

Article

Surface Properties and Micellization Behavior of Dye Solutions in CTAB/Tween-20 Mixtures

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ABSTRACT: In this paper, the interaction, surface, and micelle properties of the mixed system of cationic surfactant hexadecyltrimethylammonium bromide (CTAB), nonionic surfactant Tween-20, and Coomassie Brilliant Blue G250 (CBBG250) were studied by the surface tension method and spectroscopy method. The characteristic absorption peak in the spectra of CBBG250 is obviously changed by the addition of surfactant. The results show that the surfactant system has a synergistic effect with the aqueous solution of CBBG250. Also, cationic-nonionic mixed surfactants (CTAB/Tween-20) were used in different combinations to understand the effect of interaction with CBBG250 on surface tension and critical micelle concentration. To further study the interaction of dyes with surfactants, the Rubingh and Motomura models were used, and a series of interaction parameters and thermodynamic data were obtained.

Keywords: Surfactants; Surface properties; Micellization; Critical micelle concentration; Interaction

1. Introduction

In recent years, many scientists have focused on the interaction between surfactants and dyes [1–5], which has been widely used in many fields, such as ion recognition, dyeing technology, photographic industry, medicine, and so on [6–9]. Dyes are materials that color fibers and other materials. They are not limited to dyeing and printing textiles and are used in many sectors, including paint, plastics, leather, and food. Coomassie brilliant blue G250 (CBBG250) is an anionic dye commonly used in textiles, printing, and biotechnology [10]. This dye has a unique response to different types of solutions. Cationic surfactant cetyltrimethylammonium bromide (CTAB) is widely used as an adjuvant in textile finishing processes, which can improve the dyeing process [11,12].

Nonionic surfactant Tween-20 is a good emulsifier and drug solubilizer because it has more hydrophilic groups in its molecule [13]. As a typical nonionic surfactant, it is often used alongside other surfactants. Now, mixed surfactants are of great interest in scientific and industrial applications. Surfactants used in practical applications almost always consist of a mixture of surfactants, and the solution properties of mixed surfactant systems are often superior in application to those of the individual ones. Kabir et al. studied the micellization behavior of a mixed system comprising Tween-20 and Gemini ionic surfactants [14].



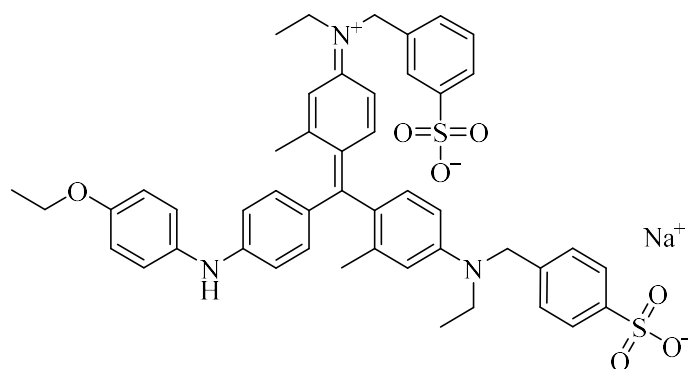
Chatterjee et al. reported the aggregation behavior and surface properties of Tween-20, Tween-40, and CTAB mixed micelles [15]. The mixed micelle theory model predicts the composition of the micelles [16], the interaction parameters, the contribution of free energy, and other thermodynamic parameters, which is helpful for understanding the cosolvent effect [17] and aggregate structure [18]. The ionic-nonionic surfactant mixing system is a new type of unique surfactant compounding system.

Many scientific studies point out that dye-surfactant is more likely linked by hydrogen bonding, ionic bonding, van der Waals force or hydrophobic interaction [19]. But the study of these mechanisms in dye solution is complex, so it is important to delve deeper into it. In this paper, the ionic surfactant cetyltrimethylammonium bromide CTAB [20] and nonionic surfactant Tween-20 [21] mixed system was used to determine the surface tension [22] and critical micelle concentration in dye CBBG250 aqueous solution [23]. By using the Rubingh model [24] and the Motomura model [25,26] to explore the influence of CBBG250 on mixed micelles, we analyzed the thermodynamic properties and micellization behavior. Unlike previous studies that mainly focused on the interaction between single surfactants and dyes, this work systematically investigates the interaction between CTAB/Tween-20 mixed surfactants and the anionic dye CBBG250, and for the first time compares the applicability of the Rubingh model and the Motomura model in this ternary mixed system. This study provides a theoretical reference for understanding the interaction mechanism between ionic/nonionic mixed surfactants and dyes. These studies are expected to shed light on the surface properties and micellization of dyes with various surfactants and may be helpful in industrial preparation and surface science.

2. Experimental

2.1. Materials

The dye Coomassie brilliant blue G250 (CBBG250, purity 98%) was obtained from Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China). Its structure is shown in Scheme 1. The surfactant Tween-20 (CP, purity 99.5%) was obtained from Yantai Chemical Industry Co., Ltd. (Yantai, China) The surfactant cetyltrimethylammonium bromide (CTAB, purity 99%) was purchased from Shanghai Zhongqin Chemical Reagent Co., Ltd. (Shanghai, China). All solutions were prepared with high-purity deionized water, and all experiments were performed at 298 K. All reagents were used as received without further purification. All solutions were prepared with freshly deionized water and equilibrated for 24 h before measurements. All measurements were performed at 298.2 ± 0.1 K controlled by a thermostated water bath.



Scheme 1. Structure of Coomassie brilliant blue 250.

2.2. Apparatus and Methods

2.2.1. Ultraviolet-Visible Spectra Measurements

A LabTech UV-2100 UV-Vis spectrophotometer was used to measure the absorption spectra and absorbance, which was manufactured by Shanghai Yuanxi Instrument Co., Ltd. (Wavelength accuracy: ± 0.3 nm).

