Electrical Conductance Measurement of Mixture of Cationic and Anionic Surfactant and Statistical Interpretation

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Abstract

Investigations on the Physico-Chemical properties of mixtures of surfactants are fascinating and useful in detergency, cosmetics, pharmaceutics and industrial fields. Mixed surfactants are of great importance because of fundamental interest as well as extensive scientific and technological applications. An attempt has been made to undertake the investigation on the measurements of electrical conductance of aqueous solutions of NaDC and CTAB and their mixtures as functions of concentration and temperature.

Keywords: *Surfactant, NaDC, CTAB, Micelle, Conductance, Cationic, Anionic*

1. Introduction

A surfactant is briefly defined as materials that can greatly reduce the surface tension of water when used in very low concentrations. Surfactants perform a particular type of molecular structure. Surfactant is abbreviation for the term SURFACE-ACTIVE-AGENT which means activity of an agent or a substance on surface. The surface can form between solid and liquid, air and liquid or liquid-liquid phase.

Surfactant molecules have two distinct parts: one that has affinity for the solvent and the other does not. In aqueous solutions these two moieties are hydrophilic and hydrophobic respectively. It is the tendency for the hydrophobic parts of the molecules to aggregates because of mutual dislike of the solvent which is the driving force for surfactant self association. However our major interest, because of their wide spread occurrence in natural, industrial and domestic areas, is in systems where the liquid phase is water. Surfactants are amphiphilic materials and are employed in industrial applications such as pharmaceuticals, polymerization processes, detergency, foods and enhanced oil recovery (Leontidis- Kyprianidou et al., 2001; Jones, 1992; Wang, 1995; Dutta, 1988; Evani, 1987; Thatberg, 1989). In most biological and industrial applications mixed surfactants are employed because they can enhance the behaviour of a single surfactant (Purdhomme, 1984; Scamehorn, Schechter &

Wade, 1982). Also, additives such as polymers alter the surface tension and the rheological properties. When surfactants are dissolved in water, they concentrate at the surface, where by orient in such a way that their hydrophobic groups are directed away from the water, the free energy of the solution is increased. Depending on the nature of the hydrophilic group, surfactants are classified as anionic, cationic, non-ionic and zwitter-ionic.

The properties of ionic surfactants are parallel to those of the strong electrolytes in dilute aqueous solution, nonionic on the other hand resemble those of simple organic compounds depicting at high concentration pronounced deviation from ideal behaviour of dilute solution. The word micelle is a Latin term meaning 'small bit' and was coined by J.W. McBain (McBain, 1920) in 1920 to describe colloidal sized particles of detergents and soaps, and the phenomenon of self association of monomers into micelles was called micellisation. The driving force behind micellisation, the hydrophobic effect was proposed by G. S. Hartley 1936 (Hartley, 1936). He also suggested the roughly spherical model for the micelles, suggestion that gained general favor later. The concentration at which micelles first appear in solution is termed as critical micelle concentration (cmc) a term proposed by Bury and Davis (Rosen, 1989; Jones, 1927) in 1930. The cmc is the single most important characteristic of the surfactant. Among the properties that have been used in determining the cmc are surface tension, electrical conductance, density, sound velocity, viscosity, solubilization and NMR chemical shift etc.

The cmc is determined experimentally from the inflection points of any physical property of the solution against concentration. The change of physical properties at the cmc occurs over a narrow concentration range rather than a precise point and the magnitude of this range depends somewhat on the physical property (Rosen, 1989). Investigations on the Physico-Chemical properties of mixtures of surfactants are fascinating and useful in detergency (Durham, 1961; Jaeger, 1993; Prescstt, 1963), cosmetic (Prescstt, 1963; Ward, 1964; Hannan, 1978), pharmaceutics (Ali, Botton & Gaylord, 1991) and industrial fields (Kilan, 1991; Somasundaram, 1985; Somasundaram, 1985). Mixed surfactants are of great importance because of fundamental interest as well as extensive scientific and technological applications. The characteristic behaviour of mixtures containing surfactant and polymer is of increasing interest because of their relevant capacity such as viscosity modulators, of their ability to control surface

