Modulating Effect of Drug Chloramphenicol on the Aggregation Behavior of the Ionic Liquid 1-tetradecyl-3-methylimidazolium Bromide: A Conductometric Study

Harsh Kumar*, Ramanjeet Kaur

Department of Chemistry Dr B R Ambedkar National Institute of Technology Jalandhar, Punjab-144011 (INDIA)

h.786.man@gmail.com, manchandah@nitj.ac.in

Abstract. In this report, the influence of addition of different wt. % of drug chloramphenicol on the aggregation phenomenon of 1-tetradecyl-3-methylimidazolium bromide (SAIL) has been extensively examined using conductometric technique at temperatures 298.15K, 308.15K, 318.15K. Utilising the values obtained from conductance measurements, the critical micelle concentration (cmc) and degree of dissociation (α) for the micelles formed in the temperature range of 298.15-318.15K at different wt. % of drug chloramphenicol in the medium have been achieved. The various thermodynamic parameters (ΔG_m^0, ΔH_m^0, ΔS_m^0) of micellization were evaluated by conductivity measurements. Effect of additive (drug) on the aggregation behavior of the ionic liquid have been discussed.

1. Introduction

Ionic Liquids (ILs) are gaining much greater attention in the scientific community for which their remarkably important physico-chemical properties such as greater thermal strength, minor vapor pressure, low bioaccumulation, good recyclability [1][2], low toxicity, antimicrobial activity [3][4] are responsible. ILs have also displayed excellent solvation abilities in many applications such as in catalysis [5], in organic synthesis [1], in extraction and separation [6][7], in the stability and dissolution of various biomolecules [8][10]. They have unique structural feature of displaying variety of physicochemical properties [11] just by making judicious choice of their constituent ions i.e. cation and anion. One of the important property of ionic liquids includes their ability to act as amphiphiles which places them in the category of surfactants and as a result they exhibit various surfactant properties such as micellization behavior etc. Due to this interesting property displayed by ionic liquids, various studies on the micellization phenomenon has been carried out by the researchers [12]-[15]. The IL 1-tetradecyl-3-methylimidazolium bromide is so chosen because in the last few years, ILs that are composed of 1-alkyl-3-methylimidazolium cation i.e, C_n mim^+, have been widely studied in the field of colloid and interface science. Also, research is being done about the structural resemblance of imidazolium IL with conventional cationic surfactants. Long-chained imidazolium IL must have amphiphilic nature considering their chemical structures, and must form various molecular assemblies in “aqueous medium” just as the case of traditional amphiphilic compounds i.e., why C_14 mimBr is being chosen. From literature survey, it was observed that value of the cmc decreases linearly with the increase in the carbon number of the alkyl chain in the IL species which means micelles are formed at lower concentration values and these formed micelles have many applications in drug delivery that’s why ionic liquid-drug pair is chosen for the study. On the other side, drug chloramphenicol is chosen for its application as an antibiotic, in the treatment of a number of bacterial infections.
The thermodynamic studies of some of imidazolium based ionic liquids in water and by addition of different additives demonstrate the dissociation of constituent ions of IL at lower concentrations and at higher concentrations, they begin to aggregate themselves by mutual attraction resulting in formation of micelles at concentration known as critical micelle concentration (cmc). The different additives which affect the cmc of ionic liquids include surfactants, ILs, drugs, carbohydrates, amino acids etc. [16]-[18]. In this respect, drugs have found to be investigated by many researchers for their wide applications. Various researchers investigated drug-Ionic Liquids interactions, as Khan et al. studied the various interactions among Ionic Liquid, 1-decyl-3-methylimidazolium chloride and drug promazine hydrochloride (PMZ) as well among Ionic Liquid, 1-octyl-3-methylimidazolium chloride and drug AMT [19]. The various drugs that have been investigated till date include dopamine hydrochloride [20], acetyl choline [20], Ibuprofen [21] etc. However, literature survey demonstrates most of the work is carried out among drug and surfactants, and not much work has been done using ionic liquids. So, present work is carried out using drug chloramphenicol and long chain imidazolium based ionic liquid, 1-tetradecyl-3-methylimidazolium bromide [C\textsubscript{14}mim][Br] for which the micellization study has not been carried out yet to the best of our knowledge. Hence, the micellization behavior and thermodynamics of chloramphenicol at variety of concentrations (i.e., 0.10, 0.25 and 0.50 wt. %) in the pre and post micellar range of [C\textsubscript{14}mim][Br] at different temperatures (298.15K, 308.15K, 318.15K) has been done using conductivity technique. Various thermodynamical quantities such as cmc, degree of dissociation ($\alpha$), Standard Gibb’s free energy ($\Delta G_m^0$), enthalpy ($\Delta H_m^0$) and entropy of micellization ($\Delta S_m^0$) were achieved using conductivity measurements to explore about micellization behavior of ionic liquid.