2.2.2. Surface Tension Measurements

Surface tension meter: JZHY-180 interfacial tensiometer (Chengde Jinhe Instrument Manufacturing Co., Ltd., Chengde, China), with a measurement accuracy of 0.1 mN/m. It was used to measure the surface tension of solutions at different ratios, and to obtain the surface tension-concentration curve and critical micelle concentration. Each measurement was repeated at least three times, and the average value was used. The experimental error was within ± 0.1 mN/m.

2.2.3. Physical Chemical Model Method

The Rubingh model and Motomura model were used to calculate interaction parameters and energy changes.

3. Results and Discussion

3.1. Spectral Properties of Mixed Systems

The ultraviolet-visible spectra of Coomassie Brilliant Blue G250, the surfactants, and Coomassie Brilliant Blue G250 in surfactant aqueous solutions were scanned. The UV-Vis spectroscopic measurements were carried out at surfactant concentrations below the CMC to reflect the interaction between the dye and surfactant monomers. Specifically, for CTAB, the concentration ranged from 1.0×10^{-5} to 1.2×10^{-5} mol/L, and for Tween-20, the concentration was 1.0×10^{-4} mol/L, both of which are well below their respective CMC values.

As shown in Figure 1a, the spectrum of CBBG250 in aqueous solution (curve 1) has a strong absorption peak at 584 nm. The absorbance of the cationic surfactant CTAB is nearly zero in the scanning range (curve 2). The addition of CTAB (curve 3) causes the characteristic absorption peaks of CBBG250 to change in both intensity and position (bathochromic shift). This phenomenon indicates that an association occurs between CBBG250 and CTAB.

As shown in Figure 1b, the addition of nonionic surfactant Tween-20 (curve 6) alters the intensity of CBBG250's characteristic absorption peaks, and the maximum absorption peak of the aqueous solution is red-shifted. The obvious shift of the maximum absorption peak after adding the surfactant indicates that an associative interaction exists between the two components.

The test is conducted at 298.2 K; moreover, in order to reduce the system error, all the values of absorbance are measured generally in the range of 0.1~1.

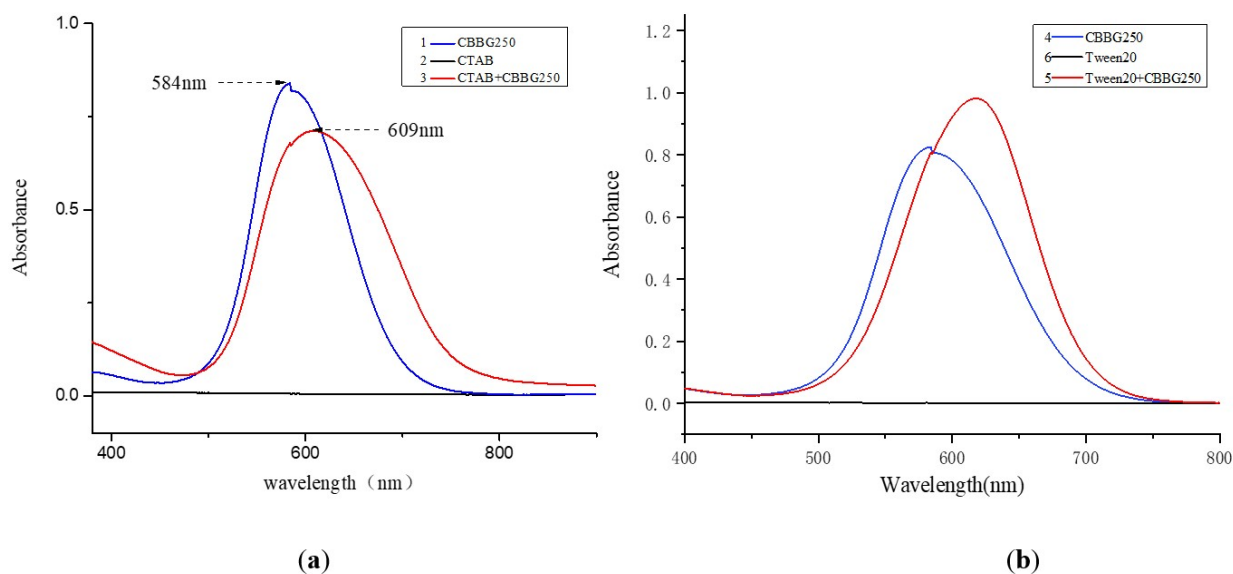


Figure 1. The absorption spectra of (a): (1) CBBG250 in aqueous solution, (2) CTAB in aqueous solution, (3) CBBG250 in CTAB aqueous solution ($C_{\text{CBBG250}}^0 = 2.0 \times 10^{-5}$ mol/L, $C_{\text{CTAB}}^0 = 1.2 \times 10^{-5}$ mol/L) (b): (4) CBBG250 in aqueous solution, (5) Tween-20 in aqueous solution, (6) CBBG250 in Tween-20 aqueous solution ($C_{\text{CBBG250}}^0 = 2.0 \times 10^{-5}$ mol/L, $C_{\text{Tween}}^0 = 1.0 \times 10^{-4}$ mol/L).

For further study, we investigated the interaction between two mixed surfactants and CBBG250. As shown in Figure 2a, the concentration of Tween-20 is fixed at 1×10^{-4} mol/L, and the concentration of Coomassie Brilliant Blue G250 is fixed at 2×10^{-5} mol/L. When a small amount of CTAB was added, the absorbance of the solution decreased significantly. However, as the concentration of CTAB increased, the absorbance at 618 nm at the maximum absorption peak of the solution gradually increased again.

