



## Conductivity Study on the Impact of Ethanol and Temperature on SDS Aggregation in the Presence of Promethazine Hydrochloride

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### Abstract

#### Keywords:

Micellization, Surfactant,  
Critical micelle  
concentration,  
Promethazine  
hydrochloride

*This study investigates the impact of ethanol (EtOH) content and temperature on the PMH + SDS system, focusing on counterion binding, degree of ionization, critical micelle concentration (CMC), and thermodynamic properties. The addition of EtOH is found to enhance and delay the assembly of the PMH + SDS mixture, influencing micelle formation. The CMC values decrease with increasing EtOH concentration, indicating altered interactions between water molecules and SDS. Temperature fluctuations also affect the CMC, with an increase observed as temperature rises. Thermodynamic analysis reveals consistently negative Gibbs free energy ( $\Delta G_m^o$ ) values, suggesting the spontaneous and exothermic nature of micellization facilitated by PMH. Enthalpy change ( $\Delta H_m^o$ ) values indicate hydrophobic interactions, while positive entropy change ( $\Delta S_m^o$ ) values signify enhanced water molecule randomness in the micelle's core. The presence of aqueous EtOH is found to influence hydrophobic interactions between SDS and PMH, emphasizing the role of additives in altering the surfactant-drug mixture's hydration and structure. Overall, this study provides valuable insights into the complex thermodynamics governing mixed surfactant systems.*

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### INTRODUCTION

Polymers, pharmaceuticals, and surfactants are examples of substances displaying an amphiphilic nature. These molecules consist of two opposing components: the hydrophilic part, with an affinity for water, and the lipophilic or hydrophobic part, which favors oil. Whether in an aqueous or non-aqueous setting, amphiphilic surfactants (Walker, 1981, Lashkarbolooki et al., 2020; Baskar et al., 2003; Zhao et al., 2008; Kumar and Rub, 2018, Siddiqui et al., 2014; Naskar et al., 2012; Alawi and Akhter, 2011), medications (Schreier et al., 2000; Tiwary et al., 2011; Alam et al., 2011; Azum et al., 2019; Azum et al., 2022; Rub et al., 2017; Rub et al., 2021; Bagheri, 2021, Khan et al., 2014), and polymers (Topel et al., 2013; Khalil et al., 2012; Lin et al., 2014;

Boughammoura and Mhalla, 2012) typically undergo self-association above a specific concentration known as the critical micelle concentration (CMC). This leads to the formation of aggregates referred to as micelles. Self-association processes are essentially spontaneous and result from various interactions, including H-bonding, metal-ligand coordination complexes, hydrophobic/electrostatic/donor-acceptor interactions, and van der Waals forces (Whitesides and Grzybowski, 2002).

Surfactants find diverse applications in detergents, paints, cosmetics, and pharmaceuticals within the chemical industry. The settlement of surfactants in water is facilitated by robust interactions with water molecules, achieved through dipole-dipole or ion-dipole interactions. However, the repulsive nature of

nonpolar moieties toward polar water induces hydrophobic interactions between the nonpolar ends of molecules, thereby pushing the hydrocarbon chain of the surfactant out of the water in an aqueous medium.

The optimal functioning of micelle-forming surfactants occurs at concentrations above the critical micelle concentration (CMC) (Rosen and Kunjappu, 2012, Hasan et al., 2022; Niraula et al., 2022; Katiyar and Singh, 2018, Edler and Bowron, 2019). Exploring different types of drug-surfactant interactions involves examining key variables associated with micelle formation and related thermodynamic properties, which significantly depend on experimental conditions such as temperature, salt, and solvent effects. A growing area of interest focuses on investigating the molecular interactions between surfactants and specific drugs. The strength of the molecular interaction between a drug and a surfactant is crucial for drug distribution, formulation, and expansion.

In surfactant-rich environments with micelles, the solubility of poorly water-soluble medications is enhanced through the solubilization properties of amphiphilic micelles. Alcohol-containing surfactant systems are commonly used to investigate reaction rates and equilibria in various industrial applications. Studies have demonstrated that the formation of surfactant micelles is influenced by the presence of hydroxyl organic molecules, namely alcohols (Benrraou and Zana, 2005, Wang et al., 2007; Sidim and Acar, 2013).

