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ORIGINAL ARTICLE

Surface Parameters and Biological Activity of *N*-(3-(Dimethyl Benzyl Ammonio) Propyl) Alkanamide Chloride Cationic Surfactants

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Abstract Three cationic surfactants containing amide groups were prepared by quaternization of dimethylaminopropylamine with benzyl chloride. FTIR and ^{1}H-NMR spectroscopy were used to confirm the chemical structure of the prepared cationic surfactants. The surface parameters were estimated using surface tension measurements at three different temperatures. The prepared cationic surfactant showed a lower CMC than conventional cationic surfactants. Thermodynamic parameters of adsorption and micellization depend mainly of alkyl chain length and temperature. The adsorption process is more favorable than micellization. The biological activity of the three surfactants was estimated using inhibition zone showing that amidoamine cationic surfactants have good activity and the surfactants C12Bn is the most effective one.

Keywords Cationic amidoamine surfactants · Surface parameters · Adsorption · Micellization · Biological activity

Introduction

Surfactant research attracts the attention of scientists around the world due to the vital role surfactants play in different industries. In the field of petroleum production, surfactants are used as corrosion inhibitors, demulsifiers, biocides, and as pour point depressants to name a few [1–6]. In addition, surfactants have widespread importance in personal care and cosmetics, pharmaceutical formulation, agrochemicals and in the food industry [7–9]. The wide application of surfactants is due to their amphipathic structure (containing two parts, hydrophobic and hydrophilic in contact with each other). Surfactants have the ability to adsorb on surfaces and aggregate to form micelles. The critical micelle concentration (CMC) is characteristic for each surfactant under certain conditions.

Surfactants are classified according to the charge on the hydrophilic head group. The four main classes are anionic, cationic, non-ionic and amphoteric. The target of the work is to prepare a new series of cationic surfactants containing amide groups (amide cationic surfactant) using readily available commercial materials. The Surface parameters (CMC, A_{min}, Pc_{20} and Γ_{max}) and thermodynamic parameters of adsorption and micellization of the prepared amidocationic surfactants were determined and compared with other conventional cationic surfactants of similar structure. The factor affecting the surface and thermodynamic parameters including temperature and hydrophobic chain length were also examined. Antimicrobial activities of the prepared cationic surfactants against bacteria (gram positive and gram negative), yeast and fungi were determined. The minimum inhibitory concentration (MIC) was determined for the most effective surfactants.

Experimental Section

Materials

All the chemicals used were analytical grade. The dimethylaminopropylamine (DMAPA), dodecanoic,

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tetradecanoic and hexadecanoic acid were purchased from Sigma-Aldrich Co. The benzyl chloride was purchased from Algomhoria Chemical Company. The reaction solvents are high purity and obtained from Fluka Chemical Co.

Apparatus

The structures of the prepared cationic surfactants were confirmed using Fourier transform infrared (FTIR) spectroscopy (Bench top 961, ATI Mattsonm Infinity series^{TM}, controlled by Win First^{TM} V2.01 software and proton nuclear magnetic resonance (H NMR) spectroscopy in DMSO-d_6 (GEMINI 200 (^{1}H 500 MHz), National research center. The surface and thermodynamic parameters were calculated from surface tension measurements using Tensiometer-K6 processor (Krüss Company, Germany).

Synthesis

Synthesis of N-(3-(Dimethylamino) propyl) Alkanamide Derivatives

1,3-dimethylamino-1-propyl amine (DMAPA) (0.1 mol) was dissolved in 150 ml xylene, then 0.1 mol of fatty acid (dodecanoic, tetradecanoic and hexadecanoic acid) was added. Finally, 0.01 % p-toluene sulphonic acid was added as catalyst. The reaction mixture was heated to 137 °C for about 24 h until complete removal of reaction water (0.1 mol, 1.8 ml) using a Dean–Stark apparatus. The solvent was evaporated under vacuum rotary evaporator. Petroleum ether was used to remove the catalyst [10]. The reaction yield was 92 %.

Synthesis of N-(3-(Dimethyl benzyl ammonio) propyl) Alkanamide Chloride Derivatives

The prepared *N*-(3-(dimethylamino) propyl) alkanamide (0.1 mol) from the previous step was refluxed with benzyl chloride (0.1 mol) in 150 ml ethanol at 78 °C from 25 to 30 h depending on the alkyl chain length of the amide (shorter chain length requires less time). The solvent was evaporated under vacuum and the residue subject to recrystallization using diethyl ether. The reaction yield was 97–98 % for the three synthesized products. The obtained amido-cationic surfactants were named C12Bn, C14Bn and C16Bn and the general procedure for the synthesis is depicted in Scheme 1.

Surface Tension Measurements

The surface and thermodynamic parameters of surfactants under studding were calculated using surface tension data. The surface tension was measured at three different temperatures 25, 40 and 60 °C for the aqueous solution of surfactants at concentration from 1×10^{-2} to 1×10^{-8} M. After each experiment, the ring and cup were cleaned with distilled water and acetone. The obtained final data was the average of three time measurements within 2 min between each reading [11].