adsorption and of their solvent capacity towards fats and oils (Goddard & Ananthapadmanabhan, 1992; Kwak, 1998). It has been found that the solid-liquid interface plays an important role in many industrial processes such as detergency, floatation and drinking. In many of these applications the use of surfactant mixtures improves significantly the performance over those of single component system (Kilan, 1991; Somasundaram, 1985; Somasundaram, 1985; Goddard & Ananthapadmanabhan, 1992). The mixing of cationic and anionic surface active agents give rise to the formation of rods, vesicles or precipitation depending on the relative amounts of the component (Hao, Hoffman, & Horbaschek, 2000). Significant results along this line have been obtained by mixing ionic and non-ionic surfactants and/or modifying the pH which have been proved very useful in forth-floatation. The Physico-chemical properties of aqueous solution of mixed surfactants will change as the concentration increases and aggregates forms. The micelle is composed of both the surfactants in equilibrium with the monomeric species in the aqueous phase. It has been observed that anionic surfactants typically react more strongly with additives than cationic surfactants (Puvvada, 1992; Sierra & Rodenas, 1993). The characteristic properties of some synthetic, ionic and non-ionic surfactants in aqueous solution in pure as well as in mixed state in absence and in presence of additives may be studied as functions of concentration and temperature. The coexistence of such peculiarities in the same system offers the opportunity to tune the required properties by changing the polymer, the surfactant, and/or their ratios. These possibilities open the way to several formulation procedures and to the preparation of fine chemicals for personal care and the pharmaceutical industry (Holmberg, Jonsson, Kreilberg & LindmaIl, 2002; Almgren, 2003; Zana, 2003).

The intrinsic theoretical interest and extensive uses in diverse areas of biological, pharmaceutical and industrial worlds, in depth information on the surfactant solutions are considered extensively important prerequisites (Rubingh & Mittal, 1979; Rosen, 1989; Haque, Das & Moulik, 1995; Moulik, Haque & Jana, 2000). Combination of surfactants and polymers normally leads to the formation of mixed miceller aggregates. Such mixtures are of much in1portance since they frequently exhibit a behaviour that is quite different fron1 that of the individual surfactant systems. The interaction between different surfactants may results in synergetic or antagonistic effects depending on the precise nature of this molecule (Rosen, 1989; Haque, Das & Moulik, 1995; Moulik, Haque & Jana, 2000). Most-studies on polymer-surfactant systems deal with Sodium Dodecyl Sulphate

(SOS) and single chain compounds (Curbane & Duplessix, 1982; Ibid, 1978; Meszaros, Thompson, Bos, Varya & Gilani, 2003). The results reported so far allow for constituent explanation of polymer-surfactant interaction (PSI) in terms of molecular properties of the surfactant and the polymer (Ortona, Derrico, Paduano & Sartori, 2002; Roscino, Asaro, Pellizer, Ortoina & Paduano, 2003). When a polymer is employed as an additive, the surfactant- polymer interaction depends upon several factors such as the nature of the surfactant head group, the nature of the polar groups embedded in the polymer backbone and the polymer hydrophobicity (Brackman & Engberts, 1991). With cationic surfactants besides the electrostatic interaction between the polar head groups of surfactant and neutral polymer the respective hydrophobic interactions also play a significant role in determining the surfactant- polymer interactions (Goddard, 1986; Garcia-Mateos, Perez & Valazquez, 1997; Brackman & Engberts, 1987; Winnik, Winnik & Tazuke, 1987).

In the mixed micelles, these interactions are also affected by the variation in the composition of the binary mixtures. Neutral polymers have been observed to interact with surfactants. Often, these interactions exhibit characteristic polymer induced self-aggregation at a concentration called the critical aggregation concentration (CAC), lower than the critical micellar concentration (cmc) of the surfactants (Lindman & Thalberg, 1993; Chari & Lehhart, 1990; Berkhira & Franta, 1994; Fox, Bloor & Holzwarth, 1998). The interaction between cationic and non-ionic surfactants and protein has received substantially less attention than the anionic ones. The non-ionic surfactant Triton-X-100 has been shown to undergo limited binding with proteins; although there was little evidence for sufficient interaction to induce the conformational changes found in the case of anionic materials (Makino & Reynolds, 1973). The phenomenon of mixed micelle formation was proposed by Clint (Clint, 1995) with the help of phase separation model.

The most common theoretical description of the micellization behaviour of p^H sensitive surfactants (and of binary surfactant mixtures in general) is the regular solution theory (RST) (Holland, P.M.; Rubingh, 1983).