Earlier studies (Benrraou and Zana, 2005, Wang et al., 2007) have indicated that alcohols with longer hydrocarbon chains facilitate micellization by reducing the critical micelle concentration (CMC), whereas shorter-chain alcohols often hinder micellization by elevating the CMC. However, there are conflicting results reported by other research groups (Sidim and Acar, 2013). The literature also discusses the influence of different alcohols on micellization and surfactant adsorption behavior (Ren et al., 2016; Ren et al., 2019; Sheng et al., 2021; Huang and Ren, 2020). The widespread applications of surfactants in technology, research, and commerce have generated increased interest in the aggregation behavior of amphiphile systems in the presence of various solutes, including chemical compounds, colors, and medications (Rafique et al., 2020; Akhlaghi and Riahi, 2019, Kumar et al., 2015; Hoque et al., 2013).

In aqueous solution of polyols an organic compound, studies have reported the existence of exothermic and hydrophobic interactions between the fluoroquinolone-family medication ciprofloxacin hydrochloride (CFH) and sodium dodecyl sulfate

(SDS) using the conductivity measurement technique (Chowdhury et al., 2021). A greater concentration of surfactants is needed for the micellization process in order to create micelles in aqueous alcohol or diol environments (Rashid et al., 2021). This is because, in comparison to values found in an aqueous environment, the critical micelle concentration (CMC) values for the combination of ciprofloxacin hydrochloride (CFH) and sodium dodecyl sulfate (SDS) in the presence of polyols decreases.

Previous studies have explored the interplay between ionic surfactants and specific essential antibiotics, considering the presence or absence of various inorganic salts and other electrolytes (Kumar and Rub, 2017, Hoque et al., 2018; Olaseni et al., 2023). Alcohols, such as 2-propanol and EtOH, serve as active components in medications. Their pharmacological effects, including sedative, carminative, cooling, antipyretic, cleansing, and antiseptic qualities, vary based on the alcohol concentration. Despite these diverse qualities, their primary function lies in their solvent properties, facilitating the solubilization of various drugs (Parker, 1982). Moreover, shorter-chain alcohols are recognized for altering solvent properties and have the ability to form hydrogen bonds with water, enhancing their solubility in aquatic environments (Almgren et al., 1985). The introduction of shorter-chain alcohol, such as EtOH which are hydrophilic molecule, modifies the bulk phase property of water.

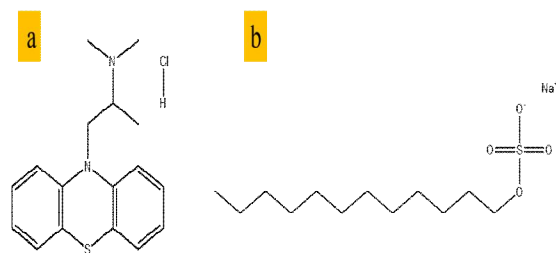
The addition of the alcohol influences the formation of mixed micelles, combining medium-to-long-chain alcohol and surfactant. These mixed micelles feature hydrophobic chains in the micelle core and alcoholic hydroxyl groups in the head group area.

This study explores the impact of short-chain alcohol (i.e EtOH) on the micellar or aggregative behavior of both the medication and surfactant. After conducting a comprehensive review of the literature, it became apparent that no in-depth investigation utilizing the conductivity approach had been undertaken concerning the surface-active behavior of sodium dodecyl sulfate (Fig. 1(a)) and the antibiotic drug promethazine hydrochloride (PMH) (Fig. 1(b)), either in the presence or absence of alcohol species. Building upon this gap in research, conductivity method was employed to examine the aggregation behavior and associated physicochemical characteristics of the SDS + PMH combination in both water and aqueous-alcoholic (EtOH) media.

Additionally, the influence of temperature and alcohol concentrations on the association of the SDS + PMH mixture was explored.