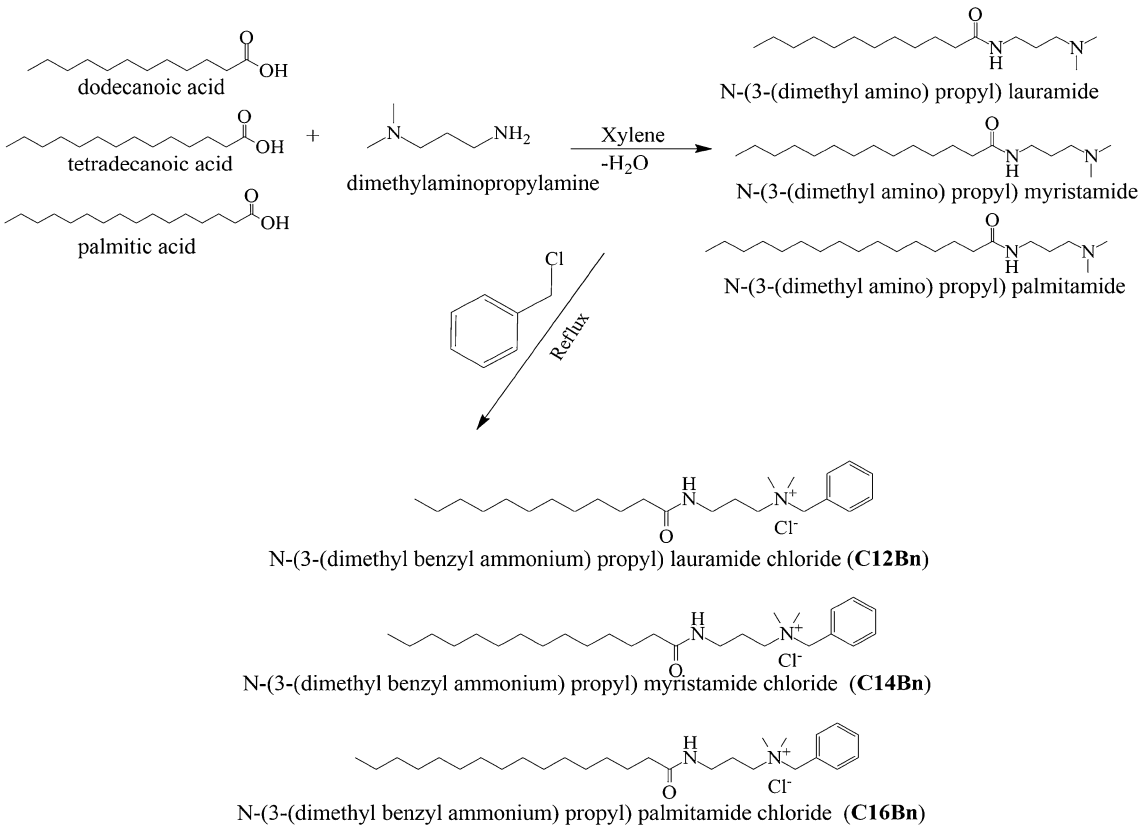
Antimicrobial Activity by a Modified Agar Well Diffusion Method

The antibiotic activity of the prepared cationic surfactants was estimated by a modified agar well diffusion method [12]. In this method, the tested microbial strains were poured with the prepared medium in the plates (nutrient agar for the bacterial strains, and Wickerham agar for the yeast and Czapek–Dox agar for the fungal strains). In each agar plate, a sterile 10-mm cork borer was used to cut three equidistant wells and 0.1 ml of the prepared cationic surfactants (concentration, 5000 ppm) was introduced into each of the wells. The agar plates were incubated overnight at 37 °C for the tested bacterial strains, 48 h at 30 °C for the yeast and the fungus strains. The antimicrobial activity was estimated by measuring the inhibition zone diameter (mm). Triplicates were maintained and the inhibition experiment was repeated thrice. For each replicates, the measurements were taken in three different fixed directions. The average values were recorded with corresponding standard deviation. Furthermore, sterile water was used as a negative control and a standard antibiotic; Tetracycline (30 mcg) as antibacterial, nalidixic acid (30 mcg) as anti-yeast and Fluconazole (100 ppm) as antifungal were used as a positive control. Minimum inhibitory concentration (MIC) of the selected surfactant was determined using a broth micro-dilution assay [13].

