



Synthesis of cationic (CTAB-EDTA-CTAB/ CTAB-Glu-CTAB) and anionic (SDS-EDTA-SDS/ SDS-Glu-SDS) Gemini surfactants: Surface and anticorrosive properties

Kuldeep Kumar*, Priyanka Sharma & Saurabh Sharma

Department of Chemistry, Career Point University, Hamirpur, Himachal Pradesh 176 041, India

*E-mail: kuldeep.sharma.753@gmail.com, kuldeep.che@cpuh.edu.in

Received 17 October 2020, revised and accepted 15 December 2020

Gemini surfactants that served as environmentally friendly corrosion inhibitors, have been successfully synthesized by the reaction of SDS/ CTAB with glucose/ EDTA as spacer. Their molecular structure is confirmed by ¹H-NMR and FTIR spectroscopy. By tensiometric method, the surface activity of the synthesized Gemini surfactants has been determined in terms of various parameters like the critical micelle concentration, surface excess at the air/water interface, minimum area per surfactant molecule, surface pressure at CMC, changes of standard free energies of adsorption, micellization and transfer. The obtained Gemini surfactants having EDTA as a spacer, exhibit a considerably higher effectiveness against corrosion as compare to Gemini surfactants having glucose as spacer.

Keywords: Anticorrosive property, Gemini surfactant, Spacer, Micellization, Thermodynamics

Gemini surfactants consist of two hydrophobic chains and two hydrophilic head groups covalently linked through a spacer, the latter of which has great importance in controlling the surface properties¹⁻⁴. The effect of spacer is related to its involvement and position in the micelle, however, many moment in this relationship remain unclear⁵. Gemini surfactants possess unique properties distinct from those of conventional surfactants: lower critical micelle concentration (CMC), stronger wetting/foaming properties, environmentally benign corrosion inhibitors and so on⁶⁻⁹. The CMC values of Gemini surfactants decrease with the length of their hydrophobic chains¹⁰. However, this observation is contradictory to the observed CMC trends of some of Gemini surfactants¹¹⁻¹³.

Carbon steel, due to its typical mechanical properties and low cost^{14,15}, is being used extensively in pipelines for the transmission of water, petroleum products and chemicals as well as for vessels in oil and gas production systems¹⁶. Therefore, corrosion problem of such type of material is one of the main concerns in industry, which reduces plant productivity, causes plant contamination by the produced products and ultimately leads to plant shutdowns^{17,18}. The use of corrosion inhibitors (like chromates, nitrites, molybdates, and organic

inhibitors) for metal protection against corrosion is the most practical method owing to its advantages of economy, high efficiency, and wide applicability in various fields¹⁹⁻²². In this context, researchers are paying more attention to Gemini surfactants as corrosion inhibitors in acidic medium due to their more efficient surface properties^{23,24}. Generally, Gemini surfactants perform inhibition action through adsorption on the corroding metal surface leading to change in the electrochemical behaviour of the metal¹¹. Thus, the power of the inhibition depends on the molecular structure of the inhibitor (Gemini surfactant). Consequently, the type of space group and presence of the lone pairs on the heteroatoms in Gemini surfactants are important features that control the adsorption on the metal surface²⁵.

In peculiarity to conventional surfactants, Gemini surfactants encompass a relatively innovative class of surfactants that has unlimited scope in terms of flexibility, economic effectiveness, and industrial applications^{9,26-28}. Pal et al.,²⁹ synthesized a series of (N,N'-bis(dimethyltetradecyl)- α,ω -alkanediammonium bromide)-based cationic Gemini surfactants with varying spacer lengths and investigated their equilibrium and dynamic interfacial properties. It was shown that the different factors influencing adsorption behaviour are interrelated, and both temperature and

