

## Electrochemical behavior, antimicrobial activities, and effect of temperature on micellization of imidazolium monomeric surfactants

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**Abstract:** In the present study, we herein report the conductance behavior, effect of temperature, and chain-length of two environmentally friendly imidazolium cationic capric and stearic surfactants. The conductance behavior has been carried out in aqueous solvent (H<sub>2</sub>O) at four different temperatures such as 24 °C, 29 °C, 34 °C, and 39 °C. The normal micelles were formed in an aqueous solvent and critical micelle concentration (CMC) can be estimated through conductivity parameters. The expected dependency of the CMC on the alkyl chain length of the 3-(2-(decanoyloxy)ethyl)-1-methyl-1H-imidazol-3-ium-bromide and 3-(2-(octadecanoyloxy)ethyl)-1-methyl-1H-imidazol-3-ium-bromide was demonstrated. It was observed that the graphs of molar conduct activity v/s square root were not linear, which specifies that the synthesized surfactants behave as weak electrolytes in the dilute solutions. The electrochemical characterization of capric and stearic surfactant modified SPCE was studied in 1mM K<sub>3</sub>FeCN<sub>6</sub> solution. The CS/SPCE and SS/SPCE were shown elevated sensitivity, high stability, and excellent conductivity. Moreover, the antimicrobial behaviors of the synthesized imidazolium cationic surfactants versus various microbial strains were evaluated. Results showed that capric surfactant demonstrated high antibacterial activity against *Escherichia coli* (MIC > 31.5 µg/mL).

**Key words:** Electrolytes, cationic surfactants, micellization, cyclic voltammetry and antimicrobial activity

### 1. Introduction

Surfactants are materials which decreased the surface parameters of fluid even at a very low concentration [1]. Within specific order to keep away from the contact of the aquo-phobic moieties with water, the single surfactant molecules self-associate to form an array of comprehensive structures, known as micelles [2]. Surfactants are the main compounds used in our regular needs and its application is increasing progressively in every field [3]. The application of surfactants in industry increases day by day at a rate of 3%–4% because of its higher physicochemical possessions, low cost, and affluence of development [4]. Surfactants generally derived from natural fatty acids can be a moral conventional method to synthesize surfactants because of their affluence of manufacturing and good biodegradability [5]. These surfactants are synthesized by using a sustainable and renewable approach with the help of containing biocompatible functional groups which are mainly degraded after use [6]. These surfactants after discarding will release back equivalent carbon [7] to the environment, which is been formerly consumed by plants for making feedstock [8].

Cationic surfactants (hydrophilic moiety is positively charged) acquire many industrialized applications [9]. Some of the most essential application of cationic surfactants includes softeners, cosmetic product, glass cleaners, bleaching aids and dish washing [10] electrode coating and the stabilization of epoxy resin polymer latexes [11] and paper manufacturing [12]. Generally, micellization occurs in front of a threshold surfactant application, known as critical micellar concentration (CMC) [13]. The surfactant particles below CMC are principally distributed as monomers and above they form micelles in surfactant solution [14]. Micellization nature of the cationic surfactants with aquophilic and aquophobic moieties in the molecule has been calculated by use of physical parameters [15]. The CMC is considered as one of the most essential factors used for the comparison of the effectiveness of surface-active agents for their valuable applications [16]. Imidazolium surfactants predominantly are significant molecule employed as corrosion inhibitors and utilized in suspension polymerization for natural resources flotation. These surfactants are mainly synthesized by using

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of renewable crude substances such as fatty alcohols as well as epichlorohydrin which is an eco-friendly substance [17]. These synthesized surfactants have shown excellent biological activities [18] biocompatibility and biodegradability [19].

Surfactants are widely used in the field of research, mainly in electrochemical studies. Because of their specific amphiphilic structure having anacquoophilic head on one side as well asacquoophobic tail on the other side, these can be absorbed on the interfaces and on the surfaces [20]. Therefore, surfactants are extensively used in electrochemical detection to get more advanced properties of electrode suspension interface. Adsorption of such molecules on the face of electrodes can effectively change the reaction potential, charge transfer, and diffusion coefficients [21–22].