Results and Discussion

Confirmation Chemical Structure

A new series of cationic surfactants were characterized using FTIR and ^{1}H-NMR spectroscopy. FTIR analysis confirmed the structure of the synthesized amido-cationic surfactants, which passed through two steps. The first step is amide formation, which was confirmed by disappearance of both carbonyl and hydroxyl groups of carboxylic acid at 1710 cm^{-1} and at 2500–3000 cm^{-1} respectively. A new band for the amide group appears at 1650 cm^{-1}. The second step was quaternization of the prepared amide with benzyl chloride, which was confirmed by the appearance of a new band for aromatic double bond as indicated in



Scheme 1 General procedures for synthesis of desired cationic surfactants

Table 1 The characteristic IR peaks of prepared cationic surfactants

Function group	Wave no cm^{-1}		
	C12Bn	C14Bn	C16Bn
$CH_{aliphatic}$ symmetric stretch	2854.24	2853.62	2851.08
$CH_{aliphatic}$ asymmetric stretch	2921	2923	2920
CH_3 bending	1373.79	1375.58	1376.2
CH_2 asymmetric bending	1459.73	1461.84	1466.5
(CH_2)n rock	729.48	729.32	728.13
C–N	1075.23	1050.34	1055.39
C–O	1299.85	1253.79	1252.22
C=C	1543.22	1544.9	1546.53
C=O	1650.41	1650.64	1650.66
–NH	3274.68	3271.62	3275.09

Table 1. For example, (C12Bn) showed bands at 2854 and 2925 cm^{-1} for aliphatic –C–H symmetric and asymmetric stretching vibration respectively as an evidence of the presence of the fatty alkyl group. Bands at 3274, 1650 and 1543 cm^{-1} correspond to –NH, amide carbonyl and aromatic double bond of the benzene ring as depicted in Fig. 1.

The chemical structure of synthesized amidoamine cationic surfactants was confirmed also using ^{1}H-NMR spectra, which confirm the distribution and number of protons. The prepared cationic surfactant (C12Bn) has the following ^{1}H-NMR signals as shown in Fig. 2 at: $\delta = 0.77$ (t,3H, $-\mathbf{CH_3}$) terminal methyl group; $\delta = 1.15$ (m,16H, $-(\mathbf{CH_2})_8CH_3$) repeated methylene group; $\delta = 1.38$ (m,2H, $-\underline{\mathbf{CH_2}}(CH_2)_8CH_3$); $\delta = 1.93$ (m,2H, $N-CH_2\underline{\mathbf{CH_2}}CH_2N$); $\delta = 2.03$ (t,2H, $-\mathbf{CH_2}C(O)NH$); $\delta = 2.99$ (s,6H, $-CH_2-N^{\oplus}\underline{(\mathbf{CH_3})_2}\ CH_2-$); $\delta = 3.31$ (t,2H, $HN-CH_2CH_2\underline{\mathbf{CH_2}}N^{\oplus}$); $\delta = 3.67$ (t,2H, $HN-\underline{\mathbf{CH_2}}CH_2CH_2N^{\oplus}$); $\delta = 4.64$ (s,2H, $-(CH_3)_2N^{\ominus}\underline{\mathbf{CH_2}}$–Ph); $\delta = 7.23$–7.58 (m,5H, $N^{\oplus}CH_2$–**Ph**) aromatic protons; $\delta = 8.37$ (s,1H, $\underline{\mathbf{H}}N-CH_2CH_2CH_2N^{\oplus}$) amide proton.

Surface Activity

The surface tension plots of the synthesized surfactant aqueous solution against the log of concentration are shown in Figs. 3, 4 and 5. As it can be seen, the surface tension decreases with increasing concentration of surfactant in the aqueous medium until an inflection point is

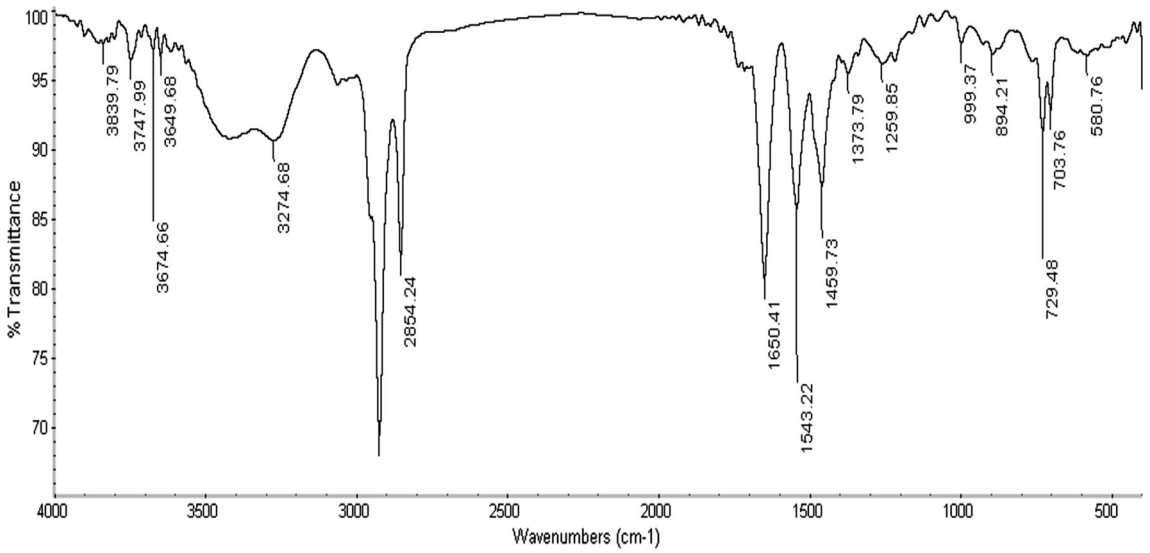


Fig. 1 IR spectrum of *N*-benzyl-*N*,*N*-dimethyl-3-lauramidopropan-1-aminium chloride (C12Bn)

