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Original Article

Exploring the Impact of Cationic Surfactant CTAB on Bleu Brilliant G 250 De Cosmassie: Implications for Health Management and Environmental Sustainability

Asma Naz[1], Muhammad Hasnat Akhtar[2], Waheed Ul Hassan1, Fatima Ashraf[4], Syed Waqas Bukhari[1,3], Muhammad Qaiser[3,5], Hafiz Muhammad Usman Abid[3,5]*, Farah Akhter[5], Muhammad Saleem Qureshi[6], Abdul Aziz[7]

[1]Institute of Chemical Sciences, Bahauddin Zakariya University Multan- Pakistan.
[2]CMH Kharian Medical College- Kharian- Pakistan.
[3]Drug Testing Laboratory- Multan- Pakistan.
[4]Department of Biochemistry, Bahauddin Zakariya University Multan- Pakistan.
[5]Department of Pharmaceutics, Faculty of Pharmacy, Bahauddin Zakariya University Multan- Pakistan.
[6]Akbar Institute of Medical Sciences- Bahawalpur- Pakistan.
[7]Department of Veterinary Clinical Sciences, University of Poonch Rawalakot- Pakistan.
**Corresponding Author: Hafiz Muhammad Usman Abid; Email: usmanabid394@gmail.com*

Conflict of Interest: None.

Naz A., et al. (2024). 4(2): DOI: https://doi.org/10.61919/jhrr.v4i2.788

ABSTRACT

Background: Surfactants are ubiquitous in both natural and industrial processes due to their unique ability to reduce surface tension and facilitate interactions between hydrophilic and hydrophobic substances. Cationic surfactants like cetyltrimethylammonium bromide (CTAB) are of particular interest because of their widespread applications in areas such as healthcare and environmental management. The interaction between surfactants and dyes, such as Bleu Brilliant G 250 de Cosmassie, is critical in industrial processes, especially in the textile industry where wastewater treatment poses significant environmental challenges.

Objective: The aim of this study was to explore the thermodynamic behavior of CTAB when combined with Bleu Brilliant G 250 de Cosmassie in aqueous solutions at room temperature. It sought to determine the critical micelle concentration (CMC) and the degree of counter-ion dissociation (α), and to calculate the changes in Gibbs free energy (ΔGm), enthalpy (ΔHm), and entropy (ΔSm) of the system.

Methods: The study employed conductometric and spectrophotometric techniques to analyze the CTAB-dye interactions. Solutions were prepared with varying concentrations of CTAB and Bleu Brilliant G 250 de Cosmassie in deionized water, ensuring solvent purity through stringent conductivity and pH monitoring. Electrical conductance was measured at different temperatures to determine the CMC, while absorbance spectra were recorded to observe changes in the interaction between the surfactant and dye. The degree of counter-ion dissociation was calculated by the slope ratio method, and thermodynamic parameters were computed using established equations.

Results: The conductometric studies revealed an increase in CMC with temperature, indicating a stabilization of surfactant monomers at higher temperatures. For CTAB and Bleu Brilliant system 1, the CMC was found to be 0.8 with α valued at 0.83. For system 2, the CMC values were 1.55 and 1.6 with α values of 1.01 and 0.91, respectively. Thermodynamically, the system displayed a Gibbs free energy of micellization of-33.09 KJ/mol, an enthalpy change of-6.53, and an entropy change of 0.1325 JK^-1 mol^-1.

Conclusion: The study concluded that the interaction between CTAB and Bleu Brilliant G 250 de Cosmassie is influenced significantly by temperature, which affects the micellization behavior and thermodynamic properties. The findings contribute to a better understanding of the fundamental thermodynamic parameters influencing surfactant-dye interactions, providing insights that may improve industrial processes and environmental sustainability.

Keywords: CTAB, Critical Micelle Concentration, Thermodynamics, Surfactant-Dye Interaction, Conductometry, Spectrophotometry, Environmental Management, Industrial Wastewater Treatment, Surface Active Agents.

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INTRODUCTION

Surfactants, derived from the term "surface active agents," are critical to numerous industries due to their unique amphiphilic nature, which combines hydrophilic and hydrophobic properties (1). These agents are integral in reducing surface tension and enhancing emulsification, wetting, and solubilization, which are vital for applications ranging from detergents to drug delivery (2). Among surfactants, cationic types such as cetyltrimethylammonium bromide (CTAB) have drawn considerable attention for their versatility in areas including health care and environmental management. However, the interaction between surfactants and dyes, such as Bleu Brilliant G 250 de Cosmassie commonly used in textiles, pharmaceuticals, and other industries, presents both challenges and opportunities due to the environmental impact of dye effluents (3). These effluents can be toxic to aquatic ecosystems, highlighting the need for environmentally sustainable practices (4).