Therefore, quaternary ammonium-containing surfactants mainly possess antimicrobial activity against bacteria or fungi [23]. These activities of imidazole-based ionic liquids or surfactants are changing with the length of alkyl chains and with varying anions [24]. The antimicrobial activity of surfactants mainly depends upon the chain length of the cationic substituent. Therefore, the antimicrobial activity was found to be completely independent of the anion type [25]. Based on these observations, the present work has been taken with the measurement of the conductance and electrochemical behavior of capric surfactant (CS) and stearic surfactant (SS) in an aqueous solvent. The antimicrobial activity of the prepared imidazolium cationic monomeric surfactants was investigated against bacterial and fungal strains.

## 2. Materials and methods

### 2.1. Chemicals

Stearic acid, capric acid 1-methylimidazole, and 2-bromoethanol were purchased from LobaChemie Pvt. Ltd. Sulphuric acid, chloroform, methanol, ethanol, diethyl ether as well as cold acetone were purchased from CDH Fine Chemicals. Silica gel for TLC and sodium sulfate were purchased from Scientific fishers. All the chemicals were used without any further purification.

### 2.2. Synthesis of capric and stearic imidazolium surfactants

The capric and stearic acid were added to bromo ethanol with a few drops of  $H_2SO_4$  and stirred for 2–3 h at 60 °C. The reaction progress was checked by thin layer chromatography (TLC) coated with silica gel layered glass plates. The intermediate esters were instantaneously reacted with 1-methyl imidazole in a 1:1 molar ratio for 30 min at 60 °C and the product was crystallized with diethyl ether and chilled acetone to obtain the product [28].

### 2.3. Conductivity

The calculated number of synthesized surfactants was taken in a standard flask and the solutions were made up by adding the required amount of distilled water. By this method, numerous solutions having different concentrations were prepared to investigate conductance behavior. The conductance measurements of both surfactants in water at four distinct temperatures were carried out with the HANNAH12300 Microprocessor conductivity meter.

### 2.4. Electrochemical measurements

The electrochemical detection was usually performed with FRA-2  $\mu$ AUTOLAB TYPE III by using a standard three-electrode system: capric surfactant and stearic surfactant modified screen printed carbon electrode (SPCE) as a working electrode; Ag/AgCl as reference electrode as well as counter electrode was also made up of carbon. All the electrochemical measurements by using cyclic voltammetry were performed in 1 mM  $K_3FeCN_6$  solution.

### 2.5. Antimicrobial activity

The two synthesized imidazolium cationic monomeric surfactants (capric and stearic surfactants) were estimated for their antimicrobial performances by serial dilution method based on nominal inhibitory concentration (MIC) against three bacterial (*Bacillus cereus*, *Escherichia coli*, and *Yersinia enterocolitica*) and one fungal (*Candida albicans*) strains. For this method, twelve test tubes were carried out and only nine were marked as 1–9, and the other three were used as TM (medium), TMC (medium + compound), and TMI (medium + inoculum). All the test tubes were filled with 2 mL of nutrient broth medium by closing with cotton and then purified in an autoclave for 15 lbs/sq. inch pressure. After cooling, 2 mL of the surfactant solution was added to the first test tube via continuous mixing after that 2 mL of this solution was added to the second test tube or from the second to the third. This procedure of serial dilution was sustained up to the ninth test tube after that add 10  $\mu$ L of properly diluted inoculum. To the control test tube TMC, 2 mL of the surfactant sample was added, and 2 mL of this was abandoned for examining the transparency of the medium in the existence of surfactant solution. The growth of the organism in the medium was observed by adding 10  $\mu$ L inoculum. Consequently, all the test tubes were incubated at 37 °C for 18 h followed via resultant concentrations ranging from 1.9–500  $\mu$ g/mL. The antibiotics (ampicillin for bacteria as well as miconazole for fungus) were generally used as controls (positive). The shortest concentration of these surfactants to inhibit the growth of fungus and bacteria was generally specified as MIC and expressed as  $\mu$ g/mL [26–27].

### 3. Results and discussion

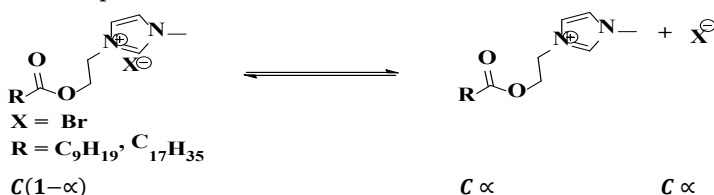
#### 3.1. Preparation and characterization of capric surfactant(CS) and stearic surfactant(SS)

The two monomeric imidazolium cationic surfactants such as 3-(2-(decanoyloxy)ethyl)-1-methyl-1H-imidazol-3-ium-bromide (Capric surfactant) and 3-(2-(octadecanoyloxy)ethyl)-1-methyl-1H-imidazol-3-ium-bromide (Stearic surfactant) have been synthesized from fatty acids as shown in the scheme. Both prepared surfactants have been characterized via FTIR, <sup>1</sup>H-NMR as well as TGA [28].