![System studied](a) [C\textsubscript{14}mim][Br] (IL) (b) Drug Chloramphenicol.

### Figure 1. System studied

#### 2. Experimental

#### 2.1 Materials

Drug Chloramphenicol was procured from HIMEDIA Laboratories Pvt. Ltd. having mass fraction purity of >97% while for the synthesis of ionic liquid, 1-tetradecyl-3-methylimidazolium bromide, 1-methylimidazole was obtained from HIMEDIA Laboratories Pvt. Ltd. India having purity of >99% and 1-bromotetradecane from TCI Co. Ltd., Tokyo, Japan having a purity of >97%. The solvents namely ethyl acetate and acetonitrile were bought from RFCL Limited India and LOBA Chemie Pvt. Ltd Mumbai respectively. The chemicals were dried under vacuum and were kept on storage over P\textsubscript{2}O\textsubscript{5} in desiccators for at least 48h before usage. Table 1 depicts the details of the chemicals used in the present study.
Table 1. Source and purity of the chemicals used.

| Chemicals Name       | Provenance                                  | CAS No | Purification Method | Mass Fraction Purity$^*$ |
|----------------------|---------------------------------------------|--------|---------------------|------------------------|
| Chloramphenicol      | HIMEDIA Laboratories Pvt. Ltd. India        | 56-75-7| Used as such        | >97%                   |
| 1-methylimidazole    | HIMEDIA Laboratories Pvt. Ltd. India        | 616-47-7| Used as such        | >99%                   |
| 1-bromotetradecane   | TCI Co. Ltd., Tokyo, Japan                  | 112-71-0| Used as such        | >97%                   |
| Ethyl acetate        | RFCL Limited India                          | 141-78-6| Used as such        | >99%                   |
| Acetonitrile         | LOBA Chemie Pvt. Ltd Mumbai                 | 75-05-8| Used as such        | >99.5%                 |

$^*$As declared by supplier

2.2 Synthesis of IL [C$_{14}$mim][Br]

The synthesis of the Ionic liquid 1-tetradecyl-3-methylimidazolium bromide has been carried out in the laboratory using the method described in the literature [22]. The method involves the addition of 1-bromotetradecane into the round bottom flask containing 1-methylimidazole and acetonitrile as the solvent. The reaction mixture was then put on refluxing at a constant temperature of about 78-80$^0$C for a period of 48 hours. The growth of the reaction was supervised using the TLC technique. After the reaction has been completed, the solvent was removed using a rota-evaporator. The obtained compound was washed with hexane for two-three times and then dried out in vacuum for two to three days before using. The $^1$H NMR and FT-IR spectra of synthesized Ionic liquid [C$_{14}$mim][Br] were found to be in good agreement with the literature.