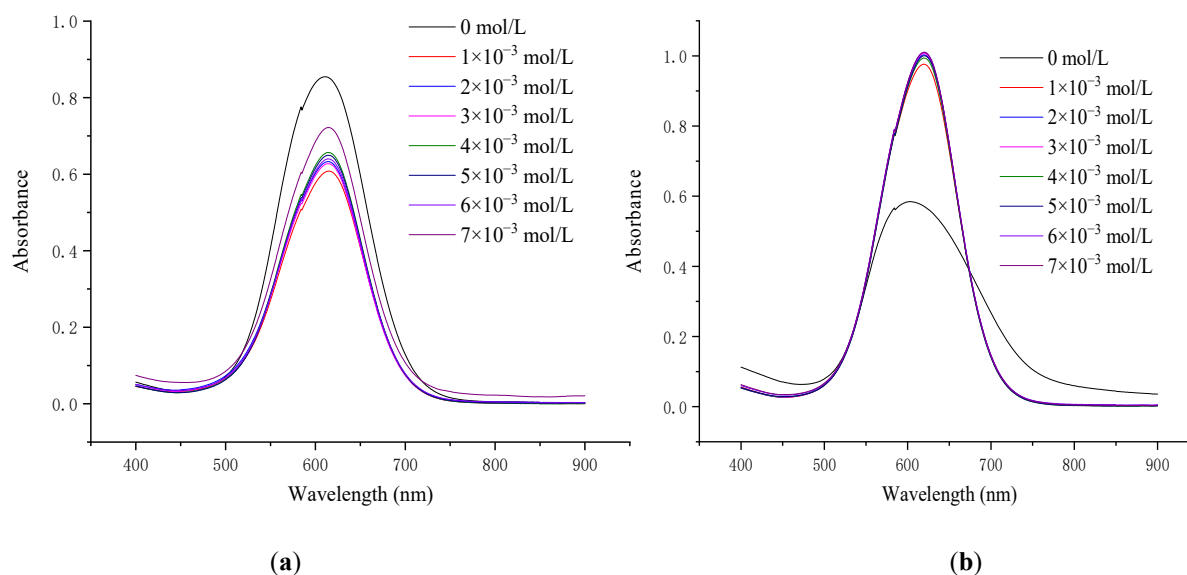


Figure 2. UV-Vis spectra of the mixed system. (a) CTAB concentration from 0 to 7.0×10^{-3} mol/L (Tween-20 fixed at 1.0×10^{-4} mol/L, CBBG250 fixed at 2.0×10^{-5} mol/L). (b) Tween-20 concentration from 0 to 7.0×10^{-3} mol/L (CTAB fixed at 1.0×10^{-4} mol/L, CBBG250 fixed at 2.0×10^{-5} mol/L).

In Figure 2b, the concentration of CTAB is fixed at 1×10^{-4} mol/L, and the concentration of Coomassie Brilliant Blue G250 is fixed at 2×10^{-5} mol/L. When the concentration of Tween-20 increases, the absorbance at the maximum absorption peak of the solution rises gradually compared with the system

without Tween-20, and a slight red shift occurs. The maximum absorption peak shifts from approximately 610 nm to about 625 nm (a red shift of 15 nm), indicating the formation of an association complex between CBBG250 and the surfactant molecules, thereby changing the dye's aggregation state. We have characterized the nature of the interaction between CBBG250 and individual surfactants. We found that the absorbance intensity of the UV-visible spectra of the mixed system varies between those of the two individual surfactants. According to the literature [27], the CMC values of CTAB and Tween-20 in aqueous solution are 8×10^{-4} mol/L and 5×10^{-5} mol/L, respectively.

Do the mixed surfactant systems exhibit new properties compared with individual surfactants on the basis of the above findings? Do they present synergistic effects, such as obvious changes in surface activity and critical micelle concentration. Therefore, it is of great significance to study the interaction between mixed surfactants and dye solutions.

3.2. Surface Properties of Mixed Systems

The surface tension isotherms of the CTAB/Tween-20 mixed system in aqueous solution and CBBG250 aqueous solution were determined at 298.2 K. It can be seen that with the increase of the molar fraction of nonionic surfactant in the mixed solution, the minimum surface tension value γ of the solution gradually decreases. In our previous studies [4,5], the CMC values of pure CTAB and Tween-20 in CBBG250 aqueous solution were determined to be 8.47×10^{-4} mol/L and 5.25×10^{-5} mol/L, respectively, both lower than those in pure aqueous solution. The lowest surface tension falls basically between those of the two pure components, which are listed in Table 1. In Figures 3 and 4, the surface tension of the mixed aqueous solution is generally higher than that of the solution containing CBBG250, and both show a continuous downward trend. This indicates that the presence of the dye CBBG250 strengthens the interaction of the mixed system and lowers the surface tension of the mixed solution.

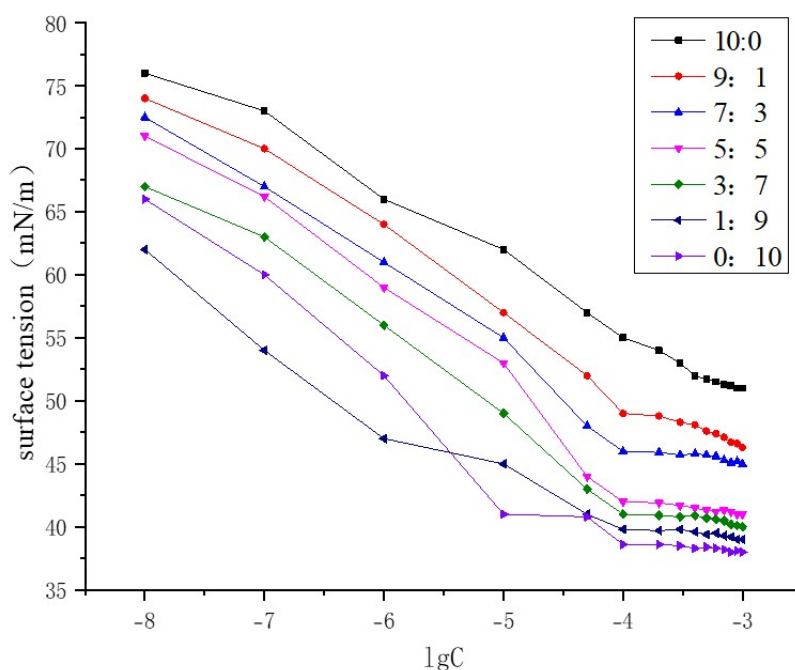


Figure 3. Surface tension of CTAB/Tween-20 mixed system in aqueous solution (the proportions represent CTAB versus Tween-20).