Use of the RST typically requires that the individual surfactant critical micelle concentrations (cmc's) be known. In addition use of the RST for a binary surfactant mixture requires input of an interaction parameter (the β_{RST} parameter), which reflects the interaction between the two surfactants types in the micelle (Goldsipe & Blankschtein, 2005).

The effect of temperature changes on the cmc of surfactants in aqueous solution have been found to be quite complex. It has been shown, for example, that the cmc of most ionic surfactants passes through a minimum (Cook, Fordyce & Trebbi, 1963) as the temperature is varied from~ 0 through 60-70°C. Non-ionic and zwitter ionic materials are not quite so predictable, although it has been found that some non-ionic reach a cmc minimum (Goddard, Hoeve & Benson, 1957) around 50°C.

Materials:

Purified and redistilled (Vogel,1994) acetone (BDH) was used for calibrating the dilatometer, viscometer, while a decinormal solution potassium chloride (MERCK, India) was used for the calibration of conductivity cell.

The surfactants Sodium Deoxycholate, (TOKYO KASEL, KOGYO CO. Ltd; Japan) as supplied was 95% pure and hence it has been recrystallised before used and N-Cetyl-N,N,N-trimethyl ammonium bromide (AR Grade, India) as supplied was 99% pure and used without Recrystallisation. $KMnO_4$ (MERCK, India) and NaOH (Qualigens Fine Chemicals; Mumbai, India) was used for the distillation of water. Purity of triple distilled water was checked by measuring its specific conductance which was found to 0.1×10^{-6} Scm^{-1} at 30°c.

2. Methods:

Purification of Acetone (Vogel, 1994): The acetone was refluxed with successive small quantities of potassium permanganate, until the violet colour persist. It was then dried with anhydrous calcium chloride, filtered from the desiccant and fractionated, b. p. 56-57°C. Precautions were taken to avoid the adsorption of moisture.

Preparation of triple distilled water: The supplied water was mixed with potassium permanganate into distillation plant which has a provision of distilling water three times. The distillation plant consists of three similar round bottom flask fitted in series with condensers and receives Permanganate water was distilled first and collected in the middle flask of the plant and again distilled and collected in the third flask which finally distilled and was collected for use.

2.1 Recrystallisation of Sodium Deoxycholate (Vogel, 1994):

Sodium Deoxycholate, (TOKYO KASEI, KOGYO CO. Ltd. Japan) was dissolved in ethanol and the solution was heated with activated charcoal and filtered hot. It was recrystallised by adding acetone to the concentrated filtrate. The white crystals obtained were vacuum dried.

2.2 Temperature and Concentration Range of Measurements:

The temperature range of measurements was from 25°C to 50°C with an interval of 5^0C. The concentration range of measurements for NaDC was 0.3 X 10^{-3} to 5.0 X 10^{-3} mol dm^{-3} and for CTAB was 0.5 X 10^{-3} to 2.5 X 10^{-3} mol dm^3 But in the case of the mixtures of surfactants the measurement range was in mole fraction and it was 0.1 to 0.9.

2.3 Temperature Control:

A thermostated water bath was used to maintain uniform temperature throughout the measurements. The bath consisted of a Remi stirrer (model no.RQD-1228) (220/230V), a check and a contact thermometer. The check thermometer was NBS calibrated to study the change in temperature ± 0.1 K, which was maintained with the help of relay (Jumo-Type - GKU 1OK, 220V~8A). A contact thermometer and an immersion rod (AC/DC, 230V, l000 watt) connected through a dimerstat to the power supply. The dilatometer, conductivity cell and viscometer were immersed in the water bath and the measurements were made after maintaining the thermal stability for half an hour.

2.4 Calibration of Dilatometer (Moynihan, 1966; Islam, Islam & Ahmad, 1979; Islam, Islam, Waris & Ismail, 1976) :

Dilatometer (PISCO Brand) 1s a flat bottomed flask of 8.2 cm^3 capacity fitted with a graduated stem of 7.0 cm length and 2.0 mm diameter. Each mark on the stem is divided into 0.01 ml. It was calibrated with triply distilled water of known density. It was washed thoroughly with chromic acid and triply distilled water and then dried in an oven. After completely dried, it was weighed on a digital balance (Adair-ADN-200W) and then filled with triply distilled water and weighed again. The dilatometer was then immersed in a thermostated water bath maintained at the required temperature of ± 0.1 K thermal stability for half an hour. The temperature was increased by means of contact thermometer so that the level of water in the stem of dilatometer gets increased. The temperature corresponding to each mark of the stem was recorded.