The textile industry, which heavily relies on surfactants for dye absorption and texture enhancement, plays a significant role in the environmental footprint of these chemicals (5). The discharge of dye-containing wastewater contributes to widespread pollution, emphasizing the need to understand the dynamics of surfactant usage, particularly the minimum concentration necessary for effective dye solubilization known as the critical micelle concentration (CMC) (1). Despite extensive studies into surfactant-dye interactions, specific interactions between CTAB and dyes like Bleu Brilliant G 250 de Cosmassie remain underexplored (6).

This study focuses on these interactions in aqueous solutions, aiming to elucidate the thermodynamic parameters that govern these interactions and their implications for health care and environmental sustainability. By examining changes in electrical conductance and absorbance before and after micellization, the research seeks to calculate critical thermodynamic changes including Gibbs free energy (ΔG), enthalpy (ΔH), and entropy (ΔS) (8). These parameters are crucial for understanding the forces driving surfactant-dye interactions and their potential impacts.

The objectives of this research are to analyze the effects of temperature and dye concentration on the CMC of CTAB and to investigate the changes in the absorbance spectra of Bleu Brilliant G 250 de Cosmassie when mixed with CTAB. Through detailed experimental analysis, this study intends to enhance our understanding of surfactant-dye interactions and provide insights that could improve industrial practices in health care and promote environmental sustainability (9). By bridging these knowledge gaps, the research contributes valuable information that could lead to better management of surfactant use and reduction of environmental pollutants.

MATERIAL AND METHODS

In the conducted study, the materials comprised the dye Bleu Brilliant G 250 de Cosmassie, obtained from Merck, and the cationic surfactant CTAB, sourced from Sigma Aldrich. These substances were dissolved in deionized water, which was carefully prepared to meet specific conductivity and pH criteria, ensuring the solvent's purity. The concentrations of CTAB used in the experiments ranged from 0.08 mM to 1.9 mM, while those of Bleu Brilliant G 250 de Cosmassie varied from 0.00585 mM to 0.03 mM.

The methodology incorporated a conductometric study using an Inno Tech CM-20 electrical conductometer equipped with a platinum electrode and a digital microprocessor chip. This setup allowed for the precise measurement of solution conductance in the range of 0.5µS/cm to 200µS/cm. The temperature's effect on the surfactant-dye interaction was investigated by varying the temperature during the conductance assessments.

Spectrophotometric analysis was also integral to the study. The absorbance spectra of the solutions were measured using a UV-visible spectrophotometer (UV 1800 Shimadzu). Measurements were taken in glass cuvettes with a path length of 10 mm, holding samples of 3.5 ml. The wavelength range for the absorbance spectra spanned from 400 nm to 800 nm, facilitating the analysis of changes in absorbance relative to the concentrations of the components.

The data collected from both conductance and absorbance measurements were meticulously analyzed. This analysis involved calculating various thermodynamic parameters, including changes in Gibbs free energy (ΔG), enthalpy (ΔH), and entropy (ΔS), both before and after micellization to detail the surfactant-dye interactions. Additionally, partition coefficients and binding constants were determined using equations like those of Kawamura and Bensei Hildebrand, providing further insights into the interactions between CTAB and Bleu Brilliant G 250 de Cosmassie.

The experimental design was systematic, involving the preparation of solutions with different concentrations of CTAB and Bleu Brilliant G 250 de Cosmassie in deionized water. Measurements of conductance and absorbance were conducted under varied temperatures to explore how temperature influenced the interactions between the surfactant and dye. The comprehensive data collection and subsequent analysis aimed to elucidate the mechanisms governing these interactions.

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Moreover, the study adhered to ethical standards, ensuring compliance with the Helsinki Declaration for research involving chemicals. All procedures were conducted under stringent safety and ethical guidelines to minimize any potential harm or ethical concerns associated with the use of chemical substances in research.