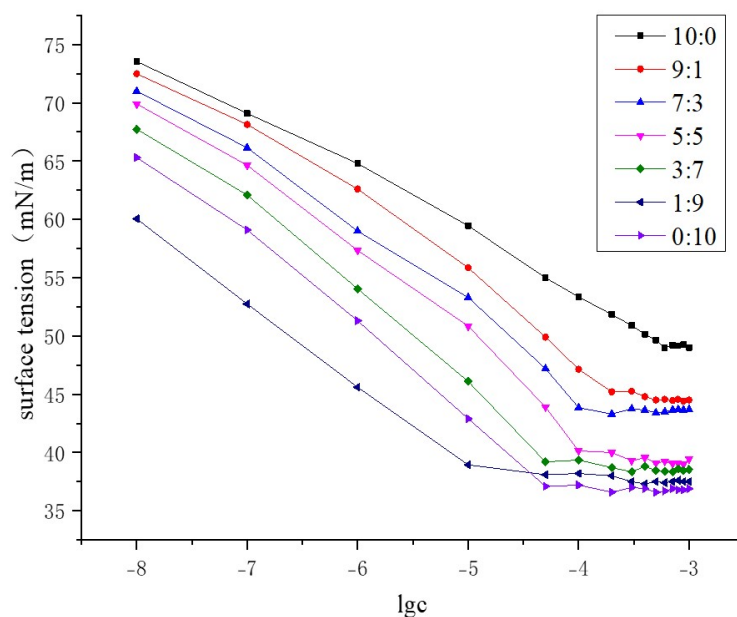


Figure 4. Surface tension of CTAB/Tween-20 mixed system in CBBG250 aqueous solution (the proportions represent CTAB versus Tween-20).

Table 1. Surface properties and micellization behavior of CTAB/Tween-20 mixed system at 298.2 K.

Aqueous Solution			CBBG250 Aqueous Solution	
$\alpha_{\text{Tween-20}}$	$\gamma_{\text{CMC}}/(\text{mN}\cdot\text{m}^{-1})$	CMC ($\text{mmol}\cdot\text{L}^{-1}$)	$\gamma_{\text{CMC}}/(\text{mN}\cdot\text{m}^{-1})$	CMC ($\text{mmol}\cdot\text{L}^{-1}$)
0	51.00	1.00×10^{-3}	49.12	6.15×10^{-4}
0.1	46.31	8.02×10^{-4}	44.74	1.56×10^{-4}
0.3	45.03	6.01×10^{-4}	43.62	6.84×10^{-5}
0.5	41.28	7.94×10^{-4}	39.31	5.50×10^{-5}
0.7	40.36	8.02×10^{-4}	38.72	4.58×10^{-5}
0.9	39.74	6.81×10^{-4}	37.75	3.62×10^{-5}
1	38.25	7.01×10^{-4}	36.86	4.49×10^{-5}

In Figures 3 and 4, the concentration at which the curve levels off corresponds to the CMC. The surface properties and micellization behavior of the CTAB/Tween-20 mixed system at 298.2 K are listed in Table 2. The driving force for surfactants to form micelles is hydrophobic interaction. Polarity can reflect the hydrophobic effect of surfactants to a certain extent. Since CTAB has stronger polarity than Tween-20, its CMC is higher than that of Tween-20. Furthermore, the CMC of the mixed dye-surfactant solution generally decreases as the proportion shifts from CTAB to Tween-20. The CMC of mixed micelles reaches its minimum at $\alpha_{\text{Tween-20}} = 0.9$ (mole fraction of Tween-20). This is probably because the mixed system of Coomassie Brilliant Blue G250 and Tween-20 exhibits the strongest synergistic effect. This CMC reduction can be attributed to three factors: the electrostatic attraction between CBBG250 and CTAB, the hydrophobic embedding of the dye into the micellar core, and the lowering of the free energy barrier for micellization.

Table 2. Rubingh model micelle parameters of the CTAB/Tween-20 mixed system at 298.2 K.

$\alpha_{\text{Tween-20}}$	X_1^s	X_1^m	β^s	β^m	f^s	f^m	$\Delta G_{\text{mix}} (\text{kJ}\cdot\text{mol}^{-1})$	$\Delta S_{\text{mix}} (\text{J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1})$
0.1	0.542	0.559	-2.633	-2.998	0.576	0.558	-1.549	5.462
0.3	0.631	0.657	-3.159	-3.999	0.650	0.625	-1.440	4.714
0.5	0.69	0.73	-2.360	-3.884	0.797	0.753	-0.902	4.038
0.7	0.745	0.783	-2.307	-4.243	0.861	0.819	-0.662	3.417
0.9	0.8	0.808	-5.130	-5.836	0.815	0.806	-0.838	2.918

It can be seen from Figure 5 that there also exists a decreasing trend of CMC in CBBG250 aqueous solution. The CMC and surface tension in aqueous solution are always higher than those in the CBBG250 aqueous solution, since the CMC of CTAB in aqueous solution is greater than that of Tween-20. When the mixed surfactant forms micelles, both CTAB and Tween-20 molecules are present in the system. Coomassie Brilliant Blue G250 is an anionic dye that readily binds to the cationic surfactant CTAB molecules, which reduces the relative content of CTAB. Meanwhile, Tween-20 becomes more enriched at the interface, raising its contribution to the CMC of mixed micelles. This leads to a lower critical micelle concentration in the system containing CBBG250 than in the pure aqueous system. Compared with the cetylpyridinium chloride/Triton X-100 system recently reported by Korzhan et al. [28], our CTAB/Tween-20/CBBG250 system exhibits a stronger synergistic effect in reducing CMC and surface tension, likely due to the longer hydrophobic chain of CTAB and the larger polar head group of Tween-20. Based on the above results, we further adopted model methods to analyze the interactions of the mixed systems containing CBBG250.