The densities of triply distilled water at these temperatures were obtained by means of an empirical equation of the type $\rho = a - bT$ ……. (1)

Where ρ is the density of water, 'a' and 'b' are the constants and T is the temperature corresponding to each mark on the stem of dilatometer. It was also

found that reported densities of water were linear in the temperature range of our interest (25°C-50°C).

According the temperature dependence of density data of water was least-squares fitted to equation (1) and the best fit values of 'a' and 'b' were computed. Using the values of 'a' and 'b' the densities of these temperatures corresponding to the marks in the stem of the dilatometer were computed. The ratio of mass of water to the above calculated density at the respective temperatures gave the volume of the dilatometer at the corresponding mark on the stem.

Then the clean, dried, empty and weighed dilatometer was filled with purified and redistilled acetone and after weighing again, immersed in the thermostated water bath maintained at the required temperature. The temperature corresponding to the volume of each mark of the stem was recorded in a manner similar to that applied in the case of distilled water. Then from the temperature-volume data, the densities of acetone at these corresponding temperatures were calculated. The whole procedure was repeated with different amounts of water and acetone. The densities of purified acetone was measured by repeating the above mentioned procedure and compared with those of the reported values (Vogel, 1994). The reproducibility was found to be within ± 0.00026 gm cm^{-3}.

2.5 Calibration of Viscometer (Islam, Islam & Ahmad, 1979; Islam, Islam, Waris & Ismail, 1976; Canon, 1960):

Canon Ubbelohde viscometer (Master suspended Level, BS/VSL/MV) consist of three parallel arms, a receiving arm, a measuring one and auxiliary one forming 'W' type arrangement. The receiving arm forms a 'U' shaped arrangement with the measuring arm through a bulb 'D'. The auxiliary arm is sealed to measuring arm has two bulbs 'A' and 'B' in the upper portion. The bulb 'B' is slightly below the bulb 'A'. Two fiducial marks 'a' and 'b' on these bulbs were used for recording the time of fall of test liquids.

In between bulbs 'B' and 'C' there is a capillary of 6.8 m length. It has been designed to align the center of gravity of all the three bulbs vertically to reduce the acceleration due to gravity and minimize the experimental error.

Special features of the suspended level of the viscometer are that the capillary effects of the various liquids surfaces were neutralized by each other so that the surface tension correction for the apparatus was negligible and the transport movement was carried out freely under the weight of the total volume of the test liquid.

The viscometer was cleaned with chromic acid, washed, dried and filled with sufficient amount of triply distilled water to avoid nay air bubble being introduced into the

capillary arm. The viscometer was then suspended in the thermostated water bath for about half an hour before recording the time of fall in order to ensure thermal stability ± 0.1 K at the required temperature. Two guard's tubes containing anhydrous calcium chloride were attached to the auxiliary and receiving arms of the viscometer in order to avoid the absorption of moisture.

Measurement of Viscosity: The calibrated viscometer was cleaned, dried and filled with the required amount of each concentration of the surfactant solutions and clamped in water bath maintained at the required temperature. The viscometer containing the sample was allowed to stand for half an hour in the thermostated water bath in order to avoid thermal fluctuations in the viscometer. The measurements were made at 25-50°C after an interval of 5^0C, the viscosity was calculated by means of equation.

Results and Discussion

Density

The experimental values of density ρ (kg m^{-3}) for aqueous solutions of Sodium Deoxycholate (NaDC) and N-Cetyl N,N,N-trimethyl (CTAB) observed as functions of concentration and temperature and presented in Table1. The experimental values of density for aqueous solutions of mixtures of (NaDC) and N-Cetyl N,N,N-trimethyl (CTAB) are also observed as functions of mole-fraction and temperature and presented in

Table1&Table2.