spacer chain influenced CMC to a considerable degree. Asadov *et al.*,³⁰ have synthesized number of counterion coupled Gemini (cocogem) surfactants by interaction of dodecyl diisopropylol amine with dicarboxylic (oxalic, succinic, adipic, sebacic, maleic, fumaric, isophthalic) acids. It was shown that an elongation of the spacer-group length in these surfactants lowers the CMC, surface excess at the air/water interface (Γ_{\max}), surface pressure at the CMC, (Π_{CMC}) values and raises minimum area per surfactant molecule (A_{\min}) values. Abd El-Salam²⁸ has reported anionic Gemini surfactants from sodium salts of monoalkyl sulfosuccinate esters of ethylene glycol with variably long tails (C_{12} , C_{16} , C_{18}) and dichloroethane. The micellization processes of the individual and mixed surfactants (anionic Gemini and non-ionic ethoxylated alkylphenol) were investigated and it was deduced that the CMC of mixed surfactants shifted to lower values compared to those of the pure surfactants. In another study, Asefi *et al.*,³¹ have investigated the corrosion inhibition effect of composite inhibitor containing cationic Gemini surfactant, {1,3-butan-bis-(dimethyl dodecyl ammonium bromide)} and halides (NaCl, NaBr and NaI) on steel in HCl. This was reported as efficient and low-cost inhibitor for steel corrosion inhibition in HCl.

The present study is dedicated to synthesize the cationic and anionic Gemini surfactants by interaction of SDS/CTAB with glucose/ethylene diamine tetra-acetic acid (EDTA) (Fig. 1). The synthesized Gemini

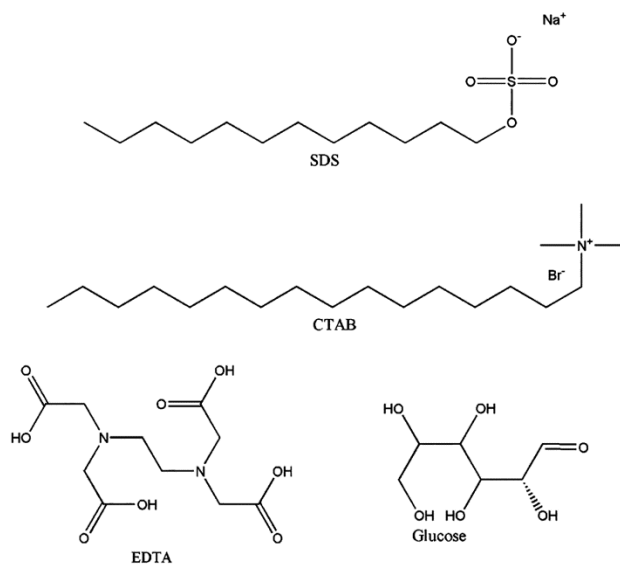


Fig. 1 — Chemical structures of sodium dodecyl sulphate (SDS), cetyltrimethylammonium bromide (CTAB), ethylene diamine tetra-acetic acid (EDTA), and glucose

surfactants (Fig. 2) have been characterized by using $^1\text{H-NMR}$ and FTIR spectroscopic techniques. The adsorption properties of these surfactants have also been deliberated by employing surface tension measurements. Further, the corrosion inhibition effect of as synthesized Gemini surfactants on tin in HCl has been measured and discussed.

Materials and Methods

Sample preparation

Deionized distilled water with conductivity $2\text{--}3\ \mu\text{S}\cdot\text{cm}^{-1}$ and pH ranges from 6.8 to 7.0 at 298.15 K has been used for all the experiments. Sodium dodecyl sulphate (SDS), cetyltrimethylammonium bromide (CTAB), glucose, bi-sodium salt of ethylene diamine tetra-acetic acid (EDTA), NaOH, HCl, and