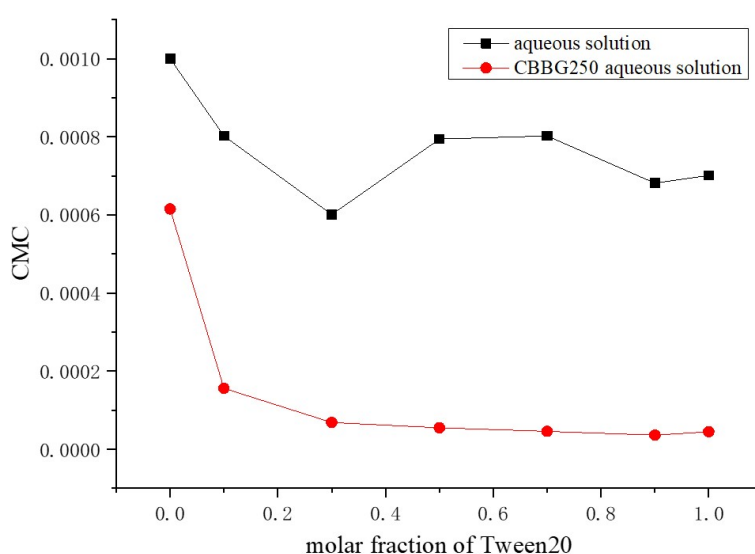


Figure 5. Trend of critical micelle concentration (CMC) of CTAB/Tween-20 mixed system with the mole fraction of Tween-20.

3.3. Composition of Surface Adsorption Layer and Mixed Micelles in CBBG250 Aqueous Solution

3.3.1. Rubingh Model

Using the regular solution theory, Rubingh [29] proposed an equation for calculating the composition X_1^m and the molecular interaction parameter β^m of a non-ideal two-component mixed micelle:

$$\frac{(X_1^m)^2 \ln(\alpha_1 C_{12} / X_1^m C_1)}{(1 - X_1^m)^2 \ln[(1 - \alpha_1) C_{12} / (1 - X_1^m) C_2]} = 1 \quad (1)$$

$$\beta^m = \frac{\ln(\alpha_1 C_{12} / X_1^m C_1)}{(1 - X_1^m)^2} \quad (2)$$

C_1 : CMC of the component 1 solution; C_2 : CMC of the component 2 solution; C_{12} : CMC of the mixed solution; α_1 : mole fraction of component 1 in the mixed system; here α_1 is $\alpha_{\text{Tween-20}}$.

The following formula is a equation for calculating the activity coefficient of component i in a mixed micelle:

$$f_i^m = \exp[\beta^m (1 - X_i^m)^2] \quad (3)$$

Using the model to calculate the activity coefficient f^m , the molecular interaction parameter β^m , the mixed free energy change ΔG_{mix} , listed in Table 2, if it is negative, the process of micelle formation is spontaneous.

The composition X_1^s of the mixed surface adsorption layer and the molecular interaction parameter β^s are calculated by the following equation [30]:

$$\frac{(X_1^s)^2 \ln(\alpha_1 C_{12}/X_1^s C_1)}{(1 - X_1^s)^2 \ln[(1 - \alpha_1)C_{12}/(1 - X_1^s)C_2]} = 1 \quad (4)$$

$$\beta^s = \frac{\ln(\alpha_1 C_{12}/X_1^s C_1)}{(1 - X_1^s)^2} \quad (5)$$

where C_1 , C_2 , and C_{12} are the concentrations of component 1, component 2, and the mixed solution when the specified surface tension is equal to $55 \text{ mN}\cdot\text{m}^{-1}$, respectively.

From the regular solution theory, use the following relationship [31].

$$G^E = H^E = \Delta H_{mix} = RT \sum X_i \ln f_i \quad (6)$$

where G^E is the excess Gibbs free energy, H^E is the excess enthalpy, ΔH_{mix} is the enthalpy change of mixing, R is the ideal gas constant ($8.314 \text{ J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$), T is the absolute temperature (298.2 K), and f_i is the activity coefficient of component i .

$$\begin{aligned} T\Delta S_{mix} &= \Delta H_{mix} - \Delta G_{mix} \\ &= RT \sum X_i \ln f_i - RT \sum X_i \ln X_i f_i \\ &= -RT \sum X_i \ln X_i \end{aligned} \quad (7)$$

The thermodynamic parameters of mixed micelle formation, including the Gibbs free energy change (ΔG_{mix}) and the entropy change (ΔS_{mix}), were calculated and are listed in Table 2. A negative ΔG_{mix} indicates a spontaneous micellization process, while a positive ΔS_{mix} suggests that the entropy effect plays an important role in the micellization. The calculation results of the mixed free energy change ΔG_{mix} and the mixed entropy change ΔS_{mix} can be calculated as shown in Table 2.

The interaction parameters β^s and β^m in Table 2 are both negative values, indicating that the components are attracted to each other, and the mixing thermodynamic parameters are the same as those in the literature [32]. The mixed free energy change ΔG_{mix} is negative, indicating that micelle formation is a spontaneous process. The entropy change of the mixture is positive. From the numerical analysis, the thermal and entropy effects also play important roles in the formation of micelles in CBBG250 aqueous solution.