Table- 1: Density ρ x 10^3 (Kg m^{-3}) for Aqueous Solutions of NaDC as Functions of Concentration and Temperature

T(K) c x10^3(mol dm-3)	298.15	303.15	308.15	313.15	318.15	323.15
0.3	0.990	0.988	0.987	0.986	0.985	0.930
0.5	0.991	0.990	0.989	0.988	0.987	0.984
1.0	0.992	0.991	0.990	0.989	0.988	0.985
1.5	0.993	0.992	0.990	0.990	0.989	0.986
2.0	0.994	0.993	0.991	0.990	0.990	0.980
2.5	0.995	0.994	0.992	0.991	0.991	0.990
3.0	0.996	0.994	0.993	0.992	0.991	0.988
3.5	0.997	0.995	0.993	0.993	0.992	0.988
4.0	0.997	0.996	0.994	0.993	0.993	0.990
4.5	0.998	0.997	0.995	0.994	0.993	0.991
5.0	0.999	0.998	0.995	0.995	0.994	0.992

Table-2: Density ρ x 10^3 (Kg m^{-3}) for Aqueous Solutions of CTAB as Functions of Concentration and Temperature

T(K) C X 10^3 (mol dm^{-3})	298.15	303.15	308.15	313.15	318.15	323.15
0.50	0.989	0.988	0.987	0.986	0.985	0.984
0.60	0.990	0.989	0.988	0.987	0.986	0.985
0.75	0.991	0.990	0.989	0.988	0.986	0.985
0.90	0.992	0.991	0.990	0.989	0.987	0.986
1.00	0.993	0.992	0.990	0.984	0.988	0.987
1.25	0.994	0.993	0.991	0.990	0.989	0.987
1.50	0.995	0.994	0.992	0.99	0.990	0.988
1.75	0.996	0.995	0.993	0.992	0.991	0.989
2.00	0.997	0.996	0.994	0.993	0.992	0.989
2.25	0.998	0.997	0.995	0.994	0.993	0.990
2.50	0.999	0.997	0.996	0.995	0.993	0.991

The temperature dependence of density data is expressed in the form of an empirical equation, $\rho = a - bT$ . . . (2)

Where 'ρ' is the density of the solution, 'a' and 'b' are constants and 'T' is the absolute temperature. The temperature dependence data of observed density for all the concentrations of NaDC, CTAB and their mixtures are least-square fitted to equation (2) and the computed values of the density parameters 'a' and 'b' along with the values of standard deviation 'σ' are, respectively given in Table 3, Table 4 and Table 5.

Table-**3:** Least Squares-Fit Parameters of Density Equation for Aqueous Solutions of NaDC as a Function of Concentrations

C X 10^3 (mol dm^{-3})	a	-bX 10^3	σ X 10^3
0.3	1.094	0.34	0.07
0.5	1.095	0.34	0.09
1.0	1.096	0.35	0.09
1.5	1.097	0.35	0.12
2.0	1.099	0.35	0.09
2.5	1.101	0.36	0.06
3.0	1.103	0.36	0.07
3.5	1.101	0.35	0.08
4.0	1.099	0.35	0.06
4.5	1.099	0.35	0.05
5.0	1.098	0.34	0.05

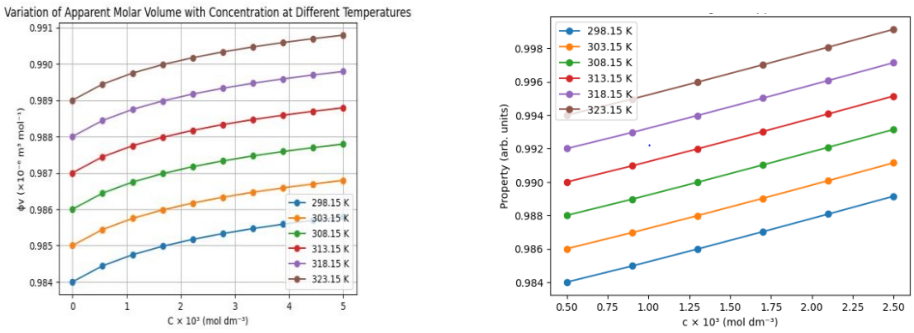
Table- 4: Least Squares-Fit Parameters of Density Equation for Aqueous

C X 10^3 (mol dm^{-3})	a	-b X 10^3	σ X 10^3
0.50	1.049	0.20	-
0.60	1.049	0.20	0.04
0.75	1.048	0.19	0.06
0.90	1.046	0.19	0.08
1.00	1.047	0.19	0.10
1.25	1.045	0.18	0.09
1.50	1.044	0.17	0.11
1.75	1.042	0.17	0.13
2.00	1.041	0.16	0.10
2.25	1.041	0.16	0.09
2.50	1.040	0.15	0.06

Table- 5: Least Squares-Fit Parameters of Density Equation for Aqueous Solutions of Mixtures of NaDC and CTAB as a Function of Mole-fractions.