#### 3.2. Conductivity measurements

The conductometric parameters of capric surfactants (CS) as well as stearic surfactants (SS) were calculated at different temperatures such as 24 °C (298K), 29 °C (303K), 34 °C (308K) as well as 39 °C (313K). The values of specific conductance (μS) of CS in the water rise linearly with increasing concentration and temperatures (Table 1). The graph of specific conductance v/s surfactant concentration of SS has revealed an intersection of dual lines at certain concentrations relates to critical micellar concentration (CMC) which demonstrates that the hydrophobic species starts the formation of ionic micelles (Figure 1).

The variation of molar conductivity with concentration for both surfactants was not found linear signifying that these surfactants act as a weak electrolyte in H<sub>2</sub>O and so the dissociation constant may be described in terms of Ostwald's manner [29]. The graphs of molar conductance v/s CS (Figure 2) and SS (Figure 3) concentrations are shown in curved lines. If C demonstrates the concentration and α is the degree of dissociation of synthesized surfactant. Concentrations of the various species could be assumed as:



Dissociation constant:  $K_D$ ,

$$K_D = \frac{C \alpha^2}{1-\alpha} \quad (1)$$

The α has been calculated efficiently by the conductance percentage,  $\mu/\mu_0$  where μ is the molar conductance at a fixed concentration and μ<sub>0</sub> is the limiting molar conductance at unfixed dilutions. Substituting, α with  $\mu/\mu_0$  and after reshuffling equation (1), expressed as:

$$C\mu = K_D\mu_0^2 \cdot \frac{1}{\mu} - K_D\mu_0 \quad (2)$$

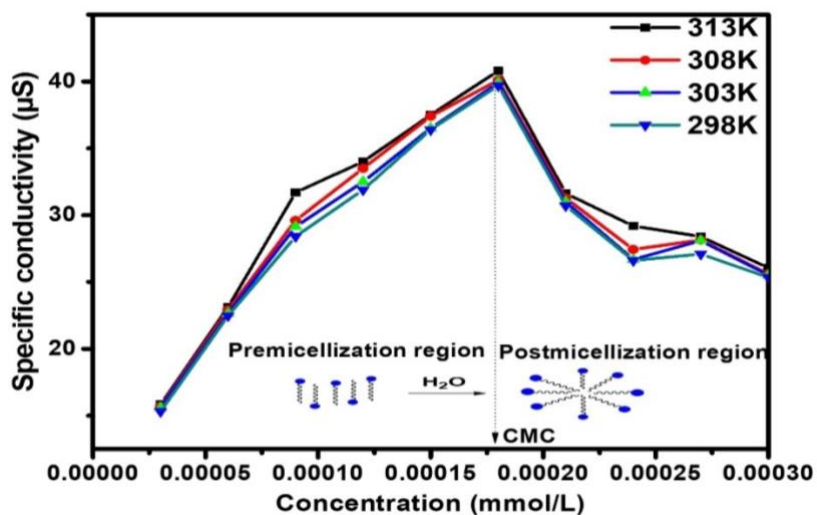
The values of the μ<sub>0</sub> of CS as well as SS, and  $K_D$  have been attained from the plot of slope and intercept between  $C\mu$  vs.  $1/\mu$  for dilute solutions (Table 2).



Scheme. Synthesis of CS and SS imidazolium surfactants.