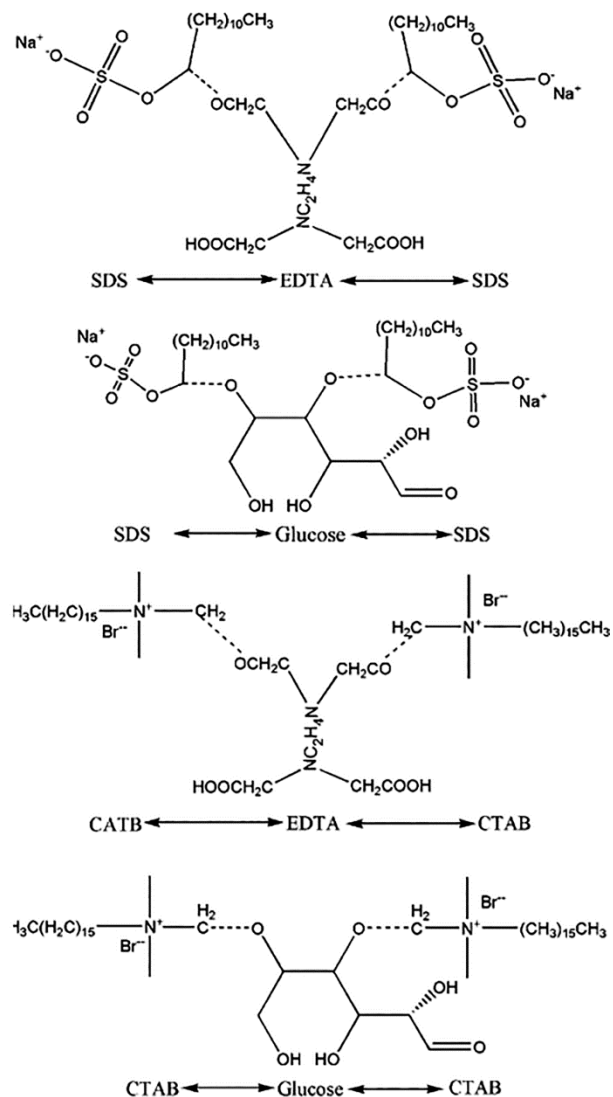


Fig. 2 — Chemical structures of synthesized Gemini surfactants of SDS and CTAB with spacers, EDTA and glucose

ethanol of high purity have been purchased from S.D. Fine-Chem. Pvt. Ltd. (India). A summary of provenance and purity of chemicals used have also been provided in Supplementary Data, Table S1.

Gemini surfactants of SDS and CTAB with two different spacers, EDTA and glucose have been synthesized by using the refluxing method as explained in the literature³². In this method, 50 mL ethanolic solution of bi-sodium salt of EDTA/Glu (1 mmol·kg⁻¹) was taken in a round bottom flask. Then 50 mL of ethanolic solution of SDS/CTAB (2.2 mmol·kg⁻¹) was added dropwise to above prepared solution under constant stirring condition. Freshly prepared 0.2 mol·kg⁻¹ NaOH solution was added dropwise to this reaction mixture. The resulting reaction mixture was refluxed at 323.15 K for about 8 h. At the end, the solution was acidified with dilute HCl solution to obtain the white crystals of Gemini surfactants. Before further use, the so obtained crystals were purified by the process of re-crystallization in ethanol.

Characterization of Gemini surfactants

Synthesized surfactants were characterized by FTIR and ¹H-NMR spectroscopy. FTIR spectra were obtained using a 600 FT-IR Agilent Technologies in the range 4,000–400 cm⁻¹ using KBr pellets. ¹H-NMR spectra were recorded on an instrument JEOL 500 MHz with CDCl₃ solvent.

Tensiometric measurements

Tensiometric measurements have been used to calculate CMC values and other thermodynamic parameters of synthesized Gemini surfactants. Stalagmometer was used to measure the surface tension of aqueous solutions of Gemini surfactants of SDS and CTAB at 298.15 K. The stalagmometer was periodically cleaned by treating with chromic acid and distilled water and finally washed with alcohol and dried in oven for 3–4 h. After drying, the stalagmometer was filled with a fixed volume of the experimental solution of Gemini surfactant. For each concentration of Gemini surfactant the number of drops fallen were calculated three times. The average deviation for three measurements of a single concentration of the solution did not exceed ±1 drop. In this way, the drops with consistent shape and size are allowed to fall under their own weight to ensure reproducible results^{33,34}.