This investigation includes a comprehensive summary of the likely interaction forces, accompanied by the determination of thermodynamic variables ( $\Delta G_m^0$ ,  $\Delta H_m^0$ , and  $\Delta S_m^0$ ) and

micellization parameters under the specified study conditions. Through exploration of these interactions, understanding the bulk properties of the binary mixed system SDS + PMH has been significantly enhanced.



**Figure 1:** Molecular structures of (a) Promethazine Hydrochloride (PMH) (b) Sodium dodecylsulphate (SDS)

## MATERIALS AND METHOD

### Materials

There has been no additional purification of the analytical-grade compounds employed in the current study. Table 1 contains the details of the materials utilized.

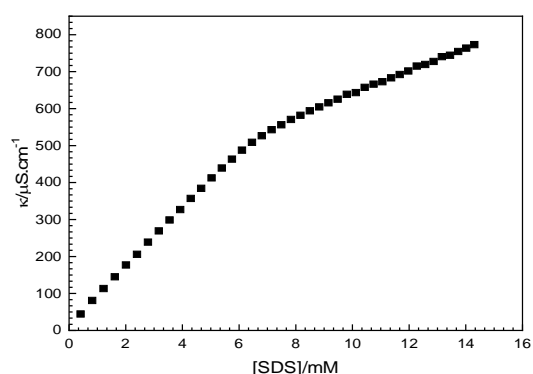
**Table 1: Chemical Components Employed in the Current Investigation: In-depth Analysis**

Material	Source	Purity/%	Molar Mass/g.mol
SDS	Sigma-Aldrich	>99	288.38
PHM	Sigma-Aldrich	>98.9	320.88
EtOH	Eurochem Globals	>96.01	46.069

### Conductivity Technique

A widely used, reliable, and popular method for investigating the assembly of various charged amphiphiles involves the conductivity approach. In this study, a Jenway 4510 conductivity meter from the UK, equipped with a glass electrode dip cell with a cell constant of 0.97 cm<sup>-1</sup>, was employed to measure the specific conductivity of the test samples using a 60-Hz alternating current (AC) source. The measurement procedures specified in references (Rahman et al., 2019; Caetano and Tabak, 2000, Minatti and Zanette, 1996, Khan et al., 2018; Mahbub et al., 2020; Abedin et al., 2021; Hasan et al., 2020; Aguiar et al., 2003; Alam et al., 2014) were meticulously followed. Surfactant stock solutions were prepared in doubly distilled Millipore water, with or without predetermined concentrations of additives. The addition of concentrated solution to either pure water (in the absence of additives) or a predetermined concentration of additive solutions was done gradually, and the conductivity was

determined. The micellization process initiates when there is a deviation in the specific conductivity ( $k$ ) vs. surfactant concentration curve (see Fig. 2). It is worth noting that the conductivity meter's glass electrode dip cell played a crucial role in these measurements, ensuring accuracy. According to the manufacturer, the observed conductivity and critical micelle concentration (CMC) were associated with errors of approximately 0.5  $\mu\text{S cm}^{-1}$  and 0.1 mM, respectively. This approach provides a robust means of examining amphiphile assembly and micellization processes.



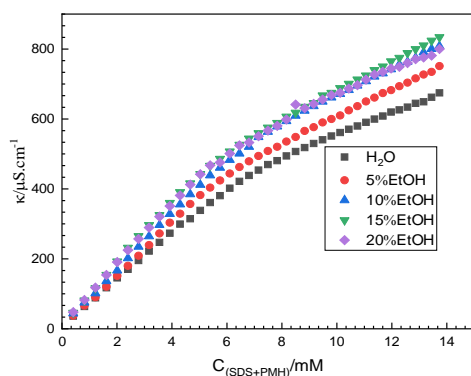
**Figure 2:** Plot of Specific Conductivity value against the concentration of SDS at 298.15K.