2.3 Conductivity measurements

In a double-walled water-jacketed flow dilution cell, the conductance study is carried out for the system using Systronics 306 digital conductivity meter that has a cell constant of 1.0 cm$^{-1}$ at different temperatures i.e., 298.15K, 308.15K, 318.15K. Inside the dilution cell, the temperature was maintained constant using the highly precise refrigerated circulated water bath purchased from Macro Scientific Works Pvt. Ltd., Delhi having an accuracy of ±0.1 K with a temperature range of 0-100$^0$C. The system studied consists of 1-tetradecyl-3-methylimidazolium bromide (IL) and drug chloramphenicol for which the stock solution (0.10, 0.25, 0.50 wt. %) of chloramphenicol was prepared using Sartorius CPA 225 D digital weighing balance having an accuracy of ±0.00001 g. The solutions used were prepared in a doubly distilled deionized water synthesized by Millipore, Milli-Q Academic water purification system. The conductivity meter was calibrated with an aqueous solution of KCl at the start of the experiment. Triplet readings were noted to get accurate results from the technique.

3. Results and discussions

3.1 Influence of adding Chloramphenicol on the critical micelle concentration of 1-tetradecyl-3-methylimidazolium bromide

The conductivity, $\kappa$, of surface-active ionic liquid [C$_{14}$mim][Br] is obtained in the presence of chloramphenicol in aqueous medium at different temperatures i.e. (298.15, 308.15, and 318.15) K using a conductivity meter. The tables 2, table 3 and table 4 represent the values of conductivity, $\kappa$, for the system involving ionic liquid [C$_{14}$mim][Br] in presence of different concentrations (0.1, 0.25, 0.50 wt. %) of chloramphenicol at various temperatures (298.15, 308.15, 318.15) K. The CMC value is determined from this conductivity data.
Table 2. Conductance $\kappa$ ($\mu$S cm$^{-1}$) values obtained for the IL, 1-tetradecyl-3-methylimidazolium bromide in 0.10 wt. % of chloramphenicol at (298.15, 308.15, 318.15) K.

| Concentration (mM) | 0.10 wt. % $[\text{C}_{14}\text{mim}][\text{Br}]$ |
|-------------------|---------------------------------------------|
|           | 298.15K     | 308.15K     | 318.15K     |
| 0.149  | 18.80       | 31.88       | 37.97       |
| 0.294  | 33.30       | 45.83       | 55.97       |
| 0.437  | 49.19       | 61.62       | 75.25       |
| 0.577  | 62.86       | 76.94       | 90.70       |
| 0.714  | 75.72       | 91.14       | 107.50      |
| 0.849  | 88.64       | 104.90      | 123.30      |
| 0.981  | 102.30      | 118.40      | 137.70      |
| 1.111  | 114.40      | 131.50      | 153.20      |
| 1.239  | 125.80      | 144.40      | 168.00      |
| 1.364  | 139.40      | 156.00      | 182.40      |
| 1.486  | 149.30      | 169.30      | 196.30      |
| 1.607  | 162.10      | 181.30      | 209.80      |
| 1.726  | 174.40      | 192.00      | 223.30      |
| 1.842  | 182.20      | 200.60      | 236.10      |
| 1.957  | 188.50      | 210.30      | 242.30      |
| 2.069  | 194.80      | 217.00      | 259.70      |
| 2.179  | 200.10      | 223.70      | 269.00      |
| 2.288  | 204.40      | 228.00      | 277.00      |
| 2.395  | 209.50      | 233.40      | 283.90      |
| 2.500  | 213.00      | 238.00      | 290.30      |
| 2.603  | 216.70      | 243.20      | 295.30      |
| 2.705  | 220.30      | 245.50      | 299.50      |
| 2.805  | 223.30      | 249.00      | 303.90      |
| 2.903  | 226.80      | 252.10      | 308.00      |

Uncertainties $u$ are $u(T) = \pm 0.1$ K, $u(\kappa) = \pm 0.0001$ mS/cm

Figure 2. Specific conductance ($\kappa$) versus concentrations of $[\text{C}_{14}\text{mim}][\text{Br}]$ in the presence of 0.10 wt. %
of chloramphenicol at temperatures (298.15, 308.15, 318.15) K.

