.32 mN/m which is at 2500 ppm, which indicates that 2350 ppm represents the optimum CMC of the SDS surfactant. This finding aligns with the results reported by Y.Xanthopoulou et al.[15], measure the surface tension Lauda GmbH Wilhelmy plate TE 2 Tensiometer, where the surface tension of SDS was observed to decrease to approximately 34.14 mN/m at a concentration of 2500 ppm, as shown in Figure 8.

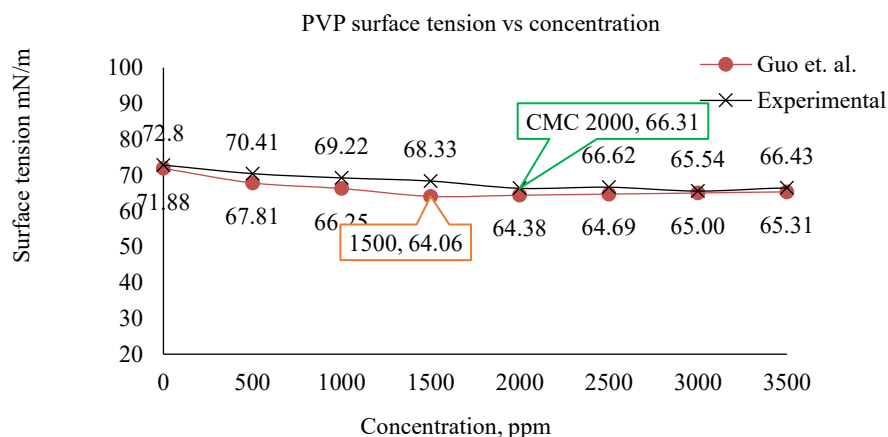
Initially, the addition of SLS surfactant to water at varying concentrations ranging from 0 ppm to 4000 ppm in 500 ppm intervals led to a significant reduction in surface tension. When SLS was thoroughly mixed with water, the surface tension dropped from 72.8 mN/m (at 0 ppm) to 26.92 mN/m at 2000 ppm and further to 25.78 mN/m at 2500 ppm. Beyond 2500 ppm, no notable change in surface tension was observed, indicating that 2500 ppm corresponds to the critical micelle concentration (CMC) of the SLS surfactant. To determine the optimum concentration more precisely, additional experiments were conducted at 2250 ppm. The surface tension measured at this concentration was approximately 25.73 mN/m, nearly identical to that at 2500 ppm. This suggests that 2250 ppm represents the optimum CMC for the SLS surfactant. This finding aligns with the results reported by Meshram et al. [16], Du Nouy ring method on a Kyowa Interface Science Tensiometer DY 300, at 20°C room temperature where the surface tension of SLS was observed to decrease to approximately 29.24 mN/m at a concentration of 2000 ppm, as shown in Figure 9.



**Figure 8.** Surface tension vs. SDS concentration.



**Figure 9.** Surface tension vs. SLS concentration.



**Figure 10.** Surface tension vs. PVP concentration.

When PVP polymer was added to water as a surfactant and thoroughly mixed, the surface tension did not show a significant decrease, reaching a maximum reduction to 66.31 mN/m at 2000 ppm. Beyond a concentration of 2000 ppm, there is no significant effect on surface tension, indicating that 2000 ppm represents the CMC of the PVP surfactant. Same result shown by the Guo et al. [17], as shown in Fig. 10

The findings indicate that the CMC values and the effectiveness of different surfactants in reducing surface tension vary significantly. Surface tension was significantly reduced at relatively low concentrations of Rhamnolipids, SLS and SDS, demonstrating their efficacy as surfactants. Many parameters, including temperature, pH, ionic strength, purity, and molecular structure, might be responsible for the variations in CMC values. Rhamnolipids are bio-surfactants that work better at lower concentrations than SDS and SLS; this could be because of their inherent amphiphilic nature. The 350 ppm experimental CMC agrees well with values found in the literature, while small variations may occur because of different experimental setups. SLS and SDS Surface tension was significantly reduced for both synthetic surfactants, with SLS having a lower CMC than SDS. There could be variations in temperature, purity, or measuring methods that account for the small variances in CMC values between the results of our investigation and those reported in the literature. PVP is less effective as a surface-active agent than SDS, SLS, and Rhamnolipids, as evidenced by the fact that it did not considerably lower the surface tension in contrast to the other surfactants. Due of its greater CMC, substantially larger concentrations are thought to be required in order to noticeably reduce surface tension.