## RESULT AND DISCUSSION

### Impact of EtOH content on PMH + SDS system counterion binding, degree of ionization, and CMC

Ionic amphiphiles, when in a solution, undergo complete dissociation and exhibit typical electrolyte characteristics. Consequently, the addition of an ionic surfactant leads to an increase in the concentration of movable ions, resulting in enhanced conductivities. This implies that higher surfactant concentrations could lead to the formation of amphiphile micelles. The continuous increase in amphiphile molecule concentration prevents the gradual enlargement of amphiphiles in an aqueous solution, promoting aggregation and the formation of larger micelles compared to monomeric amphiphiles. In Figure 3, a representative conductivity ( $k$ ) vs SDS concentrations curve for the PMH + SDS mixture is presented with various ethanol concentrations at 298.15 K. The graph illustrates a linear correlation between conductivity and surfactant level in both pre- and post-micellar conditions. The conductivity plot against SDS concentration displays a distinctive breakpoint, where the corresponding amphiphile concentration is identified as the critical micelle concentration (CMC) in this study. In the pre-micellar regime (i.e below CMC), elevated  $k$  values

are attributed to  $SD^-$  and  $Na^+$  ions. In the post-micellar regime (i.e above CMC), lower  $k$  values result from the formation of SDS micelles, reducing the mobility of aggregated ions compared to unassociated ions produced by single amphiphiles, and the binding of sodium ions at the micelle surface.



**Figure 3:** Plot of  $K$  versus SDS + PHM at different concentration of Ethanol at 298.15K

The relationship between slopes in the linear regions above and below the CMC is utilized to calculate the degree of micellar ionization ( $\alpha$ ).

The CMC and counterion of binding ( $\beta$ ) values for PMH + SDS in aqueous and 5%, 10%, 15%, and 20% aqueous EtOH medium at various temperatures are shown in Table 2. As PMH concentration increases, CMC values drop, suggesting that PMH facilitates SDS assembly and improves the interaction between PMH and SDS. Table 2 shows that the counterion binding ( $\beta$ ) values for SDS and SDS+PMH when EtOH is present are similar to those in pure water. On the other hand, the counterion binding ( $\beta$ ) value decreases with increasing EtOH concentration in the water. This decrease is explained by the increased concentration of EtOH, which either integrates into the micelle structure or adsorbs onto the micelle's outside. This integration results in a diminished repulsive interaction between the ionic head groups, subsequently leading to a decrease in the number of counterions required for the surfactant molecules to maintain micelle stability (Kolay et al., 2005).

Table 2 provides information on the critical micelle concentration (CMC) and related values for the PMH + SDS system in both aqueous and ethanol (EtOH) environments at different temperatures. An interesting trend emerges as the concentration of PMH increases, leading to a reduction in CMC values. This suggests that PMH plays a facilitative role in the assembly of SDS, enhancing the interaction between PMH and SDS. The counterion binding ( $\beta$ ) values for SDS and SDS+PMH in the presence of EtOH are akin to those observed in pure

water, as revealed in Table 2. However, a noteworthy observation is the decrease in the counterion binding ( $\beta$ ) value with escalating EtOH concentrations in the water medium. This decline is attributed to the heightened concentration of EtOH, which either integrates into the micelle structure or adsorbs onto the micelle's exterior. This integration leads to a diminished repulsive interaction between the ionic head groups, resulting in a reduced requirement for counterions to stabilize the micelle, as elucidated in prior research (Kolay et al., 2005).

Building on previous investigations into PMH with SDS in  $H_2O$  and various salt solutions, which showcased improved SDS assembly with PMH addition, the present study delves deeper into PMH + SDS micellar systems (Olaseni et al., 2023). Specifically, solutions with fixed PMH concentrations across varying EtOH percentages were explored. The CMC values for the PMH + SDS mixture in an aqueous EtOH environment exhibit fluctuation with EtOH concentration, consistently remaining lower than those in an EtOH-free environment. EtOH is found to enhance and delay the assembly of the PMH + SDS mixture. This phenomenon is attributed to the reduced repulsion among SDS monomers, requiring lower concentrations to form micelles in the aqueous EtOH medium.