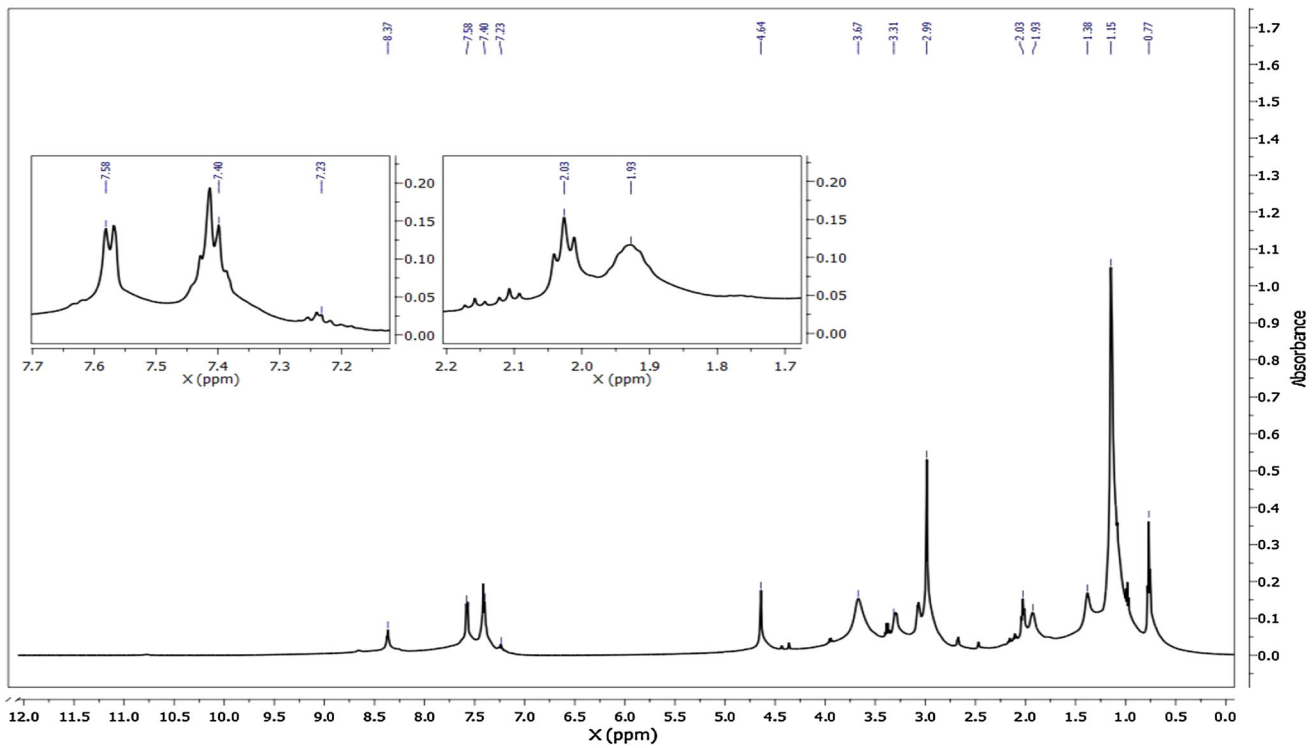


Fig. 2 ^{1}H-NMR spectrum of *N*-benzyl-*N*,*N*-dimethyl-3-lauramidopropan-1-aminium chloride (C12Bn)

reached which correspond to the critical micelle concentration. Table 2 shows that the CMC at different temperatures decreases with increasing alkyl chain length [14–16]. Because of increasing hydrophobic alkyl chain length, surfactant solubility in the aqueous medium decrease hence, destroying the structure of water increases the free energy of the system. According to the increase in the free energy of the system, the surfactants monomers aggregate into clusters in a way to decreasing the repulsion between the hydrophobic tail and aqueous medium, whereby the alkyl chain is directed towards the interior of the micelle while the polar head is in contact with water (alternative mechanism for adsorption at surface). As can be seen in Table 2, the CMC of C12Bn, C14Bn and C16Bn at 25 °C

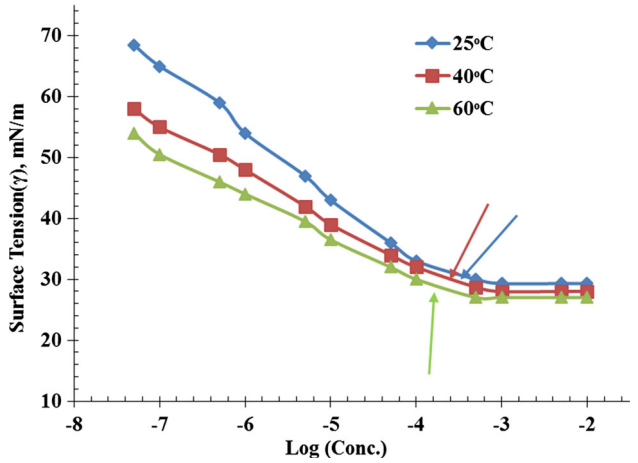


Fig. 3 The surface tension against Log concentration of synthesized surfactant (C12Bn) at different temperatures, the *arrows* point to the CMC