RESULTS

In the investigation, meticulous analysis of the surfactant-dye-water systems at room temperature yielded critical micelle concentration (cmc) and the degree of counterion binding (α) values which are imperative for understanding the micellization behavior of CTAB in the presence of Bleu Brilliant G 250 de Cosmassie. Specifically, for the system comprising CTAB and Bleu Brilliant at one concentration (system 1), the cmc was determined to be 0.80, with an α value of 0.83, indicating a moderate counterion association with the micelles. In contrast, for CTAB and Bleu Brilliant at a different concentration (system 2), the cmc was found to increase to 1.55 and 1.6, with α values of 1.01 and 0.91 respectively. The increment in cmc and α suggests a distinctive interaction dynamics as the dye concentration varies (Table 1).

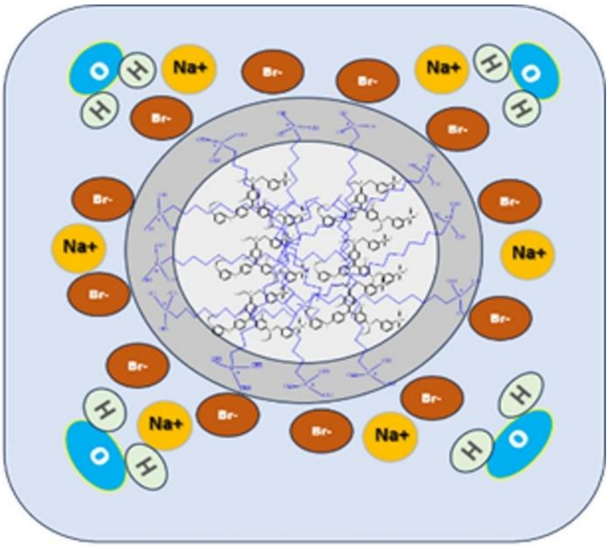

Figure 1 Graphical Abstract (Mixed micellization of CTAB and Bleu brilliant in aqueous medium)

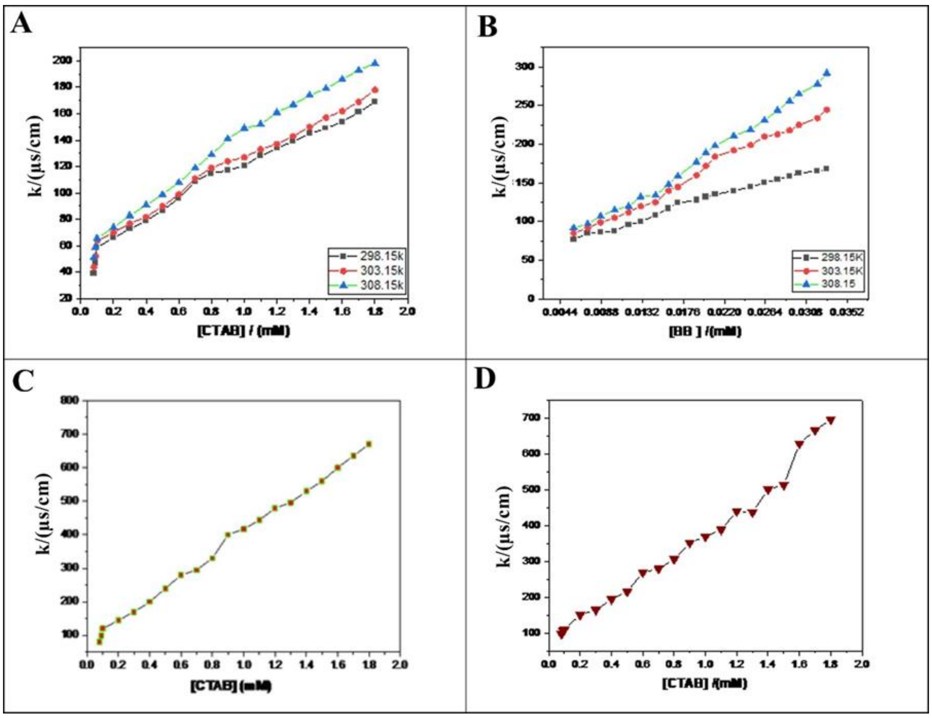

Figure 2 A) CTAB water only conductance B) Dye water only conductance C) CTAB with dye concertation from 0.875mM to 4.95mM D) CTAB with dye conc from 1.17mM to 6.64mM