α_{CTAB}	a	-b X 10^3	σ X 10^3
0.1	**1.025**	**0.09**	**0.06**
0.2	**1.026**	**0.10**	**0.07**
0.3	**1.026**	**0.10**	**0.07**
0.4	**1.027**	**0.10**	**0.10**
0.5	**1.027**	**0.10**	**0.06**
0.6	**1.028**	**0.10**	**0.08**
0.7	**1.028**	**0.10**	**0.08**
0.8	**1.029**	**0.10**	**0.08**
0.9	**1.029**	**0.10**	**0.08**

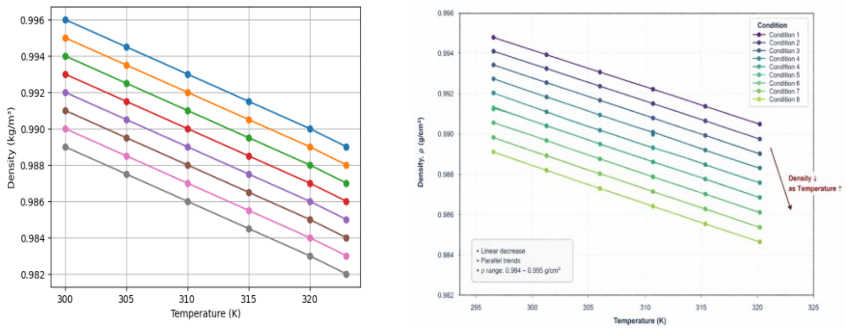
The density values of aqueous solutions of the surfactants and their mixtures are found to increase with the increase in concentration at each temperature and decrease with the increase in temperature at each concentration in a regular manner. The plots of density values of the surfactants NaDC, CTAB and their mixtures against concentrations at various lcn1peraturcs arc shown in Figure1 and Figure2.



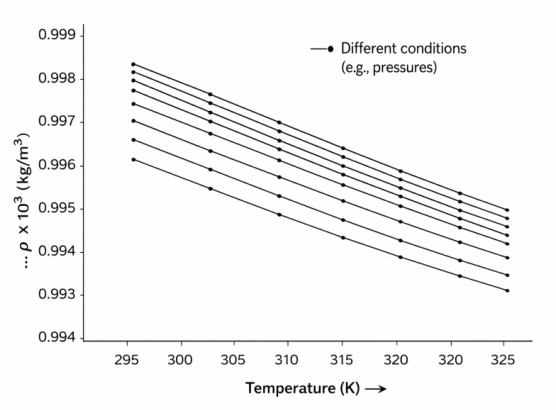
(a) (b)

Fig1:-Plots of Density versus Concentration for Aqueous Solutions of (a) NaDC at Various Temperatures (b) CTAB at Various Temperatures

These plots show that there is an increase in the density values upto certain concentration after which there is a sudden change in the slope of density versus concentration plot indicating the existence of micelles. Each plot shows two lines segments with a sharp break point corresponding to cmc at that particular temperature. A linear decrease in density value with increase in temperature is observed (Figure3, Figure 4 and Figure 5).



(a) (b)



(c)

Fig3:-Plots of Density versus Temperature for Aqueous Solutions of (a) NaDC at Various Temperatures (b) CTAB at Various Temperatures (c) NaDC and CTAB at Various Temperatures

The decrease in density is caused by an increase in volume of solution on increasing the temperature since the mass remains constant, while the magnitude of mass to volume ratio decreases. The experimental values of density were used in the determination of viscosity values and it is also being used to evaluate the mole fraction of water in solution.

