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The effect of sodium dodecyl sulphate on Furosemide — A cardiovascular drug in water–methanol at different temperature

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ABSTRACT

Different kinds of interactions have been critically assessed in order to understand the effect of methanol (MeOH) on sodium dodecyl sulphate (SDS) containing different concentrations of Furosemide with the help of densimetric and conductometric methods. A number of physico-chemical parameters viz. apparent molar volume, apparent molar adiabatic compressibility, standard enthalpy of micellization, standard entropy of micellization and standard free energy of micellization have been calculated from experimentally measured density, velocity of sound and critical micelle concentration (CMC). The CMC has been calculated from conductivity studies. The behaviour of these parameters suggests hydrophobic hydration of the surfactant molecules in a pre-micellar region and their cooperative self-association in a micellar region. The application of the Lumry–Rajender enthalpy–entropy compensation model to the present thermodynamic parameters has also been done to calculate compensation temperature T_c, which lies in the range 270–300 K suggesting solvent induced synergistic behaviour. The plot of apparent molar volume (ϕ_v) vs. (SDS) at different concentrations of Furosemide in 8.0 mol% aqueous solution of MeOH at 303 K is shown in Fig. (A) which clearly indicates the dominance of electrostatic interaction in the pre-micellar region. The data were found to be in qualitative accordance indicating the existence of intermolecular hydrophobic as well electrostatic interactions between the surfactant, MeOH and drug.

1. Introduction

The study of drug–surfactant interactions has received an increased attention recently because of widespread application of surfactants in the pharmaceutical field [1–9]. Surfactants are amphiphilic molecules composed of polar moiety known as '*head*' and relatively large nonpolar moiety known as '*tail*' and are thus able to interact with both polar and non-polar compounds. They are characterized by a wide variety of morphology of aggregates formed by the self assembly of surfactant molecules in aqueous solution to form micelles, where their properties are different from those of the non-aggregated monomer molecules. The concentration corresponding to the micelle formation is known as 'critical micelle concentration' (CMC) [10–12]. CMC serves as a measure of micelle stability in a given state and the thermodynamics of micellization can be determined from CMC-temperature dependence [13,14].

Drugs may be solubilized in the hydrophobic core and/or on the interface of the micelles. The predominant location of the drug depends on its hydrophobicity and interactions with the surfactant [15]. The main attractive force results from the hydrophobic interaction among the nonpolar surfactant tails, whereas the main opposing repulsive force comes from steric and electrostatic interactions (in the case of ionic and zwitterionic surfactants) between the surfactant polar head groups [16]. Thus, an understanding of the physicochemical properties and behaviour of surfactants with drug molecules in solution and at interfaces is desirable.

Furosemide, 4-chloro-N-furfuril-sulphamoylantranilic acid, is a derivative from the anthranilic acid. This drug represents a powerful loop diuretic, widely used in the treatment of hypertension and oedema; on the other hand, it is also used as a way to mask doping agents in competitions [17].

Micelle formation in an aqueous solution is known to be affected by organic additives and there have been many investigations concerning the effects of organic additives on the CMC of simple surfactants [18,19]. Excellent reviews of earlier work on the effect of *n*-alcohols on micellar solutions were given by many researchers [20,21]. The addition of alcohol can strongly influence the behaviour of the micelles depending upon the hydrophilic/hydrophobic character of the alcohol [22,23]. The hydrophilic alcohol like MeOH is mainly soluble in aqueous solution and affects the micellization process by modifying the solvent. The interaction energy between water and MeOH is of interest because the aqueous solution of MeOH can be considered as model for studying hydrophobic and hydrophobic–hydrophilic interactions. In the case of

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Table 1
Molar concentration, C of SDS and corresponding density, d (kg m^{-3}) in 8.0 mol% aqueous solution of MeOH containing 0, 0.001 and 0.002 M Furosemide at different temperatures.

Furosemide Concentration															
[C],10^3	0					0.001					0.002				
	T/K														
	293	298	303	308	313	293	298	303	308	313	293	298	303	308	313
0	975.859	973.939	972.483	970.393	968.310	976.849	975.244	973.474	971.500	969.306	978.179	976.645	974.897	972.955	970.811
2	976.139	974.220	972.765	970.674	968.590	977.048	975.457	973.676	971.710	969.527	978.067	976.520	974.763	972.801	970.694
3	976.144	974.235	972.773	970.689	968.595	977.104	975.517	973.729	971.793	969.587	978.182	976.623	974.845	972.884	970.732
4	976.169	974.249	972.786	970.700	968.599	977.143	975.563	973.777	971.812	969.632	978.212	976.665	974.892	972.927	970.772
5	976.213	974.293	972.826	970.745	968.638	977.216	975.649	973.855	971.878	969.707	978.247	976.685	974.901	972.936	970.780
6	976.272	974.352	972.883	970.794	968.693	977.247	975.674	973.895	971.905	969.728	978.278	976.721	974.957	972.992	970.836
7	976.292	974.372	972.899	970.815	968.705	977.267	975.694	973.910	971.921	969.746	978.325	976.785	974.998	973.042	970.884
8	976.345	974.425	972.951	970.877	968.755	977.295	975.718	973.931	971.943	969.767	978.365	976.817	975.050	973.08	970.922
9	976.428	974.508	973.032	970.915	968.838	977.339	975.769	973.981	971.993	969.817	978.412	976.861	975.095	973.126	970.966
10	976.443	974.523	973.042	970.970	968.843	977.404	975.820	974.029	972.042	969.865	978.448	976.895	975.129	973.156	970.997
11	976.507	974.587	973.106	971.019	968.908	977.449	975.871	974.080	972.103	969.919	978.504	976.943	975.171	973.190	971.010
12	976.609	974.689	973.204	971.121	969.009	977.466	975.894	974.104	972.114	969.934	978.565	977.015	975.246	973.277	971.112
13	976.623	974.703	973.222	971.135	969.022	977.544	975.959	974.167	972.175	969.997	978.690	977.127	975.358	973.391	971.231
14	976.633	974.713	973.227	971.144	969.023	977.660	976.055	974.248	972.263	970.086	978.804	977.300	975.524	973.622	971.449

alcohol/water binary mixture, water and alcohol molecules form homogeneous and stable mixture at the macroscopic scale, but non-homogeneities appear at the microscopic level because alcohol and water tend to self-aggregate and a maximum of aggregation is present at intermediate concentrations [24,25]. In the present paper, an attempt has been made to study the interaction of drug in the aqueous solution of MeOH with SDS.