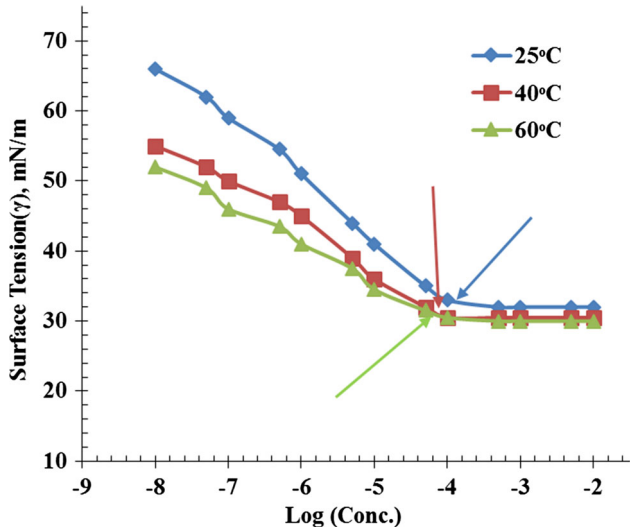


Fig. 4 The surface tension against Log concentration of synthesized surfactant (C14Bn) at different temperatures the *arrows* point to the CMC

were as follows: 0.256, 0.108 and 0.045 mM/L respectively. Raising the solution temperature was accompanied by a decreasing in both surface tension values and critical micelle concentration. The temperature has two opposing effects on the interaction between water molecules and the surfactants. Raising the temperature decreases the water hydration around the hydrophilic head groups favoring micellization. Raising the solution temperature also destroys the structured water surrounding the hydrophobic tail, an effect opposed to micelle formation. The magnitude of the two contrary effects is responsible for the trend in micelle formation with increasing the temperature [16–18].

As can be seen from Table 2 and Fig. 6, the CMC decreases with increasing temperature. The CMC values of

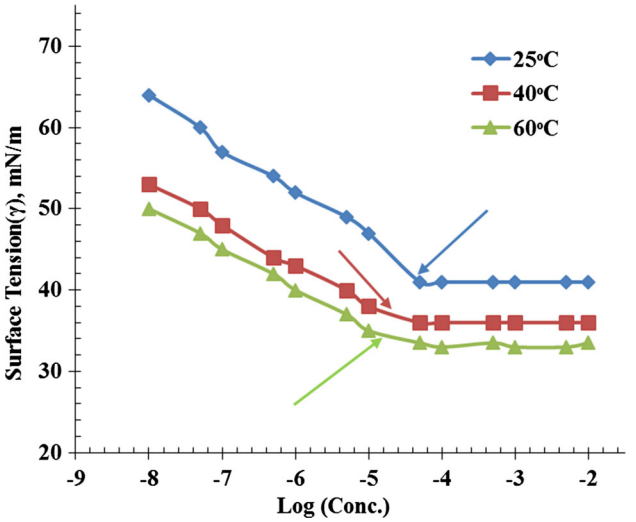


Fig. 5 The surface tension against Log concentration of synthesized surfactant (C16Bn) at different temperatures the *arrows* point to the CMC

the C12Bn surfactant were 0.256, 0.204 and 0.11 mM/L at 25, 40 and 60 °C respectively.

The CMC values of the newly synthesized cationic surfactant appear to be lower than other cationic surfactants based on dimethyl amino propyl amine (DMAPA) with the same carbon chain length and temperature [10, 19–21]. The CMC of the three prepared surfactants based on DMAPA is also lower than those of traditional cationic surfactants like alkylpyridinium bromides, alkyl trimethyl ammonium bromides, and alkyltripropylammonium bromides as shown in Table 2 [22–26].

As it can be seen from Table 2, the values of surface tension at the CMC (γ_{CMC}) increase with increasing hydrophobic chain length. The values of γ_{CMC} were 29.2, 32.3 and 41.5 mN/m at 25 °C for C12Bn, C14Bn and C16Bn. The trend of increasing surface tension at the CMC with increasing alkyl chain length can be explained based on the calculated CMC/C_{20} ratio presented in Table 2. It is well known that the ability of certain surfactants to reduce the surface tension, especially at CMC depends on the CMC/C_{20} ratio, the greater ratio of CMC/C_{20}, the greater the tendency for surfactants to reduce surface tension values [27]. The synthesized surfactant with twelve-carbon chain length has the maximum ability to reduce the surface tension at 25 °C, with higher CMC/C_{20} ratio, while surfactant with 16-carbon atom has the minimum ability to reduce the surface tension with lower CMC/C_{20} at the same temperature.