3. Conclusion

In the light of the observed density, viscosity and electrical conductance of aqueous solutions of Sodium Deoxycholate, N-Cetyl N,N,N-trimethyl ammonium bromide and their mixtures as functions of concentration and temperature, the reduced η_{red} and intrinsic $[\eta_m]$ viscosities and the cmc values were determined as a function of temperature. From the values of standard Gibbs energy change ΔG_m^0, standard enthalpy change ΔH_m^0 and standard entropy change ΔS_m^0, it may be concluded that the micellization process of aqueous solutions of Sodium Deoxycholate, N-Cetyl, N,N,N-trimethyl ammonium bromide and their mixtures is spontaneous, as it is evident from the values of ΔG_m^0. Further the temperature dependence of viscosity parameters favours spherical geometry for those individual surfactants and their mixtures.

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Declarations

Conflict of interest: The authors declare that they have no conflict of interest.

References

1. Ali, D, Botton, S. & Gaylord, G. P. (1991): Appl. Polym. Sci. 42, 947.
2. Almgren, M. (2003): Aust. J. Chem. 56, 954.
3. Berkhira, A., Franta, E. & Francois, J (1994): J. Colloid Interface Sci. 164, 428.
4. Brackman, J. C.; Engberts & J. B. (1987): F. N. Colloids Polym Sci. 265, 42.
5. Brackman, J. C.& Engberts, J.B. (1991): F.N. Langmuir 7, 2097.
6. Canon, M.R., Manning, R.E. & Bell, J.D. (1960): analyst Chem. 32, 355.
7. Chari, K.; Lehhart, W.J. Colloid Interface Sci. 137, 204 (1990).
8. Clint, J.H. (1995): J. Chem. Soc. Faraday Trans; 1, 71.
9. Cook, E.H., Fordyce, D.B. & Trebbi, G.F. (1963): J. Phys. Chem. 67, 1987.
10. Curbane, B. & Duplessix, R. (1982): J. Phys. Paris, 43, 1529.
11. Dean, J.A. (1992) : "Langes Handbook of Chemistry", 14th Ed, McGraw Hill Book Company.
12. Durham, K. (1961): "In Surface Activity and Detergency", Mc Millan and co. London, 235.
13. Dutta, P. & Moulik, S. P. (1988): lnd. J. Bioclieiii. Biopliys. 1, 35 .
14. Evani. S. & Ross. C. D. (1 987): "Polymer and Material Science Engeneering", 57, 477.
15. Fox, G.J., Bloor, D.M., Holzwarth, J.F. & Wyn-Jones, E. (1998): Langmuir 14, 1026.
16. Garcia-Mateos, I.; Perez, S. & Valazquez, (1997). M.M.J. Colloid. Interface Sci. 194, 356. Goddard, E. D. & Ananthapadmanabhan, P. (1992): Eds. "Interactions of Surfactants with Polymers and Proteins" Boca Raton, FL.
17. Goddard, E.D. (1986): Colloids Surf. 19, 255.
18. Goddard, E.D., Hoeve, C. A. & Benson, G.C. (1957): J. Phys. Chem. 61, 593.
19. Goldsipe, A. & Blankschtein, D. (2005): Langmuir 21, 9850-9865.
20. Hao, J., Hoffman, H. & Horbaschek, K. (2000): J. Phys. Chem. B. 104, l0144- 10153.
21. Hannan, R. B., Goddard, E. D. & Faucher, J. A. (1978): Text. Res. J. 48, 57.
22. Haque, M. E., Das, A. R. & Moulik, S. P. (1995): J. Phys. Chem. 99, 14032.
23. Hartley. G. S. (1936): "Aqueous Solutions of Parafjfin chain salts", Herman, Paris.
24. Holmberg, K., Jonsson, B., Kreilberg, B. & LindmaIl, B. (2002): "Surfactants an Polymers in Aqueous Solutions", 2'd ed; Willey: New York.
25. Holland, P.M. & Rubingh, D.N. (1983): J. Phys. Chem. 87, 1984-1990.
26. Islam, N., Islam, M.R. & Ahmad, R. (1979): Ind.J.Chem. 17A, 285.
27. Islam, N, Islam, M.R., Waris, B. & Ismail, K. (1976): J.Phys. Chem. 80, 291.
28. Ibid (1978); 48, 659.
29. Jaeger, M. (1993): Comun. Jorn. ESP. Deterg. 24, 165.
30. Jones, M. N. (1992): Chem. Soc. Rev. 21, 127.
31. Jones. E. R. & Bury, C. R. (1927): Phil. Mag. 4, 841.