3.3.2. Motomura Model

From a thermodynamic point of view, Motomura et al. [27] considered mixed micelles as a macroscopic stage of thermodynamic analysis. Considering the dissociation process of the surfactant at the charged interface, as well as the interactions between surfactant molecules in the micelles and the adsorption layer, the Motomura model treats mixed micelles as a macroscopic thermodynamic phase. It has been applied successfully in ionic/nonionic mixed systems [33,34]. The composition of the mixed adsorption layer Y_1^s and the composition of the mixed micelles Y_1^m are calculated by the following formula:

$$Y_1^s = X_1 + \left(\frac{X_1(1 - X_1)}{c} \right) \left(\frac{\partial c}{\partial (1 - X_1)} \right)_{T,P,\gamma} \quad (8)$$

$$Y_1^m = X_1 + \left(\frac{X_1(1 - X_1)}{cmc} \right) \left(\frac{\partial cmc}{\partial (1 - X_1)} \right)_{T,P} \quad (9)$$

where X_1 is the mole fractions of surfactants 1 in the bulk phase (and thus $1 - X_1$ is the mole fraction of surfactant 2), respectively, and c is the total concentration of the mixed solution at a specified surface tension of 55 mN/m.

The deviation from the ideal mixture can be quantitatively described by the surface adsorption excess free energy $\Delta G^{s,exc}$ and the micelle formation excess free energy $\Delta G^{m,exc}$:

$$f_i^s = \frac{cX_i}{c_i^0 Y_i^s} \quad (10)$$

$$f_i^m = \frac{cmcX_i}{cmc_i^0 Y_i^m} \quad (11)$$

$$\Delta G^{s,exc} = RT \sum Y_i^s \ln f_i^s \quad (12)$$

$$\Delta G^{m,exc} = RT \sum Y_i^m \ln f_i^m \quad (13)$$

where f_i represents the activity coefficient of component i , which c_i^0 is the concentration of component i at a specified surface tension of 55 mN/m, which cmc_i^0 is the CMC value of component i and the calculation results are shown in Table 3.

Table 3. Motomura model micelle parameters of the CTAB/Tween-20 mixed system at 298.2 K.

$\alpha_{\text{Tween-20}}$	Y_1^s	Y_1^m	f_1^s	f_1^m	f_2^s	f_2^m	$\Delta G^{s,exc}$ (kJ·mol ⁻¹)	$\Delta G^{m,exc}$ (kJ·mol ⁻¹)
0.1	0.481	0.479	0.049	0.558	0.029	0.398	-1.716	-1.742
0.3	0.343	0.386	0.0540	0.827	0.010	0.301	-1.594	-1.536
0.5	0.328	0.247	0.040	0.748	0.003	0.127	-1.568	-1.053
0.7	0.224	0.205	0.018	0.683	0.001	0.114	-1.319	-0.897
0.9	0.102	0.163	0.002	0.568	0.001	0.011	-1.176	-0.841

In Figure 6, the free energy changes calculated by the Motomura model and Rubingh model are less than 0. These values increase as the mole fraction of Tween-20 rises, and the two curves follow roughly the same trend. The free energy of surface adsorption and the micelles form is negative, indicating that both processes occur spontaneously. It depends on the interaction between the ionic and nonionic surfactants in CBBG250 aqueous solution.

Before mixing, there is a strong electrostatic repulsion [35] between the ionic surfactant molecules, and there is a short-range steric repulsion [36] between the nonionic surfactants. These repulsions cause the surfactant molecules to separate from each other and hinder the mixing. After mixing in CBBG250 aqueous solution, ionic and nonionic surfactant molecules alternate at the period of micellar formation, it reduces the repulsion between the ionic surfactant particles. Also, it reduces the steric hindrance effect of the nonionic surfactant, the presence of CBBG250 may further enhances synergy and this synergy is greatest when $\alpha_{\text{Tween-20}} = 0.9$, and the free energy values from the Rubingh model and the Motomura model are similar, indicating the consistency of the two theoretical models. The negative values of free energy changes indicate that both micellization and adsorption processes occur spontaneously.

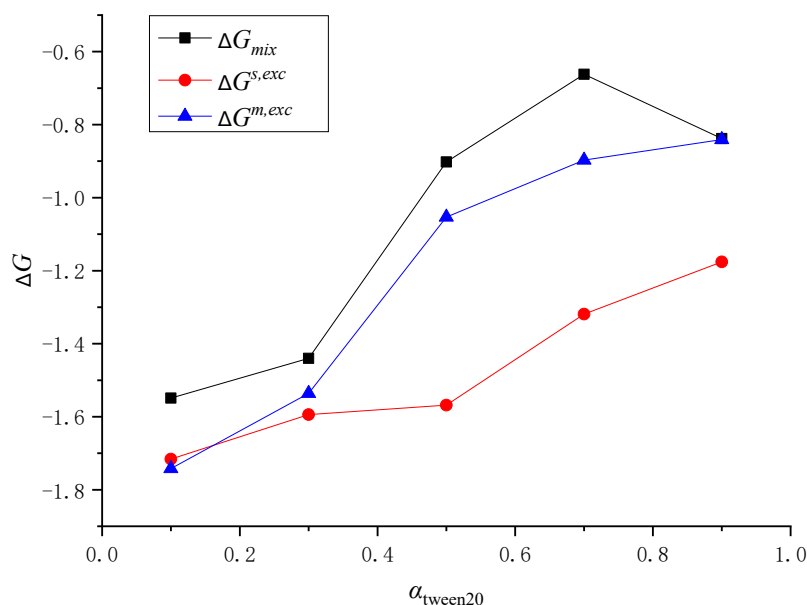


Figure 6. Free energy change ΔG of the Rubingh model and the Motomura model.