**Table 1.** Specific conductivity vs molar conductance.

Concentration (mmol/L)	Capric surfactant							
	298K		303K		308K		313K	
	Specific conductance (μS)	Molar conductance (μScm <sup>2</sup> /mol)	Specific conductance (μS)	Molar conductance (μScm <sup>2</sup> /mol)	Specific conductance (μS)	Molar conductance (μScm <sup>2</sup> /mol)	Specific conductance (μS)	Molar conductance (μScm <sup>2</sup> /mol)
0.00003	10.00	333333.3	10.53	351000.0	10.54	351333.3	10.71	357000.0
0.00006	15.34	255666.6	15.93	265500.0	15.96	266000.2	15.98	266333.3
0.00009	20.08	223111.1	20.48	227555.5	20.56	248444.4	20.86	231777.7
0.00012	24.44	203666.6	25.37	211416.6	25.62	213500.0	25.88	215666.6
0.00015	29.53	196866.6	31.61	210733.3	31.70	211333.3	31.92	212800.0
0.00018	32.71	181722.2	33.56	186444.4	34.72	192888.8	35.82	199000.0
0.00021	40.01	190532.8	40.81	194333.3	41.41	197190.4	41.7	198571.4
0.00024	43.31	180458.3	44.43	185125.0	44.52	185500.0	44.61	185875.0
0.00027	45.90	170000.0	46.00	170370.3	46.61	172629.6	48.62	180074.7
0.00030	46.01	153366.6	46.22	154066.6	46.61	155366.6	50.31	167700.0
<b>Stearic surfactant</b>								
0.00003	14.32	510666.7	14.58	486000.0	15.69	523000.0	15.83	527666.6
0.00006	22.48	374666.7	22.65	377500.0	22.90	381666.7	23.11	385166.7
0.00009	28.41	315666.7	29.15	323888.9	29.60	328888.9	31.70	352222.2
0.00012	31.90	265833.3	32.50	270833.3	33.50	279166.7	34.00	283333.3
0.00015	36.40	242666.7	36.50	243333.3	37.40	249333.3	37.50	250000.0
0.00018	39.70	220555.6	39.90	221666.7	40.10	222777.8	40.80	226666.7
0.00021	30.72	146285.7	31.00	147619	31.28	148952.4	31.63	150619.0
0.00024	26.61	110875	26.68	111166.7	27.43	114291.7	29.19	121625.0
0.00027	27.09	100333.3	28.1	104074.1	28.14	104222.2	28.40	105185.2
0.00030	25.34	84466.6	25.51	85033.3	25.61	85366.6	26.05	86833.3

**Figure 1.** Specific conductivity v/s concentration of stearic surfactant.

The heat of dissociation ( $\Delta H_D^\circ$ ) of CS and SS stated as:

$$\log K_D = \frac{-\Delta H_D^\circ}{2.303RT+C} \quad (3)$$

The values of  $\Delta H_D^\circ$  for both surfactants were calculated from the slope of the graphs of  $\log K_D$  v/s  $1/T$  (Figure 4). The dissociation process is exothermic because  $\Delta H_D^\circ$  showed negative values (Table 2). The exothermicity of CS and SS increases with an increase in the hydrocarbon chain. The change in free energy of dissociation ( $\Delta G_D^\circ$ ) and standard entropy change ( $T\Delta S_D^\circ$ ) per mole for the monomeric surfactant molecules have been calculated by the following equations.

$$\Delta G_D^\circ = -RT \log K_D \quad (4)$$

$$T\Delta S_D^\circ = \Delta H_D^\circ - \Delta G_D^\circ \quad (5)$$

The values of the  $\Delta G_D^\circ$  were mainly found to be positive and increasing with an increase in temperature as well as hydrocarbon chain (Table 2). The  $T\Delta S_D^\circ$  per mole (Table 2) for CS and SS molecules were negative in behavior such as  $T\Delta S_D^\circ < 0$ . Moreover,  $T\Delta S_D^\circ$  for dissociation decreases with increasing alkyl chain length and temperature.

In the micellization aggregation process, counter ions principally form micelles after the standard free energy change of micellization ( $\Delta G_M^\circ$ ) for the phase separation model is expressed as:

$$\Delta G_M^\circ = 2RT \log X_{CMC} \quad (6)$$

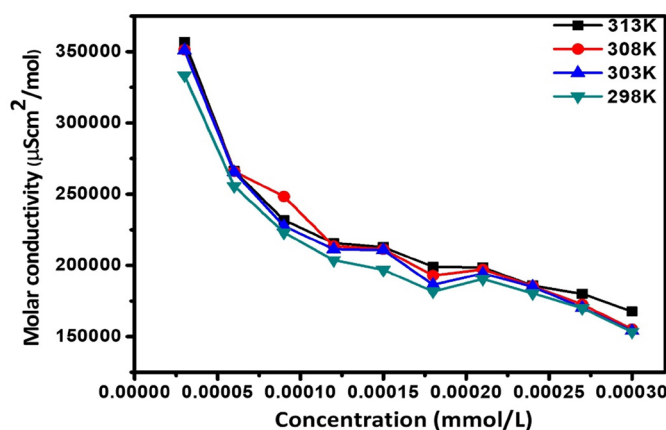


Figure 2. Molar conductivity for capric surfactant.