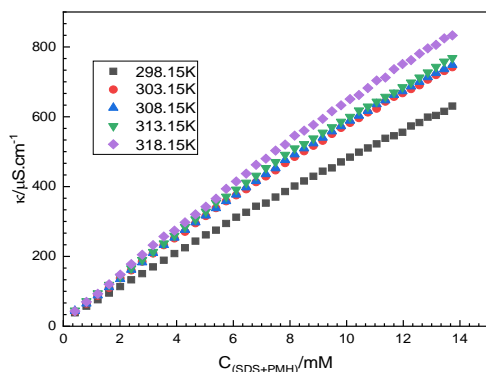
The presence of EtOH induces alterations in the interactions between water molecules and SDS, impacting the delicate equilibrium between hydrophobic and hydrophilic forces governing micelle formation. Several factors contribute to the observed decrease in the critical micelle concentration (CMC) of SDS in the presence of EtOH. Firstly, EtOH's ability to solubilize SDS molecules leads to the dispersion of individual SDS molecules in the solution, breaking up micelles and aggregates and consequently lowering the CMC. Secondly, EtOH forms hydrogen bonds with water molecules, modifying the interactions around SDS molecules and reducing the energy barrier for micelle production. Thirdly, the lower surface tension of EtOH compared to water facilitates SDS micelle formation, requiring less energy to overcome the forces resisting micelle formation. This comprehensive analysis highlights the intricate interplay between PMH, SDS, and EtOH in micellar systems, offering valuable insights into their assembly and stability.

**Table 2:** CMC,  $\alpha$  and  $\beta$  values for micellization of SDS and PMH mixture in aqueous and aqueous/Ethanol media

<i>Medium</i>	<i>C<sub>PMH</sub>(mM)</i>	<i>C<sub>EtOH</sub>/v/v</i>	<i>T/K</i>	<i>CMC/mM</i>	<i>X<sub>cmc</sub></i>	<i><math>\alpha</math></i>	<i><math>\beta</math></i>
H <sub>2</sub> O	0.10	0	298.15	7.29	-8.939	0.420	0.585
	0.10	0	303.15	7.20	-8.951	0.422	0.578
	0.10	0	308.15	7.21	-8.965	0.435	0.565
	0.10	0	313.15	7.25	-8.944	0.425	0.575
	0.10	0	318.15	7.59	-8.899	0.329	0.671
H <sub>2</sub> O	0.15	0	298.15	7.01	-8.978	0.488	0.512
	0.15	0	303.15	6.73	-9.019	0.466	0.534
	0.15	0	308.15	6.22	-9.098	0.358	0.642
	0.15	0	313.15	6.92	-8.994	0.416	0.584
	0.15	0	318.15	7.43	-8.920	0.385	0.615
H <sub>2</sub> O	0.20	0	298.15	6.62	-9.035	0.411	0.589
	0.20	0	303.15	6.57	-9.043	0.419	0.581
	0.20	0	308.15	5.83	-9.162	0.450	0.550
	0.20	0	313.15	6.81	-9.007	0.401	0.599
	0.20	0	318.15	7.41	-8.923	0.399	0.601
H <sub>2</sub> O	0.25	0	298.15	6.11	-9.115	0.444	0.556
	0.25	0	303.15	5.57	-9.208	0.383	0.617
	0.25	0	308.15	5.48	-9.224	0.419	0.581
	0.25	0	313.15	6.89	-8.999	0.368	0.632
	0.25	0	318.15	7.05	-8.972	0.420	0.580
H <sub>2</sub> O+ EtOH	0.10	5	298.15	6.62	-9.311	0.415	0.582
	0.10	5	303.15	5.57	-9.318	0.422	0.568
	0.10	5	308.15	5.85	-9.434	0.435	0.560
	0.10	5	313.15	5.11	-9.569	0.425	0.505
	0.10	5	318.15	5.63	-9.472	0.329	0.634
H <sub>2</sub> O+ EtOH	0.10	10	298.15	5.80	-9.443	0.372	0.628
	0.10	10	303.15	5.30	-9.533	0.365	0.635
	0.10	10	308.15	4.70	-9.653	0.539	0.461
	0.10	10	313.15	5.40	-9.514	0.372	0.628
	0.10	10	318.15	5.70	-9.460	0.577	0.423
H <sub>2</sub> O+ EtOH	0.10	15	298.15	5.63	-9.473	0.526	0.474
	0.10	15	303.15	5.25	-9.543	0.492	0.508
	0.10	15	308.15	5.16	-9.559	0.479	0.521
	0.10	15	313.15	6.50	-9.329	0.498	0.502
	0.10	15	318.15	6.98	-9.258	0.467	0.533
H <sub>2</sub> O+ EtOH	0.10	20	298.15	7.41	-9.198	0.554	0.446
	0.10	20	303.15	7.23	-9.222	0.496	0.504
	0.10	20	308.15	7.02	-9.945	0.452	0.548
	0.10	20	313.15	7.25	-9.219	0.391	0.609
	0.10	20	318.15	7.98	-9.124	0.455	0.545