## CONCLUSION

The study highlights the varying degrees of effectiveness of different surfactants in reducing surface tension. Effective surfactants, Rhamnolipids, SDS, and SLS greatly reduced the surface tension of water at comparatively low concentrations. Rhamnolipids are especially notable for their low CMC and their effective ability to significantly reduce surface tension. Both SDS and SLS demonstrated significant decreases in surface tension, with SLS proving to be the most successful synthetic surfactant in the experiment. PVP, on the other hand, was less successful and needed larger concentrations to reduce surface tension to a minimum. It is essential to comprehend these surfactants' unique characteristics and ideal concentrations in order to use them in a variety of industrial processes, especially those that involve heat transfer. The knowledge gathered from this research can inform the selection and use of surfactants to enhance the efficiency and effectiveness of heat transfer systems. The use of the stalagmometer has proven to be a cost-effective method for determining the critical micelle concentration (CMC) of various surfactants. Despite its simplicity and affordability compared to advanced high-cost instruments, the stalagmometer delivers results that closely align with those obtained from more sophisticated equipment. This validates its reliability and utility for experimental investigations in resource-constrained settings.

## REFERENCES

1. Yang L, Du K. A comprehensive review on heat transfer characteristics of TiO<sub>2</sub> nanofluids. *Int J Heat Mass Transf.* 2017;108:11-31.
2. Zhang X, Jackson JK, Burt HM. Determination of surfactant critical micelle concentration by a novel fluorescence depolarization technique. *J Biochem Biophys Methods.* 1996;31(3-4):145-150.
3. Wasekar VM, Manglik RM. Pool Boiling Heat Transfer in Aqueous Surfactant Solutions. *ASME Int Mech Eng Congr Expo Proc.* 1999;1999-P(November 2000):305-313.
4. Hetsroni G, Gurevich M, Mosyak A, Rozenblit R, Segal Z. Boiling enhancement with environmentally acceptable surfactants. *Int J Heat Fluid Flow.* 2004;25(5):841-848. 5
5. Fuguet E, Ràfols C, Rosés M, Bosch E. Critical micelle concentration of surfactants in aqueous buffered and unbuffered systems. *Anal Chim Acta.* 2005;548(1-2):95-100.
6. Hemantkumar H. Kadam, Ashok T. Pise. Influence of rhamnolipids, anionic surfactants, and Al<sub>2</sub>O<sub>3</sub> nanoparticles on the viscosity of distilled water-based fluids: A comparative experimental study. *Journal of Surfactant and Detergent*, 2025, 1-14.
7. H.H. Kadam, A.T. Pise. A thorough analysis of surfactant addition effects on the thermophysical properties and stability of nanofluids. *Journal of Surfactant and Detergent*, 1-38.
8. Mohsen Khooshechin, Sohrab Fathi, Farhad Salimi, Saeed Ovaysi. The influence of surfactant and ultrasonic processing on improvement of stability and heat transfer coefficient of CuO nanoparticles in the pool boiling. *International Journal of Heat and Mass Transfer*, 154 (2020) 119783.
9. Gangtao Liang, Issam Mudawar. Review of pool boiling enhancement with additives and nanofluid. *International Journal of Heat and Mass Transfer* 124 (2018) 423–453.
10. Abdul Kaggwaa, James K. Carsonb, Martin Atkinsc, Michael Walmsley. The effect of surfactants on viscosity and stability of activated carbon, alumina and copper oxide nanofluids. *Materials Today: Proceedings* 18 (2019) 510–519.
11. Xia G, Jiang H, Liu R, Zhai Y. Effects of surfactant on the stability and thermal conductivity of Al<sub>2</sub>O<sub>3</sub>/de-ionized water nanofluids. *Int J Therm Sci.* 2014;84:118-124.
12. Gouda RK, Pathak M, Kaleem Khan M. A biosurfactant as prospective additive for pool boiling heat transfer enhancement. *Int J Heat Mass Transf.* 2020;150:119292.
13. Qiao Y, Sheng W, He C, Liu C, Rao Z. Experimental study on the effect of different surfactants on the thermophysical properties of graphene filled nanofluids. *Int J Energy Res.* 2021;45(7):10043-10063.
14. Yuan Z, Herold KE. Surface Tension of Aqueous Lithium Bromide with Controlled Vapor Concentration of 2-Ethyl-Hexanol. *ASHRAE Winter Meet CD, Tech Symp Pap.* 2001;21:605-610.
15. Xanthopoulou Y, Vlachou MC, Kostoglou M, Karapantsios TD. Experimental study on subcooled flow boiling heat transfer of water-SDS mixtures in a vertical macrochannel. *Exp Therm Fluid Sci.* 2023;145(December 2022):110902.
16. Meshram PD, Shingade S, Madankar CS. Comparative study of saponin for surfactant properties and potential application in personal care products. *Mater Today Proc.* 2021;45:5010-5013.
17. Guo DS, Li X Bin, Zhang HN, Li FC, Su WT, Zhu H. Bubble behaviors during subcooled pool boiling in water and nonionic surfactant aqueous solution. *Int J Heat Mass Transf.* 2020;159.
18. Sasan Etedalia, Masoud Afranda, Ali Abdollahia. Effect of different surfactants on the pool boiling heat transfer of SiO<sub>2</sub>/ deionized water nanofluid on a copper surface. *International Journal of Thermal Sciences*, 145 (2019) 105977.