Table 3. Conductance $\kappa$ (µS cm$^{-1}$) values obtained for the IL, 1-tetradecyl-3-methylimidazolium bromide in 0.25 wt. % of chloramphenicol at (298.15, 308.15, 318.15) K.

| Concentration (mM) | $\kappa$ (µS cm$^{-1}$) | 0.25 wt. % [C$_{14}$mim][Br] |
|-------------------|-------------------------|---------------------------------|
|                   | 298.15K                  | 308.15K                         | 318.15K                         |
| 0.149             | 17.30                    | 27.00                           | 28.59                           |
| 0.294             | 30.15                    | 41.18                           | 47.67                           |
| 0.437             | 44.24                    | 53.00                           | 64.71                           |
| 0.577             | 54.72                    | 64.47                           | 81.58                           |
| 0.714             | 65.91                    | 81.14                           | 97.94                           |
| 0.849             | 80.28                    | 92.49                           | 115.00                          |
| 0.981             | 93.11                    | 104.90                          | 131.30                          |
| 1.111             | 103.90                   | 117.40                          | 145.70                          |
| 1.239             | 114.40                   | 129.90                          | 161.00                          |
| 1.364             | 124.00                   | 141.20                          | 175.30                          |
| 1.486             | 133.30                   | 151.70                          | 190.30                          |
| 1.607             | 140.30                   | 162.90                          | 203.10                          |
| 1.726             | 147.20                   | 171.70                          | 215.50                          |
| 1.842             | 152.30                   | 179.80                          | 226.40                          |
| 1.957             | 157.40                   | 184.30                          | 232.30                          |
| 2.069             | 161.50                   | 188.90                          | 238.00                          |
| 2.179             | 165.30                   | 194.20                          | 245.40                          |
| 2.288             | 168.30                   | 197.00                          | 251.60                          |
| 2.395             | 171.60                   | 200.70                          | 258.00                          |
| 2.500             | 175.70                   | 205.90                          | 262.20                          |
| 2.603             | 178.90                   | 209.60                          | 268.10                          |
| 2.705             | 181.50                   | 214.10                          | 272.60                          |
| 2.805             | 184.60                   | 216.30                          | 274.50                          |
| 2.903             | 185.70                   | 218.50                          | 280.00                          |

Uncertainties $\mu$ are $\mu(T) = \pm 0.1$ K, $\mu(\kappa) = \pm 0.0001$ mS/cm
Figure 3. Specific conductance ($\kappa$) versus concentrations of $[C_{14}\text{mim}][\text{Br}]$ in the presence of 0.25 wt. % of chloramphenicol at temperatures (298.15, 308.15, 318.15) K.

Table 4. Conductance $\kappa$ (µS cm$^{-1}$) values obtained for the IL, 1-tetradecyl-3-methylimidazolium bromide in 0.50 wt. % of chloramphenicol at (298.15, 308.15, 318.15) K.