4. Conclusions

The mixed surfactant of CTAB/Tween-20 in CBBG250 aqueous solution has a different CMC than the single surfactants CTAB and Tween-20. It reaches the minimum CMC at $\alpha_{\text{Tween-20}} = 0.9$, indicating that aqueous solutions of mixed ionic surfactants exhibit many new properties compared with individual surfactants, with synergistic effects such as a significant increase in surface activity, enhanced solubilization, and lower critical micelle concentration. The free energy of the micelle calculated by the Rubingh and Motomura models is basically consistent, indicating that the application of two micelle theoretical models to the ion/nonionic mixed system is reasonable. This study clearly confirms the interactions between mixed surfactant systems and the dye. Further research is required to explore the interaction mechanism in greater detail.

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Author Contributions

Formal analysis, Investigation, Methodology: S.Z.; Writing—original draft: J.Z.; Writing—review & editing, Resources, Formal analysis, Investigation, Methodology: N.W. All authors have read and approved the final version to be published.

Ethics Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

All relevant data are within the paper.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Akbaş H, Kartal Ç. C.I. Reactive Orange 16-dodecylpyridinium chloride interactions in electrolytic solutions. *Spectrochim. Acta Part A Mol. Biomol. Spectrosc.* **2006**, *65*, 95–99. DOI:10.1016/j.saa.2005.09.033
2. Shen T, Xiao R, Wang Q, Yang L, Wang N. Study of Interactions and Association Thermodynamics Between Sudan Red and Sodium Dodecyl Sulfate in Microemulsions. *J. Dispers. Sci. Technol.* **2014**, *35*, 435–440. DOI:10.1080/01932691.2013.794424
3. Wang N, Zhao M. Study on Thermodynamics and Kinetics of Association Interactions between Malachite Green and OP-10 in Aqueous Solutions. *J. Dispers. Sci. Technol.* **2016**, *37*, 190–195. DOI:10.1080/01932691.2015.1039019
4. Wang N, Wang X, Yang L, Chen H. Morphology and size control of nanocalcium carbonate crystallised in reverse micelle system with cationic surfactant cetyltrimethylammonium bromide. *Micro Nano Lett.* **2013**, *8*, 94–98. DOI:10.1049/mnl.2012.0831
5. Wang N, Su C, Xiao S. Interaction of Phenol Red with cetyltrimethylammonium bromide in aqueous solution. *Color. Technol.* **2015**, *131*, 434–438. DOI:10.1111/cote.12183
6. Yadav CK, Bhattarai A, Niraula TP, Yadav AP, Adhikari MK, Yadav YP, et al. Critical Analysis of Surfactant-Dye Interaction: A Review. *Amrit J.* **2023**, *3*, 66–77. DOI:10.3126/amritj.v3i1.61543
7. Tehrani-Bagha A, Holmberg K. Solubilization of Hydrophobic Dyes in Surfactant Solutions. *Materials* **2013**, *6*, 580–608. DOI:10.3390/ma6020580
8. Wang Z, Jing J, Wang N. Surface and associated studies between Coomassie brilliant blue G250 and CTAB in Aqueous Solution. *IOP Conf. Ser. Mater. Sci. Eng.* **2018**, *392*, 032009. DOI:10.1088/1757-899X/392/3/032009
9. Wang Z, Jing J, Wang D, Tong J, Wang N. Dye-Surfactant Solution of Coomassie Brilliant Blue G250 and Tween 20: Micellar and Interaction Parametric Studies. *AATCC J. Res.* **2019**, *6*, 20–27. DOI:10.14504/ajr.6.3.3
10. Guo J, Wang Z, Jing J, Tong J, Wang N. Interaction between Coomassie brilliant blue G250 and octylphenol polyoxyethylene ether (10) in aqueous solution. *J. Dispers. Sci. Technol.* **2018**, *39*, 1208–1213. DOI:10.1080/01932691.2017.1388180
11. Wang N, Lin H, Zhu H. Study of the Association Behavior Between Bromophenol Blue and Octylphenol Polyoxyethylene Ether (10) in Aqueous Solution and the Solubilization of Bromophenol Blue by Micelles. *J. Solut. Chem.* **2016**, *45*, 1689–1700. DOI:10.1007/s10953-016-0535-1
12. Lin H, Zhu H, Guo J, Wang N. Interactions Between Bromophenol Blue and Cetyl-Trimethylammonium Bromide in Aqueous Solutions and Microemulsions. *J. Dispers. Sci. Technol.* **2017**, *38*, 1410–1414. DOI:10.1080/01932691.2016.1250215
13. Biswal NR, Singh JK. Interfacial behavior of nonionic Tween 20 surfactant at oil-water interfaces in the presence of different types of nanoparticles. *RSC Adv.* **2016**, *6*, 113307–113314. DOI:10.1039/C6RA23093H
14. Haque R, Kabir M, Noor Z, Rahman SMM, Mondal D, Alam F, et al. Diagnosis of Amebic Liver Abscess and Amebic Colitis by Detection of *Entamoeba histolytica* DNA in Blood, Urine, and Saliva by a Real-Time PCR Assay. *J. Clin. Microbiol.* **2010**, *48*, 2798–2801. DOI:10.1128/JCM.00152-10
15. Chatterjee S, Bhattacharya SC. Spectroscopic studies of interaction of Safranin T with nonionic micelles and mixed micelles. *Spectrochim. Acta Part A Mol. Biomol. Spectrosc.* **2006**, *64*, 355–362. DOI:10.1016/j.saa.2005.07.031
16. Nagarajan R. Molecular theory for mixed micelles. *Langmuir* **1985**, *1*, 331–341. DOI:10.1021/la00063a012
17. Minnick DL, Flores RA, DeStefano MR, Scurto AM. Cellulose Solubility in Ionic Liquid Mixtures: Temperature, Cosolvent, and Antisolvent Effects. *J. Phys. Chem. B* **2016**, *120*, 7906–7919. DOI:10.1021/acs.jpcc.6b04309
18. Choi JH, Cho M. Ion aggregation in high salt solutions. V. Graph entropy analyses of ion aggregate structure and water hydrogen bonding network. *J. Chem. Phys.* **2016**, *144*, 204126. DOI:10.1063/1.4952648