Corrosion inhibition properties

The corrosion inhibition effect of Gemini surfactants on the metal tin in 2 mol·kg⁻¹ aqueous solution of HCl was studied by simple weight loss

method³². In this method, two stripes of metal tin of equal weights, with and without the layer of Gemini surfactants were suspended in 2 mol·kg⁻¹ aqueous solution of HCl for 20 h at 298.15 K. However, the coating/layer of Gemini surfactant on the surface of metal tin was imparted by dipping the metal strips into the saturated solution of Gemini surfactant and then drying it in air. After that, the layers of corrosion on two strips were removed and weights of stripes were measured and the weight loss was then determined²⁰.

Results and Discussion

Identification of synthesized Gemini surfactants

The obtained Gemini surfactants have been identified by FTIR and NMR and the spectra are given in Supplementary Data, Figs S1 & S2.

SDS-EDTA-SDS: IR (Fig. S1a), (ν, cm⁻¹): 3463 ν(OH), 2916 and 2849 ν(CH), 1597 ν_{as}(COO⁻), 1407 ν_s(COO⁻), 1468 δ(CH), 1216 ν(CO), 1080 ν(CN) and 721.3 δ(CH₂)_x. ¹H-NMR (Fig. S3a), δ (ppm): 0.90 triplet (CH₂-CH₃), 1.319 singlet ((CH₂)₁₀), 3.62 triplet (NCH₂CH₂N), 3.87 singlet (N-CH₂-CO), 4.03 triplet (2OCH(CH₂)(C=O)).

SDS-Glu-SDS: IR (Fig. S1b), (ν, cm⁻¹): 3392 ν(OH), 2916 and 2849 ν(CH), 1590 ν_{as}(CHO), 1407 ν_s(COO⁻), 1468 δ(CH), 1216 ν(CO), 1080 ν(CN) and 721.3 δ(CH₂)_x. ¹H-NMR (Fig. S3b), δ (ppm): 0.96 triplet (CH₂-CH₃), 1.337 singlet ((CH₂)₁₀), 1.933 singlet (OH), 3.95 doublet (CH-CH=O), 8.470 singlet (O-CH-O).

CTAB-EDTA-CTAB: IR (Fig. S2a), (ν, cm⁻¹): 3390 ν(OH), 2916 and 2849 ν(CH), 1637 ν(CHO), 1479 δ(CH), 1031 ν(CN), and 719 δ(CH₂)_x. ¹H-NMR (Fig. S4a), at δ (ppm): 0.88 triplet (CH₂-CH₃), 1.306 singlet ((CH₂)₁₅), 3.20 singlet (N-CH₂), 4.08 singlet (2(N-CH₂-CO)).

CTAB-Glu-CTAB: IR (Fig. S2b), (ν, cm⁻¹): 3364 ν(OH), 2916 and 2849 ν(CH), 1720 ν_{as}(COO⁻), 1637 ν(CHO), 1478 δ(CH), 1209 ν(CO), 1055 ν(CN), and 719 δ(CH₂)_x. ¹H-NMR (Fig. S4b), at δ (ppm): 0.88 triplet (CH₂-CH₃), 1.30 singlet ((CH₂)₁₅), 3.20 singlet (N-CH₂).

Peak around 2360 cm⁻¹, which is obtained in all the IR spectra, is related much with the background CO₂. However, in NMR, the sharp signal at δ 4.8 ppm (triplet) in every NMR spectrum of synthesized Gemini surfactants is due to HDO used as reference³⁵⁻³⁷.