### Effect of temperature on PMH + SDS mixed system aggregation

This study investigated the influence of temperature, spanning from 298.15 K to 318.15 K at five distinct temperatures within a 5-K interval, on the association properties and conductivity of an SDS + PMH (0.1 mM) mixture in both H<sub>2</sub>O and aqueous EtOH medium. The selected temperature range covers both ambient and human body temperatures. Fig. 4 depicts the conductivity variation of a mixture of PMH (0.1 mM) + SDS in an aqueous environment at different temperatures (298.15–318.15 K), demonstrating an increase in conductivity with higher SDS concentration. The enhanced conductivity is attributed to the improved flow of both free and aggregated ions in mixed solvent systems containing aqueous EtOH and H<sub>2</sub>O.



**Figure 4:** Plot of  $K$  versus SDS + PHM in aqueous Ethanol medium at different temperature

Temperature fluctuations had notable effects on the critical micelle concentrations (CMCs) (Kumar et al., 2018). Fig. 4 and Table 3 illustrate the micellar properties of the PMH/SDS/EtOH mixed system. The CMC of SDS + PMH (0.1 mM) mixes gradually increased with temperature in both aqueous and EtOH solutions. The variation in CMC as a function of temperature may be influenced by both the formed amphiphiles and the arrangement of water molecules around the unassociated surfactant. Hydrophilic hydration around the hydrophilic surface of the micellized amphiphiles may occur, leading to two types of water arrangements around free amphiphiles: (a) hydrophobic hydration near the nonpolar tail and (b) hydrophilic hydration near the hydrophilic head. Both types of hydrations tend to decrease with rising temperatures. The decreased organization of water molecules around the charged/hydrophilic group of amphiphiles, indicating an enhanced hydrophobic character, results in decreased CMC values and

increased micelle formation (Rosen and Kunjappu, 2012, Mata et al., 2005; Sultana et al., 2021).

Conversely, the disruption of water arrangement near the hydrophobic moieties of amphiphiles leads to delayed aggregation and increased CMC. Therefore, the rise or fall of the CMC over the experimental temperature range is primarily determined by these two aforementioned features. Throughout the entire temperature range studied in the assembly phenomena of the SDS + PMH mixture in aqueous EtOH media, the first feature, related to the hydrophilic and hydrophobic characteristics, predominates over the second.

### Energetic of SDS + PMH mixture

Determining the kinds and magnitude of interactions inside a system requires an understanding of thermodynamic properties. This paper evaluated the thermodynamic characteristics of the micellization of SDS + drug combinations using Eqs. (1)-(4) (Sultana et al., 2021; Hoque et al., 2021):