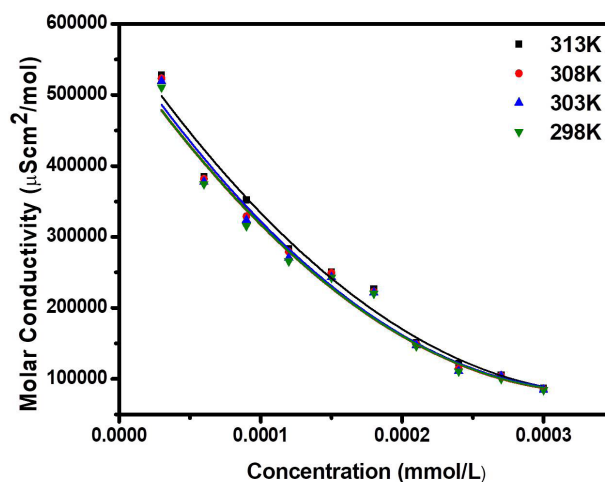
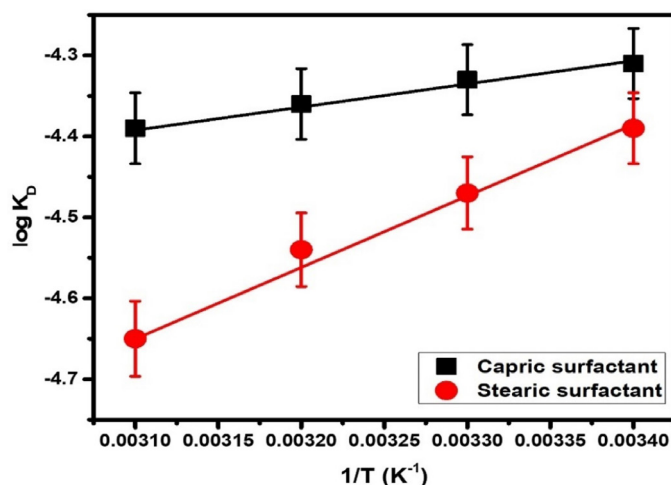


Figure 3. Molar conductivity for stearic surfactant.

**Table 2.** Thermodynamic parameters of capric as well as stearic surfactant and the heat of dissociation ( $\Delta H_D^\circ$ ) calculated from the slope of the plots of  $\log K_D$  v/s  $1/T$  and standard enthalpy change of micellization ( $\Delta H_M^\circ$ ) found from slope of the plots of  $\ln X_{CMC}$  v/s  $1/T$ .

Physical parameters	CS				SS			
	298K	303K	308K	313K	298K	303K	308K	313K
$\mu_o \times 10^3$ ( $\mu\text{Scm}^2/\text{mol}$ )	450	475	482	500	650	670	690	700
CMC $\times 10^{-4}$ (mol/L)	2.346	2.531	2.897	3.265	1.752	1.795	1.818	1.865
$K_D \times 10^{-5}$	4.90	4.70	4.40	4.10	4.10	3.40	2.90	2.30
$\Delta G_D^\circ$ (kJ/mol)	24.59	25.11	25.69	26.29	25.03	25.92	26.76	27.79
$-\Delta G_m^\circ$ (kJ/mol)	64.23	64.92	65.31	65.74	64.23	64.92	64.99	65.74
$-T\Delta S_D^\circ$ (kJ/mol)	31.61	32.13	32.71	33.31	45.45	46.34	47.18	48.21
$-T\Delta S_M^\circ$ (kJ/mol)	41.37	42.06	42.45	42.88	38.37	39.06	39.13	39.88
$-\Delta H_D^\circ$ (kJ/mol)	7.02				20.42			
$\Delta H_M^\circ$ (kJ/mol)	22.86				25.86			



**Figure 4.**  $\log K_D$  v/s  $1/T$  of capric as well as stearic surfactant.

Where  $X_{CMC}$  is the CMC of mole fraction,

$$X_{CMC} = \frac{n_s}{n_s + n_o} \approx \frac{n_s}{n_o}$$

where  $n_s$  is the moles of surfactant and  $n_o$  is number of solution as well as pure solvent. Values of CMC for CS and SS at diverse temperatures are mentioned in Table 2. It is observed that values of CMC were increasing with a rise in temperature and decreased with an increase in the hydrocarbon chain. The micellization process hypothetically occurred when the energy was released. Therefore, the aggregation of the hydrocarbon chain of the surfactant molecules were sufficient to balance the decrease in entropy. The kinetic energy and CMC value of the prepared surfactant were very high at greater temperature. The standard enthalpy changes of micellization ( $\Delta H_M^\circ$ ) for the phase separation model as shown below:

$$\partial \log X_{CMC} = \frac{-\Delta H_M^\circ}{2RT^2} \quad (7)$$

The  $\Delta H_M^\circ$  is attained from the slope of the plots of  $\ln X_{CMC}$  v/s  $1/T$  (Figure 5). The values of  $\Delta H_M^\circ$  of CS and SS are mentioned in (Table 2).