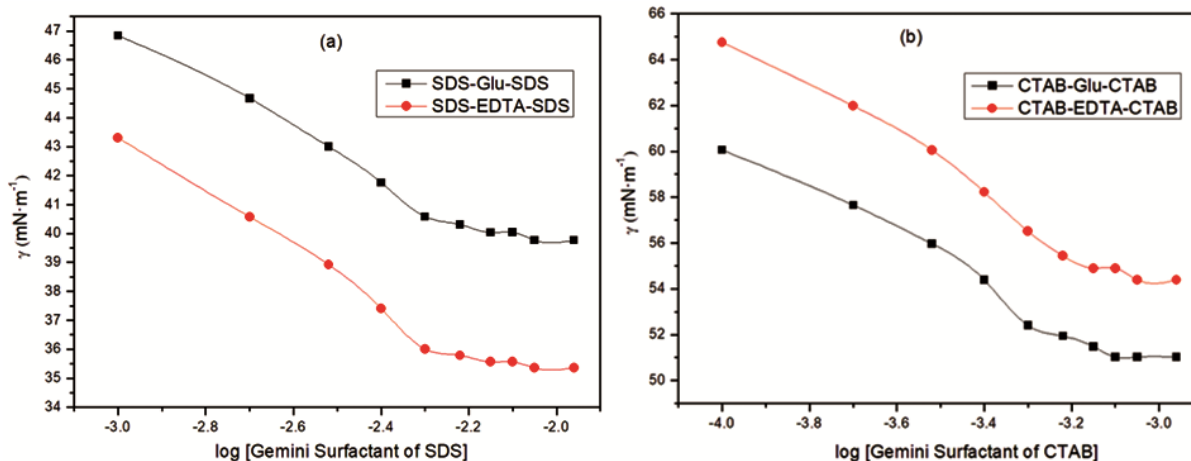


Fig. 3 — Plots of surface tension versus log of concentration of Gemini surfactants of (a) SDS and (b) CTAB

Table 1 — Surface tension (γ) values of Gemini surfactants in aqueous medium at 298.15 K

m (mmol·kg ⁻¹)	γ (mN·m ⁻¹)		m (mmol·kg ⁻¹)	γ (mN·m ⁻¹)	
	SDS-EDTA-SDS	SDS-Glu-SDS		CTAB-EDTA-CTAB	CTAB-Glu-CTAB
1	43.31	46.84	0.1	64.76	60.05
2	40.57	44.67	0.2	61.98	57.65
3	38.93	43.00	0.3	60.04	55.97
4	37.41	41.76	0.4	58.22	54.39
5	36.01	40.59	0.5	56.51	52.41
6	35.79	40.31	0.6	55.43	51.94
7	35.57	40.03	0.7	54.90	51.48
8	35.57	40.04	0.8	54.90	51.02
9	35.36	39.77	0.9	54.39	51.02
11	35.36	39.77	1.1	54.39	51.03

Standard uncertainties, u , are $u(T) = \pm 1$ K, $u(\gamma) = \pm 0.40$ and ± 0.30 mN·m⁻¹, and $u(m) = \pm 0.2$ and ± 0.03 mmol·kg⁻¹ in the case of Gemini surfactants of SDS and CTAB, respectively

Surface tension measurements

The experimentally calculated surface tension (γ) values for all the synthesized Gemini surfactants are tabulated in Table 1. Fig. 3 illustrates the plots for surface tension (γ) of Gemini surfactants of SDS and CTAB (1-11 and 0.1-1.1 mmol·kg⁻¹, respectively) in aqueous medium at 298.15 K. The shape of the graphs is in agreement with well established surface tension plots of Gemini surfactants in aqueous solution³⁸. The CMC values of surfactants were obtained by employing the same procedure as reported in literature^{39,40}. The CMC data have been presented in Table 2 with standard uncertainties. In addition to this, the CMC values of corresponding conventional surfactants⁴¹ have also been included in Table 2 for the sake of comparison. Table 3 shows that CMC values of Gemini surfactants become almost half of the values of respective conventional surfactants. It

Table 2 — CMC values of synthesized Gemini surfactants at 298.15 K

Gemini surfactant	CMC (mmol·kg ⁻¹)	CMC of corresponding conventional surfactant (mmol·kg ⁻¹)
SDS-EDTA-SDS	5.03	8.10 ^a
SDS-Glu-SDS	4.51	8.10 ^a
CTAB-EDTA-CTAB	0.52	0.91 ^a
CTAB-Glu-CTAB	0.48	0.91 ^a

Standard uncertainties, u , are $u(T) = \pm 1$ K and $u(\text{CMC}) = \pm 0.1$ and ± 0.02 mmol·kg⁻¹ in the case of Gemini surfactants of SDS and CTAB, respectively. ^aRef.⁴¹

may be due to facilitation of micellization as a result of the lowering of repulsion between polar head groups and increase in the hydrophobic nature of Gemini surfactants as well. However, the smaller CMC values with glucose as a spacer may be attributed to the more hydrophobic nature of glucose as compared to EDTA. The same conclusion has also