19. Delaney MJ, Datyner A. The Interaction between Acid Dyes and Non-ionic Surfactants and its Effect on Sorption and Diffusion Behaviour. II–Sorption of Dyes and Surfactants on Nylon 6.6 Fibres from Finite Baths. *J. Soc. Dye. Colour.* **1971**, *87*, 263–268. DOI:10.1111/j.1478-4408.1971.tb03026.x
20. Sinha TB, Das HS, Dubey RK, Das R, Roymahapatra G, Khatua PK. Analysis of CMC of Polyoxyethylene(20)sorbitan monopalmitate (Tween40) and Cetyltrimethylammoniumbromide (CTAB) in aqueous medium. *J. Indian Chem. Soc.* **2018**, *95*, 55–63. Available online: [https://www.semanticscholar.org/paper/Analysis-of-CMC-of-polyoxyethylene\(20\)sorbitan-and-Sinha-Das/687e693c02bcd54b17f4bdf0498e9a1e89b526ea](https://www.semanticscholar.org/paper/Analysis-of-CMC-of-polyoxyethylene(20)sorbitan-and-Sinha-Das/687e693c02bcd54b17f4bdf0498e9a1e89b526ea) (accessed on 27 September 2026).
21. Bąk A, Podgórska W. Interfacial and surface tensions of toluene/water and air/water systems with nonionic surfactants Tween 20 and Tween 80. *Colloids Surf. A Physicochem. Eng. Asp.* **2016**, *504*, 414–425. DOI:10.1016/j.colsurfa.2016.05.091
22. Ybert C, di Meglio JM. Study of Protein Adsorption by Dynamic Surface Tension Measurements: Diffusive Regime. *Langmuir* **1998**, *14*, 471–475. DOI:10.1021/la970999c
23. Wang N, Lin H, Zhao M, Xiao R. Spectroscopic Studies of Sodium Dodecyl Sulfate and Sudan Red III Associations in Solutions. *AATCC J. Res.* **2017**, *4*, 16–21. DOI:10.14504/ajr.4.4.3
24. Mittal KL. *Solution Chemistry of Surfactants*. Plenum Press: New York, NY, USA, 1979.
25. Motomura K, Yamanaka M, Aratono M. Thermodynamic consideration of the mixed micelle of surfactants. *Colloid Polym. Sci.* **1984**, *262*, 948–955. DOI:10.1007/BF01490027
26. Yamanaka M, Aratono M, Motomura K, Matuura R. Effect of pressure on the adsorption and micelle formation of aqueous dodecyltrimethylammonium chloride solution-hexane system. *Colloid Polym. Sci.* **1984**, *262*, 338–341. DOI:10.1007/BF01410472
27. Motomura K, Aratono M. Miscibility in Binary Mixtures of Surfactants. In *Mixed Surfactant Systems*; Surfactant Science Series 46; Ogino K, Abe M, Eds.; Marcel Dekker: New York, NY, USA, 1993; pp. 99–144.
28. Korzhan L, Kulichenko S, Lelyushok S, Klovak V. Coomassie Brilliant Blue G for Smart Colorimetric Determination of the Ionic Surfactants in Triton X-100 Solutions. *Appl. Spectrosc. Rev.* **2024**, *78*, 1105–1114. DOI:10.1177/00037028241267900
29. Rubingh DN. Mixed Micelle Solutions. In *Solution Chemistry of Surfactants*; Springer: New York, NY, USA, 1979; pp. 337–354. DOI:10.1007/978-1-4615-7880-2_15
30. Scamehorn JF. *Phenomena in Mixed Surfactant Systems*; American Chemical Society: Washington, DC, USA, 1986; pp. 294–297.
31. Rodenas E, Valiente M, del Sol Villafuella M. Different Theoretical Approaches for the Study of the Mixed Tetraethylene Glycol Mono-*n*-dodecyl Ether/Hexadecyltrimethylammonium Bromide Micelles. *J. Phys. Chem. B* **1999**, *103*, 4549–4554. DOI:10.1021/jp981871m
32. Moore SA, Glenn KM, MacDonald AM, Palepu RM. Micellar and associated thermodynamic properties of binary mixtures of alkyl triphenyl phosphonium bromides in ethylene glycol and water mixtures. *Colloid Polym. Sci.* **2007**, *285*, 543–552. DOI:10.1007/s00396-006-1604-6
33. Jarek E, Wydro P, Warszyński P, Paluch M. Surface properties of mixtures of surface-active sugar derivatives with ionic surfactants: Theoretical and experimental investigations. *J. Colloid Interface Sci.* **2006**, *293*, 194–202. DOI:10.1016/j.jcis.2005.06.028
34. Chakraborty T, Ghosh S. Mixed micellization of an anionic gemini surfactant (GA) with conventional polyethoxylated nonionic surfactants in brine solution at pH 5 and 298 K. *Colloid Polym. Sci.* **2007**, *285*, 1665–1673. DOI:10.1007/s00396-007-1738-1
35. Thadros T. Interaction Parameter. In *Encyclopedia of Colloid and Interface Science*; Springer: Berlin/Heidelberg, Germany, 2013; pp. 634–634.
36. Scc VDL, Fonseca GC. Hydrogen-Bond Strength of CC and GG Pairs Determined by Steric Repulsion: Electrostatics and Charge Transfer Overruled. *Chem. Eur. J.* **2017**, *23*, 10234–10234. DOI:10.1002/chem.201702441