$$\Delta G_m^0 = (2 - \alpha)RT \ln(\chi_{cmc}) \quad (1.0)$$

$$\Delta H_m^0 = -RT^2(2 - \alpha)[d(\ln \chi_{cmc}) / dT]_p \quad (2.0)$$

$$\Delta S_m^0 = (\Delta H_m^0 - \Delta G_m^0) / T \quad (3.0)$$

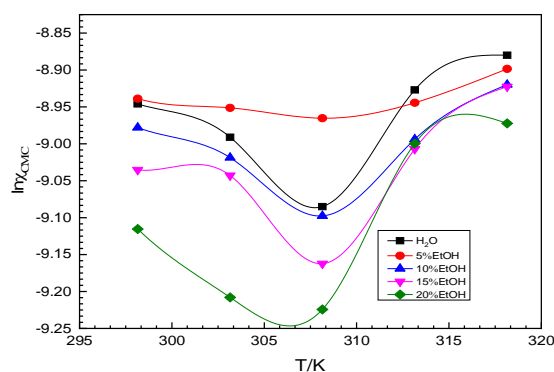
Where  $\chi_{cmc}$  is the value of CMC expressed on a mole fraction basis in Eqs. (1) and (2), defined as;

$$\chi_{cmc} = \frac{CMC}{CMC + [PMH] + 55.56} \quad (4.0)$$

The change in  $\ln \chi_{cmc}$  with  $T$  can be expressed as follows (Hoque et al., 2021):

$$\ln \chi_{cmc} = A + BT + CT^2 \quad (5.0)$$

The  $\ln \chi_{cmc}$  vs  $T$  plots of the PMH + SDS system were nonlinear in all of the media that were examined for H<sub>2</sub>O and aq. EtOH media Fig. 5.



**Figure 5:** Plot of  $\ln \chi_{cmc}$  versus temperature in the presence and absence of EtOH for the mixture of PMH+SDS

**Table 3:** Thermodynamic parameters for the micellization of SDS and PMH (0.10mM) mixture in aqueous and aqueous 5%,10%,15% and 20% Ethanol media

Medium	$C_{EtOH}$ v/v	T/K	$\Delta G_m^0$ KJ/mol <sup>-1</sup>	$\Delta H_m^0$ KJ/mol <sup>-1</sup>	$\Delta S_m^0$ J.mol <sup>-1</sup> . K <sup>-1</sup>
H <sub>2</sub> O	0	298.15	-35.12	-10.53	83.89
	0	303.15	-35.60	-10.84	82.47
	0	308.15	-35.94	-11.11	81.67
	0	313.15	-36.68	-11.54	80.60
	0	318.15	-39.33	-12.64	80.25
H <sub>2</sub> O + EtOH	5	298.15	-36.51	-10.51	89.82
	5	303.15	-36.82	-10.77	87.21
	5	308.15	-37.49	-11.03	86.42
	5	313.15	-37.70	-11.07	88.94
	5	318.15	-40.94	-12.36	84.50
H <sub>2</sub> O + EtOH	10	298.15	-34.52	-9.80	92.54
	10	303.15	-36.27	-10.36	91.53
	10	308.15	-36.48	-10.80	90.67
	10	313.15	-37.25	-11.01	83.60
	10	318.15	-37.54	-11.60	78.08
H <sub>2</sub> O + EtOH	15	298.15	-34.52	-9.79	85.84
	15	303.15	-36.27	-10.36	88.47
	15	308.15	-36.48	-10.80	82.92
	15	313.15	-37.25	-11.01	81.54
	15	318.15	-37.54	-11.60	81.34
H <sub>2</sub> O + EtOH	20	298.15	-32.97	-9.61	92.34
	20	303.15	-34.96	-10.33	85.66
	20	308.15	-37.29	-10.99	81.24
	20	313.15	-38.61	-11.69	80.46
	20	318.15	-39.44	-11.79	78.36

The values of A, B, and C were then ascertained using Eq. (6) (Hoque et al., 2021) after the  $\ln \chi_{cmc}$  vs T plots were fitted with a second-order polynomial.

$$\Delta H_m^0 = -(1 + \beta)RT^2(B + 2CT) \quad (6.0)$$

Table 3 provides the values of enthalpy change ( $\Delta H_m^0$ ), entropy change ( $\Delta S_m^0$ ), and Gibbs free energy change ( $\Delta G_m^0$ ) for the association of SDS + PMH systems in both EtOH and H<sub>2</sub>O media. Notably, the  $\Delta G_m^0$  values for the SDS + PMH (0.1 mM) mixture exhibited consistently negative values across all investigated cases, and these values diminished with rising temperature. The study suggests that the spontaneous thermodynamic nature of the surfactant micelle formation at different temperatures, facilitated by the presence of PMH, is evidenced by the noteworthy negative Gibbs free energy ( $-\Delta G_m^0$ ) values. Consequently, the micellization process of the PMH + SDS mixture is identified as exothermic at all studied temperatures.