The surface pressure at the critical micelle concentration is defined as effectiveness and calculated using the following equation:

$$\pi_{CMC} = \gamma_o - \gamma_{CMC} \quad (1)$$

Table 2 The surface properties of synthesized amidoamine cationic surfactant at different temperatures

Comp.	Temp. °C	CMC (mM L^{-1})	γ_{CMC} (mN m^{-1})	π_{CMC} (mN m^{-1})	CMC/C_{20}	PC_{20} (mol L^{-1})	$\Gamma_{max} \times 10^{11}$ (mol cm^{-2})	A_{min} nm^2
C12Bn	25	0.256 ± 0.014	29.23 ± 0.17	43.27 ± 0.17	185.2 ± 4.90	5.86 ± 0.034	9.51 ± 0.14	1.75 ± 0.026
	40	0.204 ± 0.011	29.03 ± 0.16	40.47 ± 0.16	311.1 ± 8.24	6.18 ± 0.034	6.62 ± 0.12	2.51 ± 0.046
	60	0.110 ± 0.006	27.10 ± 0.20	38.90 ± 0.2	217.8 ± 11.54	6.30 ± 0.046	5.57 ± 0.07	2.98 ± 0.038
C14Bn	25	0.108 ± 0.010	32.31 ± 0.17	40.19 ± 0.17	159.8 ± 4.47	6.17 ± 0.051	7.56 ± 0.11	2.20 ± 0.033
	40	0.058 ± 0.007	31.33 ± 0.11	38.17 ± 0.11	389.1 ± 12.16	6.83 ± 0.038	5.21 ± 0.06	3.19 ± 0.037
	60	0.046 ± 0.006	30.65 ± 0.11	35.35 ± 0.11	464.2 ± 0.87	7.00 ± 0.051	4.46 ± 0.07	3.72 ± 0.059
C16Bn	25	0.045 ± 0.005	41.54 ± 0.19	30.96 ± 0.19	62.6 ± 1.84	6.14 ± 0.038	4.9 ± 0.06	3.39 ± 0.040
	40	0.014 ± 0.002	36.33 ± 0.16	33.17 ± 0.16	179.5 ± 5.36	7.10 ± 0.039	4.14 ± 0.05	4.01 ± 0.046
	60	0.010 ± 0.001	33.75 ± 0.13	32.25 ± 0.13	169.8 ± 4.55	7.22 ± 0.033	3.83 ± 0.06	4.33 ± 0.065
DTAB	25	14.6[a]						
	40	16.6[a]						
	60	18.3[a]						
TTAB	25	3.72[a]						
	40	4.19[a]						
	60	4.9[a]						
CTAB	25	0.96[a]						
	40	1.08[a]						
	60	1.33[a]						

[a] From Ref. [26]

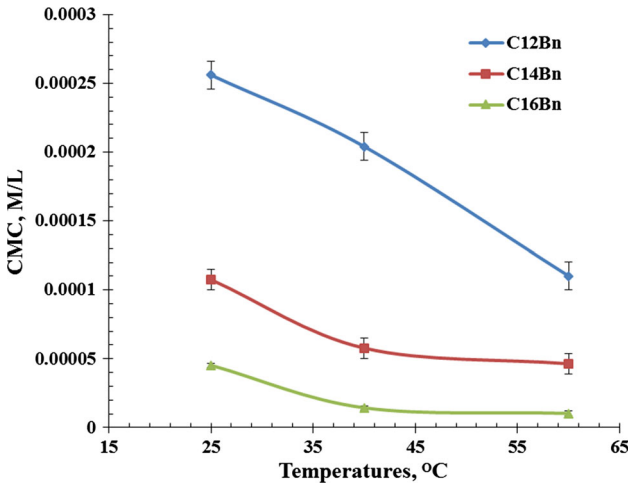


Fig. 6 Effect of temperatures and hydrophobic chain length on critical micelle concentration values of prepared cationic surfactants

The effectiveness is the difference between the surface tension of pure water (γ_o) and the surface tension of surfactant solution (γ_{CMC}) at the critical micelle concentration. The surface pressure measures the effect of surfactant to reduce the surface tension of the system. From Table 2, the surfactant C12Bn is the most effective, giving the largest reduction in the surface tension at CMC [28].

The efficiency of the surfactant adsorption at the water/air interface was measured by the negative logarithm of the concentration of surfactant required to reduce the surface tension of pure water by 20 mN/m. The calculated values of efficiencies for the three prepared cationic surfactant are listed in Table 2. The efficiency increases (shift to lower concentration) with increasing alkyl chain length. Increasing the hydrophobicity promotes migration of the methylene group to the surface to avoid the interaction with the polar medium, hence surface tension decrease [29–31].

The surfactants maximum surface excess at the air/solution depends on the temperature and the hydrophobicity. The Gibb's adsorption isotherm equation can be used to calculate the maximum surface excess [32–34]:

$$\Gamma_{max} = -(1/2.303nRT)(\delta\gamma/\delta \log c)_T \quad (2)$$

where $d\gamma/d\log C$ is the change in surface tension with concentration below the CMC, R is the universal gas constant (8.314 J $mol^{-1}K^{-1}$), T is the temperature in Kelvin and n is the Gibbs prefactor (i.e., the number of dissociated ions; for univalent ionic surfactant $n = 2$).