The positive values of  $\Delta H_M^\circ > 0$  specify that the micellization of CS and SS in  $H_2O$  are endothermic. The endothermicity increases with a rise in the chain length of synthesized surfactants. The results specified that the values of  $T\Delta S_D^\circ$  per mole

of surfactant monomers were usually calculated to be positive i.e.  $T\Delta S_M^\circ > 0$  (Table 2). The  $T\Delta S_M^\circ$  increases with an increase in temperature and decreases with hydrocarbon chain length. The  $\Delta G_M^\circ$  (Table 2) for CS and SS, is negative ( $\Delta G_M^\circ < 0$ ) which increases with a rise in temperature. All results were found to be comparable with other literature [30–31].

### 3. 3. Micelle solutions models of the electrode

The spherical micelles were formed when the concentration of surfactant is above the critical micellar concentration (CMC). The development of micelles produced the interface within the aquaphobic area holding the surfactant ends in the aqueous standard Figure 6 (A). Surfactant solutions show electrostatic repulsion through  $\text{OH}^-$  by using the negative charges of the cationic micellar surface. Moreover, the  $\text{H}^+$  ion and the negative charges of cationic micelles appeal to each other. Therefore, micellar anions adsorbed nearby the working screen-printed carbon electrode (SPCE) and create some space for  $\text{OH}^-$ . Consequently, only the  $\text{OH}^-$  ions can be oxidated, which may lead to an increase in the anodic peak current value of the prepared surfactant. Based on the cyclic voltammograms (CV), we mentioned the plausible mechanism for the behavior of surfactant micelle solutions nearby the SPCE electrode as shown in Figure 6 (B).

### 3. 4. Electrochemical behaviors of bare/SPCE, CS/SPCE and SS/SPCE

The electrochemical activities of bare, capric surfactant (CS), and stearic surfactant (SS) modified SPCE in 1mM potassium ferrocyanide ( $\text{K}_3\text{FeCN}_6$ ) at a  $50 \text{ mVs}^{-1}$  scan rate (Figure 7). The  $0.00018 \text{ mmol/L}$  concentration of CS and SS solutions was used for the electrode modification of screen-printed carbon electrode (SPCE). Consequently, a few drops of nafion (binder) were added to the solution followed by 1 h of sonication. The cyclic voltammograms were generally recorded by dropping  $60 \mu\text{L}$  of testing solution ( $\text{K}_3\text{FeCN}_6$ ) on the surface of the bare, CS, and SS modified electrode through a micropipette. The CV graphs were recorded in the potential range of  $-0.6$  to  $0.6 \text{ V}$ . The peak current of SPCE was increased when modified with CS (red), SS (blue) as compared to that of bare/SPCE (black). The peak potential for two modified electrode systems were such as anodic (Epa) =  $0.118\text{V}$  and cathodic (Epc) =  $0.039\text{V}$  peak potentials for SS/SPCE, while Epa =  $0.0115\text{V}$  as well as Epc =  $0.004\text{V}$  for CS/SPCE. Therefore, these redox peak potentials indicated that the SS/SPCE showed a high value of anodic peak current as compared to that of CS/SPCE and bare/SPCE due to the presence of higher chain length. The surface modified SPCE electrodes with surfactants increase with increasing carbon chain length [32]. Therefore, both prepared surfactants exhibited good electrochemical performances with higher conductivity.

### 3.6. Antimicrobial activity

Nowadays, cationic surfactants are known to act as effective biocides properties and antibacterial agents [33]. The antimicrobial activities of molecules can be evaluated by different methods [34]. In this study, the effects of the imidazolium cationic surfactants (capric and stearic surfactants) on the selected microbial strains were investigated. The MIC values of these surfactants against *B. cereus*, *E. coli*, *Y. enterocolitica*, *C. albicans* are reported in Table 3. The results demonstrated that the prepared imidazolium cationic surfactants showed antimicrobial activities against the tested microbial strains. Interestingly, significant antibacterial activity was observed for capric surfactant, with a MIC value of  $>31.5 \mu\text{g/mL}$  against the Gram-negative bacterium, *E. coli*. However, the MIC value of both synthesized surfactants against *B. cereus*, *Y. enterocolitica*, and *C. albicans* as well as stearic surfactant against *E. coli* was  $>62.5 \mu\text{g/mL}$  (Table 3).