Examining the enthalpy change ( $\Delta H_m^0$ ) values reveals that they were consistently negative for the drug + SDS mixture in all studied media, with the magnitudes decreasing as temperature increased in both aqueous and EtOH media. Throughout the entire examined temperature range, positive entropy change ( $+\Delta S$ ) values were observed. In water and aqueous EtOH mediums, the positive entropy change ( $+\Delta S$ ) values decreased with the rise in temperature. Two factors pertaining to the entropy change ( $+\Delta S$ ) values have been employed to categorize surfactant aggregation phenomena: (i) the increased randomness of water molecules in the bulk environment due to the hydrocarbon tail transitioning from the aqueous system to the inner side (core) of the micelle; and (ii) the heightened freedom of rotation of nonpolar components in the micelle compared to the bulk water environment, as the micelle's core is the sole hydrophobic component.

The study highlights the enhanced hydration of water molecules in the hydrophilic portion of the surfactant-drug mixture following the addition of additives, contributing to the apparent increase in negative values of enthalpy change ( $\Delta H_m^0$ ). This disruption of the water's structure leads to hydrophobic interactions between the nonpolar moieties of the surfactant. The negative values of the standard enthalpy change ( $\Delta H_m^0$ ) are a consequence of the surfactant aggregation process, primarily driven by London dispersion forces. As temperature increases, the negative entropy change ( $-\Delta S_m^0$ ) and

positive entropy change ( $+\Delta S_m^0$ ) contribute less to the association phenomenon of SDS + PMH. Consequently, the negative entropy change ( $-\Delta S_m^0$ ) and positive entropy change ( $+\Delta S_m^0$ ) increase, while the positive values of entropy change ( $\Delta S_m^0$ ) simultaneously decrease. The hydrophobic interactions between nonpolar moieties of the surfactant become more pronounced, resulting in changes to the negative values of the standard enthalpy change ( $\Delta H_m^0$ ). Contrastingly, when both entropy change ( $\Delta S_m^0$ ) and enthalpy change ( $\Delta H_m^0$ ) are negative, hydrophilic interactions between the components dominate. This study reveals that in the presence of aqueous ethanol, SDS and PMH primarily interact hydrophobically.

## CONCLUSION

In this study, the impact of EtOH content on the PMH + SDS system was investigated, focusing on counterion binding, degree of ionization, critical micelle concentration (CMC), and the effect of temperature on the system's aggregation. The results provide valuable insights into the intricate interplay between PMH, SDS, and EtOH in micellar systems and the findings allow us to draw the following conclusions

- The results reveal that increasing the PMH content in water causes CMC to decrease, whereas the  $\beta$  values increase, indicating greater surfactant dissociation.
- PMH was observed to facilitate SDS assembly, evident from the decrease in CMC values with increasing PMH concentration
- The rise or fall of CMC over the temperature range was attributed to the hydrophilic and hydrophobic characteristics of the amphiphiles, with hydrophobic interactions dominating.
- The micellization process of the PMH + SDS mixture was identified as exothermic, supported by consistently negative Gibbs free energy values ( $-\Delta G_m^0$ )
- The negative enthalpy change ( $-\Delta H_m^0$ ) values indicated the dominance of hydrophobic interactions between SDS and PMH, especially in the presence of aqueous EtOH.
- EtOH was found to impact the interactions between water molecules and SDS, affecting the delicate balance between hydrophobic and hydrophilic forces governing micelle formation.



Overall, these findings contribute to a comprehensive understanding of mixed surfactant systems, with potential implications for various applications in diverse fields.

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