| Concentration (mM) | 0.50 wt. % $[C_{14}\text{mim}][\text{Br}]$ |
|-------------------|-------------------------------------|
|                   | 298.15K | 308.15K | 318.15K |
| 0.149             | 16.68   | 22.54   | 26.89   |
| 0.294             | 28.63   | 36.42   | 44.21   |
| 0.437             | 39.64   | 50.47   | 60.32   |
| 0.577             | 52.55   | 64.55   | 71.94   |
| 0.714             | 63.45   | 76.82   | 85.54   |
| 0.849             | 78.92   | 89.08   | 100.70  |
| 0.981             | 86.54   | 101.90  | 111.50  |
| 1.111             | 98.41   | 113.70  | 128.10  |
| 1.239             | 110.36  | 126.60  | 136.60  |
| 1.364             | 121.00  | 135.80  | 150.20  |
| 1.486             | 126.40  | 146.80  | 163.50  |
| 1.607             | 131.40  | 153.90  | 172.70  |
| 1.726             | 136.50  | 160.70  | 180.30  |
| 1.842             | 141.20  | 166.60  | 184.20  |
| 1.957             | 145.40  | 171.70  | 194.50  |
| 2.069             | 149.70  | 174.80  | 200.90  |
| 2.179             | 154.10  | 179.00  | 209.20  |
| 2.288             | 156.90  | 182.70  | 213.60  |
| 2.395             | 159.80  | 186.20  | 215.40  |
| 2.500             | 162.20  | 190.10  | 217.10  |
| 2.603             | 166.80  | 194.70  | 220.10  |
| 2.705             | 169.60  | 199.10  | 225.10  |
Uncertainties are $u(T) = \pm 0.1$ K, $u(\kappa) = \pm 0.0001$ mS/cm.

**Figure 4.** Specific conductance ($\kappa$) versus concentrations of $[C_{14}\text{mim}][\text{Br}]$ in the presence of 0.50 wt. % of chloramphenicol at temperatures (298.15, 308.15, 318.15) K.

The plots of conductivity v/s concentration of $[C_{14}\text{mim}][\text{Br}]$ in the presence of 0.10, 0.25 and 0.50 wt. % of chloramphenicol has been shown in figures 2, figure 3, figure 4 respectively. The cmc value reported for the ionic liquid $[C_{14}\text{mim}][\text{Br}]$ in aqueous solution is 2.61mM and degree of counter ion dissociation is 0.78 [19] The conductivity plots obtained shows that electrical conductivity at first increases with a gradual decrease in slope and then increases after the micellization has taken place. The intersection of two lines represents the critical micelle concentration and that the process of micellization has originated at the point of intersection i.e., cmc. The reason behind change in slope at critical micelle concentration is that a part of counter ions are confined to the micellar surface which results in loss of ionic charges and the micelles, due to their low mobility contribute less towards charge transport in comparison to free ions.

**Table 5.** CMC i.e., critical micelle concentration, and $\alpha$ i.e., degree of counter ion dissociation of $[C_{14}\text{mim}][\text{Br}]$ in different wt. % of chloramphenicol at temperatures (298.15, 308.15, 318.15) K.

| Temperature (K) | Chloramphenicol (wt. %) | CMC (mM) | $\alpha$ |
|----------------|-------------------------|----------|---------|
| 298.15K        | 0.10                    | 1.87     | 0.40    |
|                | 0.25                    | 1.58     | 0.39    |
|                | 0.50                    | 1.35     | 0.39    |
| 308.15K        | 0.10                    | 1.92     | 0.40    |
|                | 0.25                    | 1.66     | 0.40    |
|                | 0.50                    | 1.55     | 0.40    |
| 318.15K        | 0.10                    | 2.11     | 0.44    |
|                | 0.25                    | 1.75     | 0.43    |
|                | 0.50                    | 1.63     | 0.42    |
Uncertainties $u$ are $u(T) = \pm 0.1$ K, $u(\kappa) = \pm 0.0001$ mS/cm

The representative values for critical micelle concentration (CMC) and degree of counter-ion dissociation ($\alpha$) for the system studied i.e., $[C_{14}\text{mim}][\text{Br}]$ and drug chloramphenicol has been shown in table 5 at different concentrations as well as different temperatures. The degree of counter-ion dissociation ($\alpha$) is calculated as the ratio between slopes of post micellar ($S_2$) and pre-micellar regions ($S_1$) represented by equation (1).