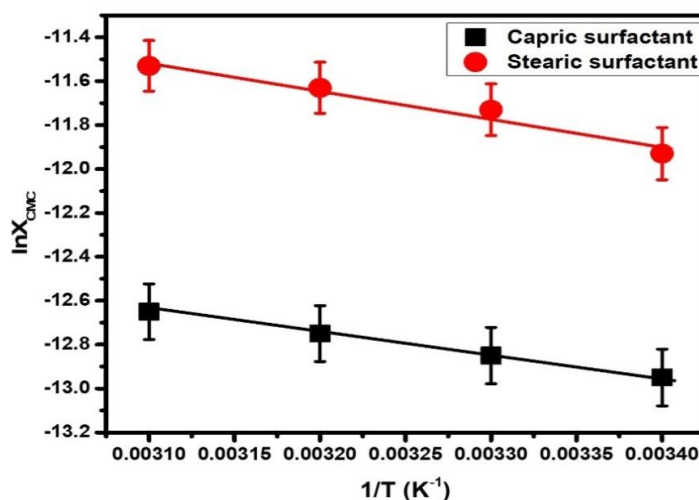
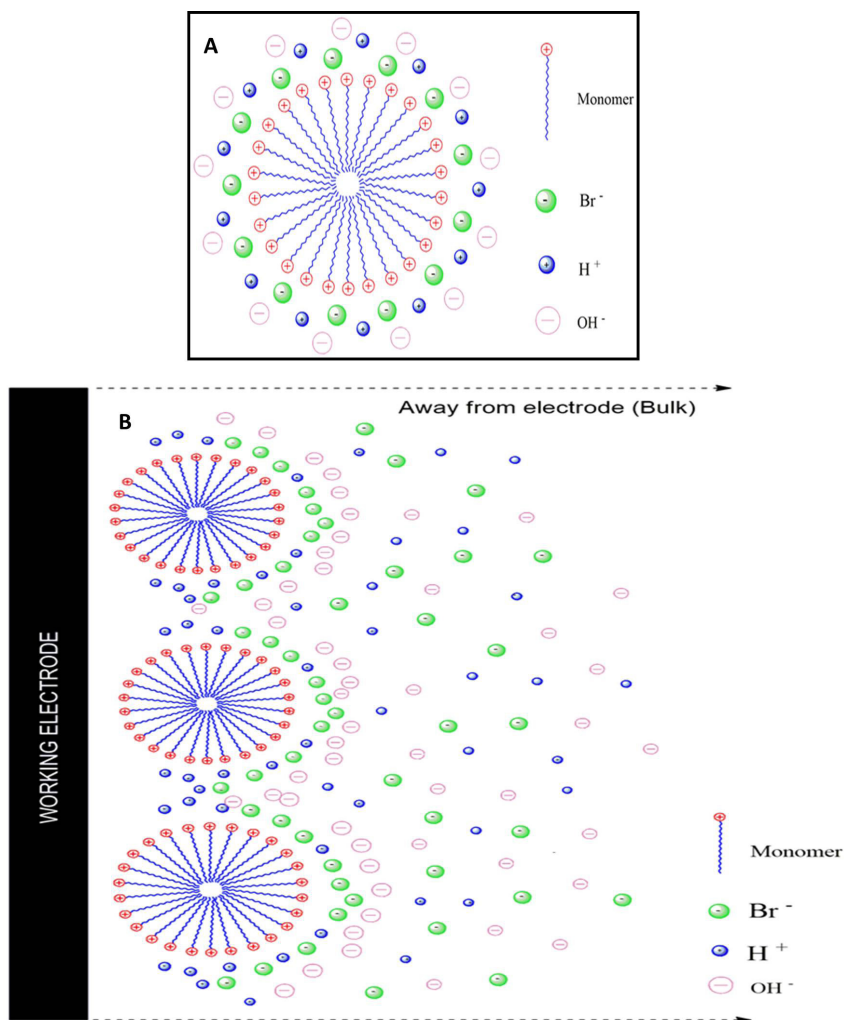
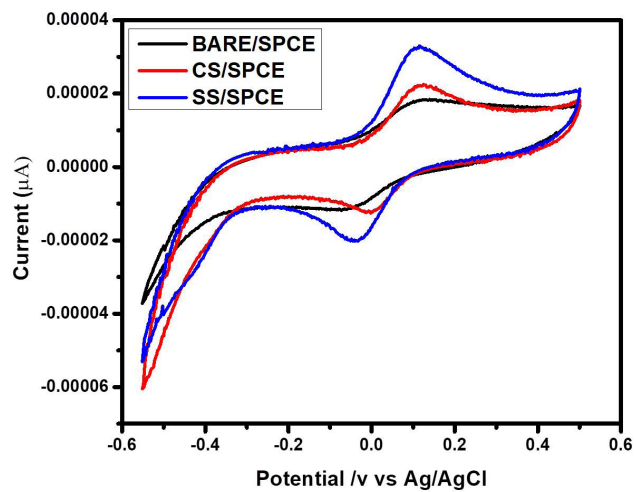