Increasing the hydrophobic alkyl chain length and increasing the temperature have an opposite effect on the Γ_{max} values as shown in Table 2. Increasing alkyl chain length makes the surfactant monomer less soluble so they concentrate at the air–water interface. Rising the solution temperature decreases the repulsive forces between non-polar alkyl chains and the aqueous medium, and consequently the population of surfactant monomers at the air/water interface decreases.

Minimum surface area (A_{min}) is the average area occupied by each surfactant molecule at the air–water interface. A_{min} values depend on the angular position of surfactant molecules at the interface. [35]. A_{min} values have been calculated based on the Gibb's adsorption equation:

$$A_{min} = 10^{16}/\Gamma_{Max}N \quad (3)$$

where N is Avogadro's number. A_{min} values increase with increasing alkyl chain length and temperature because of decreasing Γ_{Max} values as indicated in Table 2. By decreasing Γ_{Max}, the distances between surfactant monomers at the interface increases [36, 37]. Increasing the temperature decreases the repulsion force between the fatty alkyl chain and the aqueous medium, which allows the molecules to orientate horizontally at the interface, hence, A_{min} increases.

The micellization and thermodynamic parameters of the prepared amido-amine cationic surfactants were calculated using Gibb's equations [32, 38]:

$$\Delta G^{o}_{mic} = RT\,ln\,(CMC) \quad (4)$$

$$\Delta G^{o}_{ads} = \Delta G^{o}_{mic} - 6.023 * 10^{-2} * \pi_{CMC} * A_{min} \quad (5)$$

$$\Delta S_{mic} = -d\left(\Delta G^{0}_{mic}/\Delta T\right) \quad (6)$$

$$\Delta S_{ads} = -d\left(\Delta G^{o}_{ads}/\Delta T\right) \quad (7)$$

$$\Delta H_{mic} = \Delta G^{o}_{mic} + T\,\Delta S_{mic} \quad (8)$$

$$\Delta H_{ads} = \Delta G^{o}_{ads} + T\,\Delta S_{ads} \quad (9)$$

As can been seen from Table 3, temperature and the hydrophobic alkyl chain length of the synthesized cationic surfactant are the major factors responsible for adsorption and micellization processes of surfactant. The free energy of adsorption and micellization are both negative indicating that the two processes are spontaneous. By increasing the alkyl chain length and raising the solution temperature, the change in free energy of adsorption and micellization increase in the negative direction, which gives an indication about the affinity of the synthesized surfactants toward adsorption and micellization respectively [39]. By increasing the alkyl chain length of the surfactant, the hydrophobicity increases and solubility decreases which forces the surfactants molecules to migrate to the surface or aggregate in clusters to avoid contacting the hydrophobic chain with polar aqueous medium, thus free energy of the system decreases.

We also can observe that ΔS_{mic} values are positive and increase with increasing hydrophobic chain length which indicates increasing randomness upon conversion from the monomer state to the micelle state [21, 40]. By inspection data in Table 3, it has been found that with the same alkyl chain of synthesized surfactant and at the same temperature, the change in the free energy of adsorption is the more negative compared to micellization. The surface molecules tend to adsorb at the interface until maximum surface saturation then the molecule migrate to the bulk forming micelles. The ΔS_{ads} values in Table 3 are slightly positive compared to ΔS_{mic} values, which reflects increased freedom of movement of fatty alkyl chains at the interface [28].

By comparing the tendency of the newly synthesized cationic surfactants to form micelles or to adsorb at the air/water interface with previously reported cationic surfactants [20, 21] we found that the presence of the carbonyl group attached to the hydrophobic tail increases the tendency of the synthesized cationic surfactants to adsorb at the interface or to form micelles in the bulk.

Biological Activity

The prepared cationic surfactants (C12Bn, C14Bn and C16Bn) were tested for their antimicrobial activities against Gram-positive bacteria, Gram-negative bacteria and against fungi. The six test organisms (standard strains) represent all groups of common microflora in Egypt (two strains for Gram positive, two for gram negative, one for yeast and one for fungi) and also contain some pathogenic microorganisms like *E. coli* and *Staphylococcus aureus*. The antimicrobial activity was found to be dependent on the length of the aliphatic chains of the tested compounds, this behavior known by cut-off effect [41, 42]. The cut-off behavior depend on some parameters like, the change in the free energy of adsorption of prepared amidoamine cationic surfactant on the bacteria cell membrane, critical micelle concentration of the used surfactant, the hydrophobic character and the size of the diffused surfactant. The magnitude of all these parameters determines the cut-off point. As discussed previously, increasing the chain length of the surfactant decreases the critical micelle concentration, hence the surfactant concentration at the cell membrane will be lower. Consequently, the activity of surfactant with shorter chain length will be higher (C12Bn > C14Bn > C16Bn). On the other hand, by increasing the hydrophobic character of the surfactant, the adsorption rate at the membrane interface should be higher as discussed earlier. Other theories attribute the cut-off effect to a perturbation of the membrane, assuming that the longer the fatty alkyl chain, the better they mimic molecules in the layer lipid, leading to disruption in the membrane. The data in Table 4 reveal that the prepared amidoamine cationic surfactant with shorter chain length (12-carbon atom) has the maximum effect on Gram positive and Gram-negative bacteria and on fungi [43, 44].