Table 3 — Surface excess at air/water interface (Γ_{\max}), minimum area per surfactant molecule (A_{\min}), standard Gibb's free energy of adsorption (ΔG_{ad}^o), standard free energy of micellization (ΔG_m^o), standard free energy of transfer (ΔG_{tr}^o) and surface pressure at *CMC* (Π_{CMC}) values for different Gemini surfactants at 298.15 K

Gemini surfactant	$\Gamma_{\max}, 10^{10} (\text{mol}\cdot\text{cm}^{-2})$	$A_{\min}, 10^2 (\text{nm}^2)$	$\Delta G_{ad}^o (\text{kJ}\cdot\text{mol}^{-1})$	$\Delta G_m^o (\text{kJ}\cdot\text{mol}^{-1})$	$\Delta G_{tr}^o (\text{kJ}\cdot\text{mol}^{-1})$	$\Pi_{CMC} (\text{mN}\cdot\text{m}^{-1})$
SDS-EDTA-SDS	0.85	195.33	-64.76	-23.23	-8.03	35.30
SDS-Glu-SDS	0.74	224.37	-70.94	-23.23	-7.69	35.33
CTAB-EDTA-CTAB	0.94	176.63	-46.63	-28.59	-11.86	16.67
CTAB-Glu-CTAB	0.81	204.98	-44.31	-28.94	-11.72	20.06

Standard uncertainties, u , are $u(T) = \pm 1 \text{ K}$, $u(\Gamma_{\max}) = 0.2 \times 10^{-10} \text{ mol}\cdot\text{cm}^{-2}$, $u(A_{\min}) = 0.3 \times 10^{-2} \text{ nm}^2$, $u(\Delta G_{ad}^o) = \pm 0.02 \text{ kJ}\cdot\text{mol}^{-1}$, $u(\Delta G_m^o) = \pm 0.3 \text{ kJ}\cdot\text{mol}^{-1}$, $u(\Delta G_{tr}^o) = 0.04 \text{ kJ}\cdot\text{mol}^{-1}$ and $u(\Pi_{CMC}) = 0.2 \text{ mN}\cdot\text{m}^{-1}$

been reported by Kumari et al.,⁴² on the hydrophobicity of various spacers towards the effect on the CMC values of ionic Gemini surfactants. Recently, Garcia et al.,⁷ have reported that the CMC of synthesized Gemini surfactants in water decreases with the flexibility and hydrophobicity of the spacer. Similarly the micellar properties of the Gemini surfactants in binary aqueous mixtures of various organic solvents have been studied by Deepti and Ghosh⁴³ and Sood et al.,⁴⁴. They found that the CMC values of Gemini surfactants are increasing with decreasing hydrophobic effect of the solvent mixtures.

The surface tension data have been further analysed in terms of interfacial parameters such as surface excess at the air/water interface, Γ_{\max} , minimum area per surfactant molecule, A_{\min} , surface pressure at the *CMC*, Π_{CMC} , standard free energy of adsorption, ΔG_{ad}^o , standard free energy of micellization, ΔG_m^o and standard free energy of transfer, ΔG_{tr}^o , to gain more clearer insight into the surface effectiveness of Gemini surfactants in aqueous medium.

The surface excess concentration at the interface, Γ_{\max} , which represents a measurement of the effectiveness of adsorption of the surfactant, is calculated using the Gibbs adsorption equation^{45,46}.

$$\Gamma_{\max} = -(1/2.303nRT)(\partial\gamma/\partial \log C)_{T,P} \quad \dots (1)$$

where, 'n' is the number of particles per molecule of the surfactant whose surface concentration varies with change in bulk concentration of the surfactant, and has been taken as '3' for the reason described earlier^{46,47}. The $(\partial\gamma/\partial \log C)_{T,P}$ is the slope of the

γ vs. $\log[\text{Gemini surfactant}]$ plots and has been determined by using a linear fit to the γ vs. $\log[\text{Gemini surfactant}]$ values in pre-micellar region⁴⁸.