Figure 5.  $\ln X_{\text{CMC}}$  v/s  $1/T$  of capric and stearic surfactant.



**Figure 6.** (A) Spherical micelle models, (B) Plausible mechanism for micelle solutions at the working electrode.



**Figure 7.** Cyclic voltammograms of 1 mM K<sub>3</sub>Fe(CN)<sub>6</sub> at bare/SPCE and CS and SS modified SPCE at a scan rate of 50 mV s<sup>-1</sup>.



**Table 3.** MIC values of CS and SS against microbial strains.

Compounds	MIC ( $\mu\text{g/mL}$ )			
	<i>Bacillus cereus</i>	<i>Escherichia coli</i>	<i>Yersinia enterocolitica</i>	<i>Candida albicans</i>
Capric Surfactant	>62.5	>31.5	>62.5	>62.5
Stearic Surfactant	>62.5	>62.5	>62.5	>62.5
Ampicillin	39	78.1	39	-
Miconazole	-	-	-	78.1

The fatty acids from which these surfactants were synthesized have been known for their antimicrobial activities which were dependent on their alkyl chains [35]. The antimicrobial activity results against *E. coli* also showed that the biological activities of the synthesized surfactants depend on the alkyl chain length. The antibacterial activity of the two surfactants increased by decreasing the alkyl chain length. This may be observed that the large decrease in the lipophilicity of the molecules showed the existence of a hydrophobic chain, which helped to take less time for crossing the cell membrane and hence activity increases. Moreover, the antimicrobial activity is depending on the cationic moiety of the cationic surfactants as well. The microbial cell wall has a net negative charge due to the presence of teichoic acid attached to either peptidoglycan or to the underlying plasma membrane, or the outer covering of the cell wall contains phospholipids and lipopolysaccharides which provide a negative charge to the outer surface. The cationic moieties of the surfactants are attracted by the negative charge of the microbial cell wall; this causes strong adsorption of the surfactants due to ionic interactions with phospholipids of the microbial cell wall. Ultimately, the protective barrier (cell wall) loses its role and active ingredients are easily able to enter the cytoplasmic membrane which is responsible for the antimicrobial activities of these cationic surfactants [36–37]. In contrast, CS and SS showed comparable reasonable activity against *B. cereus* (Gram-positive bacterium), *Y. enterocolitica* (Gram-negative bacterium), and *C. albicans* (fungus).

#### 4. Conclusion

It may be concluded, that the micellization process of CS and SS is reliable with  $\Delta H_M^\circ > 0$ ,  $\Delta G_M^\circ < 0$ , and  $T\Delta S_M^\circ > 0$ , whereas the dissociation process of these molecules' agreements with  $\Delta H_D^\circ < 0$ ,  $\Delta G_D^\circ > 0$ , and  $T\Delta S_D^\circ < 0$ . The critical explanations of thermodynamic results specify that the micellization process is spontaneous and favored over the dissociation process. The results showed that the thermodynamics of dissociation and micellization can be explained suitably by using the phase separation model. The CS/SPCE and SS/SPCE displayed tremendous electrochemical performance as compared to that of bare/SPCE and showed superior stability, excellent conductivity, and good sensitivity. Additionally, both imidazolium cationic surfactants gave good antimicrobial activity. However, capric surfactant showed strong antibacterial activity than stearic surfactant towards Gram-negative *E. coli* bacterium.

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