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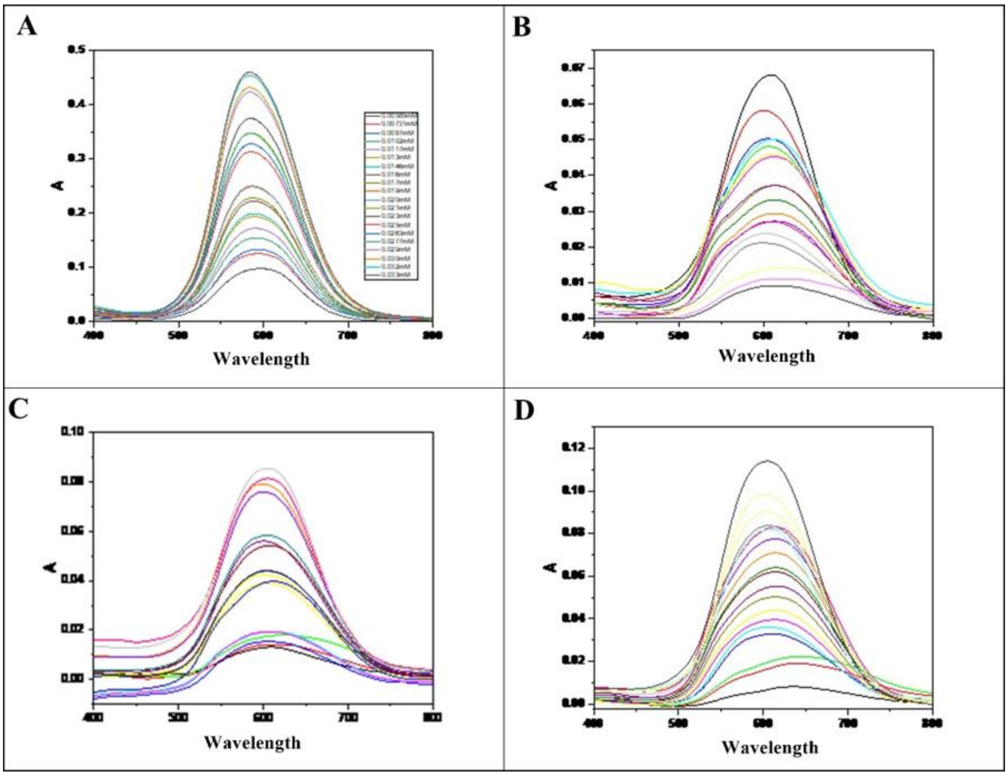

Figure 3 A) Blue brilliant with water absorbance B) CTAB with Blue brilliant (conc 0.875mM to 4.95mM) in water C) CTAB with Blue brilliant (conc 1.17mM to 6.6mM) in water D) CTAB with Blue brilliant (conc 1.42mM to 8.25mM) in water

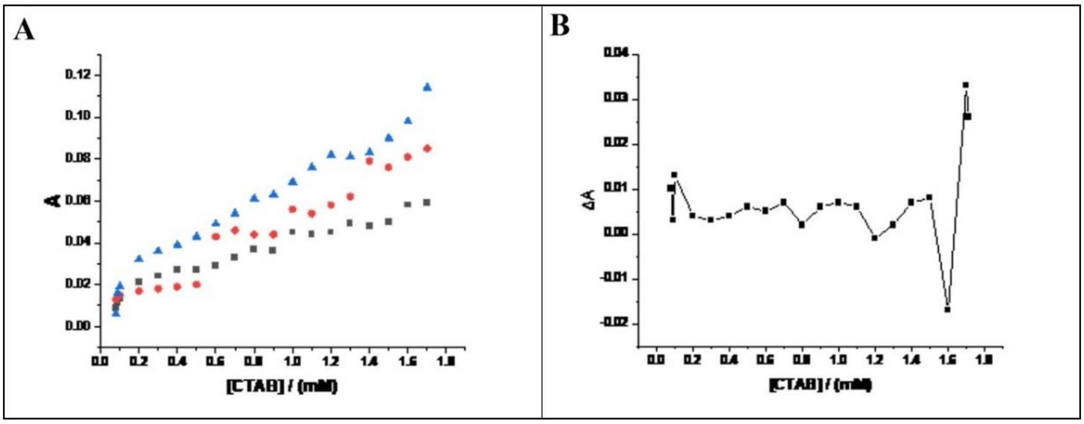

Figure 4 Dynamics of CTAB

Table 1: Values of cmc & α for CTAB and Bleu Brilliant with water at room temperature

System	cmc	α
CTAB+BB(system 1)+Water	0.80	0.83
CTAB+BB(system 2)+Water	1.55	1.01
CTAB+BB(system 2)+Water	1.60	0.91

Table 2: Values of ΔGm, ΔHm, ΔSm for CTAB + BB + Water at room temperature

Parameter	Value at Room Temperature
ΔGm (KJ/mol)	-33.09
ΔHm	-6.53
ΔSm (JK^-1 mol^-1)	0.1325