The minimum area occupied by each surfactant molecule, A_{\min} at the air–water interface is another parameter derived from surface tension measurements which has been evaluated according to the following Eqn^{39,45,49}

$$A_{\min} = 10^{18}/\Gamma_{\max} N_A \quad \dots (2)$$

where, N_A is Avogadro's number. The Π_{CMC} known as surface pressure at *CMC*, is calculated as^{39,45}

$$\Pi_{CMC} = \gamma_o - \gamma_{CMC} \quad \dots (3)$$

where, γ_o and γ_{CMC} are the surface tension of the solvent and of the micellar solution at *CMC*, respectively. The standard free energy of adsorption, ΔG_{ad}^o has been calculated from the Eqn (4)^{30,39}.

$$\Delta G_{ad}^o = \Delta G_m^o - N_A A_{\min} \Pi_{CMC} \quad \dots (4)$$

where ΔG_m^o known as standard free energy of micellization of Gemini surfactants is determined using Eqn (5)⁵⁰.

$$\Delta G_m^o = RT \ln(X_{CMC}) \quad \dots (5)$$

The *CMC* and Γ_{\max} values have been further used to estimate the standard free energy of transfer, ΔG_{tr}^o of Gemini surfactants from the bulk to the micellar region using the Eqn (6)³⁹.

$$\Delta G_{tr}^o = -RT \ln[100 \Gamma_{\max} N_A^{1/3} / (CMC)^{2/3}] \dots (6)$$

The values obtained for all these interfacial parameters as well as standard thermodynamic parameters of micellization of Gemini surfactants in pure water have been summarized in Table 3. A perusal of the data in Table 3 divulges that in aqueous medium the values of Γ_{\max} for SDS-EDTA-SDS and CTAB-EDTA-CTAB at 298.15 K are found to be equal to 0.85 and 0.94 $\mu\text{mol}\cdot\text{m}^{-2}$, respectively, which are nearly equal to the values 0.76 and 0.92 $\mu\text{mol}\cdot\text{m}^{-2}$ as reported by Wettig *et al.*⁴⁶ and Tikariha *et al.*⁴⁷, respectively. Similar values of Γ_{\max} for SDS-EDTA-SDS and CTAB-EDTA-CTAB (2.53 and 1.10 $\mu\text{mol}\cdot\text{m}^{-2}$) have also been cited in literature at 303 and 300 K, respectively^{47,49}. However, it must be remarked that these values of Γ_{\max} for SDS-EDTA-SDS and CTAB-EDTA-CTAB are much smaller than those of conventional surfactants as shown by Kumar *et al.* for SDS ($\Gamma_{\max} = 1.83 \mu\text{mol}\cdot\text{m}^{-2}$ at 298.15 K)³⁹ and Szymczyk and Janczuk for CTAB ($\Gamma_{\max} = 3.10 \mu\text{mol}\cdot\text{m}^{-2}$ at 293.15 K)⁵¹, implying that the adsorption of Gemini surfactants at the air-water interface is less effective as compared to the conventional surfactants.

Larger A_{\min} values presented in Table 3 indicate that Gemini surfactant molecules arrange loosely at the air/water interface. This observation about A_{\min} is in accordance with the Γ_{\max} values. The surface pressure at CMC, Π_{CMC} , since measures the effectiveness of a surface active molecule⁴¹, the slight increase in Π_{CMC} values with type of spacer molecule suggest about the increased surface activity of Gemini surfactants of SDS and CTAB.

ΔG_{ad}^o is a hypothetical monolayer at its minimum surface area/molecule and zero surface pressure. As all ΔG_{ad}^o values reported in Table 3 are negative, it indicates that the adsorption of all the synthesized Gemini surfactants at the air-water interface takes place spontaneously and ΔG_{ad}^o becomes more negative with the type of spacers. In addition, it is apparent that ΔG_{ad}^o values are more negative than the corresponding ΔG_m^o values, indicating that the adsorption of the surfactant at the air-water interface

is more favourable than micellization, so that when the micelles are formed; some work must be done to transfer the surfactant monomer from the saturated interface to the micelle. Kumar *et al.*,³⁹ have also shown similar results for bile salts in aqueous solutions of amino acids.