$$\alpha = \frac{S_2}{S_1} \quad (1)$$

The variation in slope value assists in the evaluation of $\alpha$ for the studied system. On examination of the data, we found that both critical micelle concentration (CMC) as well as degree of counter-ion dissociation ($\alpha$) values decreases with the increase in concentration value of drug chloramphenicol. The explanation for the decrease in value of cme of $[C_{14}\text{mim}][\text{Br}]$ follows as the micelle formation involves electrostatic as well as hydrophobic interactions among the hydrophilic head group and hydrophobic tail of ionic liquid with the additive used which results in lowering or raising of cme of ionic liquid [20]. The electrostatic interactions among the IL and drug chloramphenicol allows ionic liquid molecules to come closer and form micelles at low concentrations in comparison to the one in absence of added drug additive, thereby reducing the cme of ionic liquid upon increasing concentrations of drug chloramphenicol.

### 3.2 Effect of temperature on the critical micelle concentration (CMC) of $[C_{14}\text{mim}][\text{Br}]$

The value of critical micelle concentration (CMC) of $[C_{14}\text{mim}][\text{Br}]$ has been found to increase with the increase in temperature for the system of Ionic liquid $[C_{14}\text{mim}][\text{Br}]$ and drug chloramphenicol. It is due to the fact that increase in temperature promotes the thermal agitation which restricts the ionic liquid molecules to come closer and form micelles. Thus, increasing temperature delays the micellization process and leads to upsurge in critical micelle concentration value.

The consequence of increasing concentration of drug chloramphenicol and increasing temperature on the value of $\alpha$ and CMC has been depicted in the figure 5 & figure 6.

![Figure 5](image1.png) ![Figure 6](image2.png)

**Figure 5.** Plot of $\alpha$ of $[C_{14}\text{mim}][\text{Br}]$ in (0.10, 0.25, 0.50) wt.% of drug chloramphenicol at temperatures (298.15K, 308.15K, 318.15K).

**Figure 6.** Plot of CMC of $[C_{14}\text{mim}][\text{Br}]$ in (0.10, 0.25, 0.50) wt.% of drug chloramphenicol at temperatures (298.15K, 308.15K, 318.15K).
3.3 Thermodynamics of micellization

Thermodynamic parameters such as standard Gibbs free energy $\Delta G^0_m$, enthalpy $\Delta H^0_m$ and entropy of micellization $\Delta S^0_m$, have also been evaluated using the temperature dependency of cmc and $\alpha$ in order to have better understanding about the process of micellization. The values of these thermodynamic parameters determined for the system consisting of [C$_{14}$mim][Br] and different concentrations of chloramphenicol has been represented in Table 6.

3.3.1. The standard Gibbs’ free energy of micellization ($\Delta G^0_m$)

The thermodynamic parameter, standard Gibbs free energy of micellization, $\Delta G^0_m$ has been determined using the charged pseudo-phase separation model of micelle formation [21]. Equation 2 is used to calculate the value for $\Delta G^0_m$.

$$\Delta G^0_m = (2-\alpha) RT \ln X_{CMC}$$  \hspace{1cm} (2)

where, $R$ is universal gas constant, $T$ is absolute temperature $X_{CMC}$ represents the value of CMC obtained from conductivity-concentration plots and expressed in mole fraction units, $\alpha$ is the degree of counter-ion dissociation. A perusal of the values of $\Delta G^0_m$ form table 6 indicates that the value for standard Gibbs free energy of micellization, $\Delta G^0_m$ is generally negative for all the concentrations of drug Chloramphenicol as well as temperatures signifying that the process of micellization is spontaneous at studied concentrations and temperatures. The negative values of $\Delta G^0_m$ become more negative with increase in wt. % of drug Chloramphenicol and also with the rise in temperature. Thus, it can be stated that the process of micellization become more spontaneous at increased wt. % of drug chloramphenicol and also with the increase in temperature.