The target of cationic surfactants is the cytoplasmic membrane, which is composed of a phospholipid bilayer where proteins are anchored. The outer surface of the Gram-positive bacterial cell wall carries negative charge

Table 3 Micellization and adsorption thermodynamic parameters of the prepared amidoamine cationic surfactants

Comp	Temp. °C	ΔG^{o}_{mic} KJ mol^{-1}	ΔH_{mic} KJ mol^{-1}	ΔS_{mic} KJ mol^{-1}K^{-1}	ΔG^{o}_{ads} KJ mol^{-1}	ΔH_{ads} KJ mol^{-1}	ΔS_{ads} KJ mol^{-1}K^{-1}
C12Bn	25	−20.49 ± 0.12	–	–	−25.05 ± 0.218	–	–
	40	−22.12 ± 0.09	11.75 ± 0.83	0.11 ± 0.0024	−28.23 ± 0.276	38.29 ± 0.937	0.21 ± 0.004
	60	−25.24 ± 0.09	26.72 ± 0.36	0.16 ± 0.0011	−32.22 ± 0.272	34.29 ± 0.340	0.20 ± 0.000
C14Bn	25	−22.65 ± 0.22	–	–	−27.96 ± 0.325	–	–
	40	−25.40 ± 0.31	32.15 ± 1.54	0.18 ± 0.0059	−32.73 ± 0.417	66.76 ± 1.508	0.32 ± 0.006
	60	−27.63 ± 0.32	9.51 ± 0.29	0.11 ± 0.0006	−35.55 ± 0.481	11.49 ± 0.582	0.14 ± 0.003
C16Bn	25	−24.79 ± 0.29	–	–	−31.11 ± 0.403	–	–
	40	−29.02 ± 0.31	59.28 ± 0.09	0.28 ± 0.0013	−37.03 ± 0.441	86.72 ± 0.337	0.40 ± 0.002
	60	−31.79 ± 0.29	14.48 ± 0.71	0.14 ± 0.0013	−40.21 ± 0.446	12.75 ± 0.357	0.16 ± 0.000

Table 4 Antibiotic effect of synthesized amidoamine surfactants against pathogenic bacteria and fungi

Compound ID	*B. subtilis*	*S. aureus*	*E. coli*	*P. aeruginosa*	*C. albicans*	*A. niger*
C12Bn	26	25	21	20	23	24
C14Bn	19	20	16	17	17	17
C16Bn	18	18	16	15	16	15
Reference	30	32	34	42	25	27

The uncertainty of the measurement equal to 0.816

The Standard error equal to 0.471

due to the presence of Mg^{2+} and Ca^{2+} divalent cations. Cationic antimicrobial surfactants interact with the cell surface and migrate into the cytoplasmic membrane of the cell. Such interaction disorganize growth, which is sufficient to cause fluidity loss of the membrane causing cell death [45, 46].

The gram-negative bacteria are more resistant to antibiotics than that of gram-positive bacteria, fungi and yeast. The presence of outer membrane of the Gram-negative bacterial cell wall contains lipopolysaccharide molecules acting as a barrier to the penetration of antibacterial substances making the Gram-negative bacteria more resistant to antibiotics [47–51]. It appears from the data shown in Table 4, that the antibiotic effect of our prepared cationic surfactants is higher on gram-positive bacteria, fungi and yeast than Gram-negative bacteria. The minimum inhibitory concentration (MIC) of the most potent prepared surfactant showed highest antimicrobial activity was determined *in vitro* using a broth micro-dilution assay and listed in Table 5. The MIC values showed 100 % inhibition of microbial growth.

Table 5 Minimum inhibitory concentrations (MIC) of the prepared cationic surfactant (C12Bn)

Microorganism	MIC range (μg/mL)
B. subtilis	75–150 ± 2
S. aureus	37–75 ± 1
E. coli	625–1250 ± 3
P. aeruginosa	625–1250 ± 3
C. albicans	313–625 ± 2
A. niger	313–625 ± 2

The Standard error equal to 1.5 μg/mL

Conclusion

A new series of cationic surfactants was prepared and their chemical structures were confirmed using Fourier transform infrared spectroscopy and proton nuclear magnetic resonance. The determined surface parameters from the surface tension are hydrophobic and temperature dependent. The critical micelle concentration of the synthesized amido-cationic surfactants decrease by increasing the hydrophobic chain length and the solution temperature. By increasing the length of the hydrophobic chain and temperature, the adsorption at air/water interface and micellization in solution bulk increase. The adsorption process is more favorable than micellization by increasing the hydrophobicity and solution temperature. The synthesized cationic surfactant showed a good antibiotic effect against bacteria and fungi and the synthesized C12Bn surfactant had the maximum activity.

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