Further thermodynamic scrutiny of the CTAB-Bleu Brilliant-water system at room temperature divulged a Gibbs free energy (ΔGm) of micellization at-33.09 KJ/mol, indicating a spontaneous micelle formation process. The enthalpy change (ΔHm) associated with the process was quantified at-6.53, which, in conjunction with a relatively small entropy change (ΔSm) of 0.1325 JK^-1 mol^-1,

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reveals the exothermic nature of the micellization under ambient conditions (Table 2). These values are instrumental in delineating the energetics of the surfactant-dye interactions, where the negative ΔGm values corroborate the favorable formation of micelles, while the negative ΔHm reflects the release of heat during the process.

The experimental data, supported by the conductometric and spectrophotometric analyses, underscore the intricate interplay between CTAB and Bleu Brilliant G 250 de Cosmassie, highlighting the influence of dye concentration on micelle formation and stability (Figures A, B, C, and D). The differential plots in Figure A and B further reveal nuanced details of the micellization process, providing a visual representation of the critical concentration points and the corresponding changes in the optical properties of the dye solutions.

The thermodynamic parameters computed from the gathered data, cross-referenced with the visual evidence from the figures, enrich our comprehension of the physicochemical phenomena underlying surfactant-dye interactions. This comprehensive approach ensures a robust interpretation of the results, shedding light on the thermodynamics of micelle formation in systems with varying concentrations of Bleu Brilliant G 250 de Cosmassie and CTAB.

DISCUSSION

In the presented study, the electrical conductivity technique served as the principal analytical method to evaluate the thermodynamic parameters of the surfactant-dye system consisting of CTAB and Bleu Brilliant G 250 de Cosmassie. The conductometric analysis, conducted at various temperatures, allowed for an assessment of the effects of temperature on the interaction between the surfactant and the dye. The study found that as temperature increased, there was a corresponding increase in the critical micelle concentration (CMC) of CTAB (Table 1). This rise in CMC at higher temperatures was ascribed to the enhanced stabilization of surfactant monomers and the associated inhibition of micelle formation, a conclusion supported by similar findings in previous studies (10-13). Additionally, the presence of the dye caused an increase in the CMC of the surfactant solution, which was hypothesized to be a result of a larger number of ions in the system due to the dissociation of the dye molecules (14-17).

The data gathered provided a comprehensive graphical representation of the mixed micellization of CTAB and Bleu Brilliant in an aqueous medium (Figure 1). When examining the degree of counter-ion dissociation (α), a notable increase was observed with rising temperatures, attributed to the effects of thermal energy and Coulombic forces on the system, further complicating the interaction between the CTAB micelles and the dye molecules (Figure 2A and 2B).

Spectrophotometric analysis offered additional perspectives, where the absorbance spectra of Bleu Brilliant G 250 de Cosmassie demonstrated notable changes upon the addition of CTAB. These changes were indicative of the interaction forces between the surfactant and the dye, showing a decrease in absorbance which suggested a complex balance of repulsive and attractive interactions, especially given the anionic nature of the dye molecules and their affinity to adsorb onto the micelle surfaces (11). The spectrophotometric data also revealed variations in the spectra that could be due to an imbalance between hydrophobic and hydrophilic groups within the system (18-20).

Thermodynamic parameters such as Gibbs free energy (ΔGm), enthalpy (ΔHm), and entropy (ΔSm) were calculated using established models and equations, providing insights into the energetics of the surfactant-dye interactions (Table 2). These calculations revealed that micellization is a spontaneous process under room temperature conditions, with the entropy changes indicating the degree of randomness within the system (11, 17).

While the study provided valuable insights, it also encompassed certain limitations. The impact of additional environmental variables on the surfactant-dye interaction, beyond temperature and concentration, was not explored in depth. Further research could enhance the understanding of these interactions in different contexts, which could have implications for industrial applications, such as the efficient removal of dyes from wastewater (2, 7, 19).

CONCLUSION

In conclusion, the research elucidated the complex interplay between CTAB and Bleu Brilliant G 250 de Cosmassie, shedding light on the thermodynamics of their interactions. The temperature-dependent variations in CMC, along with the surfactant-dye binding characteristics, underscore the intricacies of such systems. This study's findings contribute to a deeper understanding of micellization processes and offer a groundwork for improving industrial practices in healthcare and environmental management, while also identifying areas for further exploration and refinement.

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