The behaviour of all derived parameters suggests hydrophobic hydration of the surfactant molecules in pre-micellar region and their cooperative self-association in micellar region. Also the compensation temperature T_c, from enthalpy–entropy compensation model which lies in the range 270–300 K suggesting solvent induced synergistic behaviour.

2. Experimental

2.1. Materials

About 1000 ml of pure water was collected from the Millipore distillation unit which was subjected to further distillation on acidified $KMnO_4$ over a 750 mm long fractionating column. Different fractions of distilled water were collected and their conductivity, κ (S cm^{-1}) and pH were determined. The sample of κ value ~1–3 × 10^{-6} S cm^{-1} was collected for use and the pH of the sample collected remained in the range 6.75–6.95 at room temperature. Furosemide also known as Lasix purchased from Aventis Pharma Ltd. having a composition of 20 mg in 2 ml was used. Sodium dodecyl sulphate (SDS) of AR grade was obtained from SD Fine Chem. Ltd., and was purified as described in the literature [26]. Methanol (MeOH) of AR grade, obtained from Ranbaxy and was used as received.

2.2. Apparatus and measurements

2.2.1. Density and speed of sound measurements

Density, d and speed of sound, v of SDS solution were measured with high precision Anton Paar DSA-5000 which was calibrated with deionised water obtained from Millipore-Elix system. The temperature was maintained at ±0.001 °C. The reproducibility of speed of sound and density data was ±0.5 m s^{-1} and ±5 × 10^{-6} kg m^{-3} respectively over the entire concentration and temperature range of measurements.

2.2.2. Conductivity measurements

The conductivity measurements were carried out with a calibrated digital conductivity metre (CM 180 Elico Ltd.) using a dip type conductivity cell. The solution under investigation was taken in the jacketed measuring cell. The temperature of the cell was maintained precisely at ±0.05 K by circulating thermostatic water from the calibrated automatic digital temperature controlled high precision

Table 2
Molar concentration, C of SDS and corresponding speed of sound, v (m s^{-1}) in 8.0 mol% aqueous solution of MeOH containing 0, 0.001 and 0.002 M Furosemide at different temperatures.

[C],10^3	Furosemide concentration														
	0					0.001					0.002				
	T/K														
	293	298	303	308	313	293	298	303	308	313	293	298	303	308	313
0	1544.40	1548.30	1552.70	1554.65	1556.80	1543.29	1548.42	1552.45	1555.70	1557.14	1541.63	1546.89	1551.10	1554.19	1556.28
2	1544.36	1548.24	1552.55	1554.46	1556.58	1543.37	1548.32	1552.22	1555.38	1556.72	1541.83	1547.10	1551.29	1554.39	1556.38
3	1544.62	1548.47	1552.76	1554.60	1556.73	1543.48	1548.37	1552.30	1555.36	1556.72	1541.96	1547.16	1551.32	1554.42	1556.41
4	1544.75	1548.60	1552.89	1554.75	1556.84	1543.60	1548.48	1552.36	1555.50	1556.84	1542.05	1547.21	1551.38	1554.45	1556.44
5	1544.83	1548.68	1552.95	1554.83	1556.87	1543.59	1548.47	1552.31	1555.50	1556.83	1542.04	1547.23	1551.40	1554.47	1556.46
6	1544.83	1548.68	1552.94	1554.83	1556.89	1543.61	1548.50	1552.34	1555.52	1556.84	1542.01	1547.19	1551.36	1554.43	1556.44
7	1544.91	1548.76	1552.98	1554.88	1556.89	1543.73	1548.57	1552.39	1555.55	1556.86	1541.99	1547.20	1551.36	1554.42	1556.42
8	1544.91	1548.76	1552.97	1554.85	1556.87	1543.69	1548.56	1552.38	1555.54	1556.85	1542.00	1547.23	1551.37	1554.43	1556.41
9	1544.85	1548.63	1552.92	1554.82	1556.81	1543.72	1548.57	1552.36	1555.51	1556.80	1542.02	1547.23	1551.35	1554.40	1556.38
10	1544.83	1548.62	1552.89	1554.75	1556.77	1543.62	1548.43	1552.29	1555.40	1556.70	1541.97	1547.16	1551.31	1554.35	1556.34
11	1544.71	1548.49	1552.79	1554.67	1556.67	1543.65	1548.43	1552.25	1554.34	1556.63	1541.97	1547.15	1551.28	1554.32	1556.32
12	1544.68	1548.46	1552.69	1554.58	1556.59	1543.63	1548.42	1552.26	1554.33	1556.62	1541.89	1547.10	1551.22	1554.25	1556.23
13	1544.62	1548.40	1552.68	1554.54	1556.56	1543.56	1548.40	1552.20	1554.33	1556.60	1541.66	1546.89	1551.07	1554.09	1556.10
14	1544.62	1548.40	1552.66	1554.51	1556.52	1543.34	1548.24	1552.02	1554.19	1556.45	1541.49	1546.65	1550.87	1553.87	1555.93