The ΔG_{tr}^o values which indicate the transfer of the surfactant molecule from the bulk to the micellar region are observed to substantiate above contention because it can be seen that ΔG_{tr}^o are negative, but small in magnitude (Table 3) for both types of Gemini surfactants. All these molecular parameters explaining the micellar behaviour and surface properties of synthesized Gemini surfactants in aqueous medium are in qualitative agreement with those reported in literature as discussed above.

Corrosion inhibition studies

The corrosion inhibition behaviour of synthesized Gemini surfactants has been investigated by taking two metal strips of tin of equal weights in 2 mol·kg⁻¹ aqueous solution of HCl by employing simple weight loss method³² as discussed above in experimental section. From the data given in Table 4, it is evident that all the synthesized Gemini surfactants have good corrosion inhibition efficiency for metals. However, cationic/anionic Gemini surfactants with EDTA as spacer provide better corrosion inhibition results. The same conclusion has also been drawn by Sadek³² that Gemini surfactants with more methylene groups are good corrosion inhibitors. Moreover, Hamed *et al.*⁵² have reported the reverse effect of alkyl chain length on the corrosion inhibition property of the surfactant. They reported that the decrease in inhibiting properties of the Gemini surfactants with increasing size of the alkyl chain might be due to the effect of van der Waals' forces on attraction between the alkyl

Table 4 — Corrosion inhibition data of synthesized Gemini surfactants

Type of Gemini surfactant used	Weight of tin strip before applying Gemini surfactant (g)	Weight of tin strip after removing layer of corrosion (g)	Weight loss (g)
SDS-EDTA-SDS	1.15	1.11	0.04
SDS-Glu-SDS	1.15	1.09	0.06
CTAB-EDTA-CTAB	1.15	1.12	0.03
CTAB-Glu-CTAB	1.15	1.10	0.05
Without Gemini surfactant	1.15	1.02	0.13

Standard uncertainty, u, in measurements of weights is ± 0.01 g

chains of adjacently adsorbed positive head-group ions. Despite this, the corrosion rate in the petroleum pipelines, tanks, ships, etc. is being investigated as to be controlled with the help of environment friendly and cost effective Gemini surfactants. Hence, these surfactants are being used widely in petroleum and watercraft industries to avoid the heavy loss due to corrosion. The mechanism of corrosion inhibition action of synthesized cationic/anionic Gemini surfactants can be attributed to adsorption behaviour of these compounds on the metal surface. The adsorption of the Gemini surfactants on the metal surface occurs in three different ways depending on their concentration. At low, intermediate and very high concentration the adsorption takes place horizontally, perpendicular or vertically and plateau like, respectively⁵³.

Conclusions

In the present work, Gemini surfactants of SDS and CTAB with spacers EDTA and glucose have been synthesized by using a simple reflux method. These synthesised Gemini surfactants have been characterized by using FTIR and ¹H-NMR spectroscopy. Further, the surface tension measurements show that the CMC values of synthesized Gemini surfactants are reduced to approximately half of the values for corresponding conventional surfactants, SDS and CTAB. Moreover, the CMC values for Gemini surfactants with glucose as spacer are smaller than that of EDTA as a spacer. This may be attributed to more the hydrophobic nature of glucose. The Γ_{\max} values reveal that the adsorption of Gemini surfactants at the interface is less effective as compared to the conventional surfactants. The synthesized Gemini surfactants efficiently inhibit the process of corrosion in strong acidic conditions. However, Gemini surfactants with EDTA as spacer give better corrosion inhibition results.

Supplementary Data

Supplementary data associated with this article are available in the electronic form at [http://nopr.niscair.res.in/jinfo/ijca/IJCA_60A\(05\)692-699_SupplData.pdf](http://nopr.niscair.res.in/jinfo/ijca/IJCA_60A(05)692-699_SupplData.pdf).

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