**Table 6.** The standard Gibbs’ free energy ($\Delta G^0_m$), enthalpy ($\Delta H^0_m$), and entropy ($\Delta S^0_m$) of micellization of [C$_{14}$mim][Br] in different wt.% of drug chloramphenicol at temperatures (298.15K, 308.15K, 318.15K).

| Chloramphenicol (wt.%) | $\Delta G^0_m$ (kJ·mol$^{-1}$) | $\Delta H^0_m$ (kJ·mol$^{-1}$) | $\Delta S^0_m$ (J·mol$^{-1}$·K$^{-1}$) |
|------------------------|-------------------------------|--------------------------------|----------------------------------|
| 0.10                   | -40.95                        | -7.26                          | 113.03                           |
| 0.25                   | -41.70                        | -6.19                          | 119.10                           |
| 0.50                   | -42.36                        | -10.94                         | 105.39                           |
| **T = 308.15 K**       |                               |                                |                                  |
| 0.10                   | -42.01                        | -7.71                          | 111.30                           |
| 0.25                   | -42.63                        | -6.58                          | 116.99                           |
| 0.50                   | -42.93                        | -11.61                         | 101.62                           |
| **T = 318.15 K**       |                               |                                |                                  |
| 0.10                   | -42.10                        | -8.05                          | 107.01                           |
| 0.25                   | -43.01                        | -6.89                          | 113.54                           |
| 0.50                   | -43.52                        | -12.21                         | 98.42                            |

Uncertainties u are $u(\Delta G^0_m) = \pm 0.03$ kJ·mol$^{-1}$, $u(\Delta H^0_m) = \pm 0.02$ kJ·mol$^{-1}$, $u(\Delta S^0_m) = \pm 0.02$ J·mol$^{-1}$·K$^{-1}$

3.3.2. The enthalpy of micellization ($\Delta H^0_m$)

The enthalpy of micellization, $\Delta H^0_m$ has been determined from the conductivity data and the following equation (3) is used to calculate its magnitude [21].

$$\Delta H^0_m = -RT(2-\alpha)[d(\ln X_{CMC})/dT]$$ \hspace{1cm} (3)

The negative values of $\Delta H^0_m$ at all studied concentrations and temperatures obtained using above equation shows that the aggregation process is exothermic in nature. The more negative values obtained for $\Delta H^0_m$ at increasing wt. % of chloramphenicol are result of counter-ions being dissociated from micellar surface leading to highly exothermic process. The values of $\Delta H^0_m$ calculated have been given in table 6.
3.3.3. The entropy of micellization ($\Delta S_{m}^{0}$)

By application of the equation (4), the entropy of micellization, $\Delta S_{m}^{0}$ [21], has been determined and values for $\Delta S_{m}^{0}$ are given in table 6.

$$\Delta S_{m}^{0} = \frac{(\Delta H_{m}^{0} - \Delta G_{m}^{0})}{T}$$

(4)

It has been observed that large and positive values for $\Delta S_{m}^{0}$ are obtained from the thermodynamic calculations and these contribute majorly to the value of $\Delta G_{m}^{0}$ and discloses that aggregation process is entropy driven at lower wt. % of chloramphenicol. With increasing wt. % of chloramphenicol, enthalpic contribution increases towards $\Delta G_{m}^{0}$. This is due to the fact that when degree of dissociation ($\alpha$) is high, rate of solvation of ions is enhanced which leads to release of solvation energy in larger amount. In the process of micellization, hydrophobic alkyl chains of ionic liquid, due to various interactions with additive drug come closer to each other which leads to release of water molecules, whereas the hydrophilic head group interactions results in the disrupted water structures, hence, resulting in entropy rise of the system. However, entropy value is reduced on increasing the temperature of the system as can be seen from the table 6.

4. Conclusion

Consequence of addition of drug Chloramphenicol on the aggregation properties of ionic liquid [C$_{14}$mim][Br] such as cmc, degree of counter-ion dissociation and thermodynamic parameters ($\Delta G_{m}^{0}$, $\Delta H_{m}^{0}$, $\Delta S_{m}^{0}$) has been found to be fascinating. In this report, cmc has been determined using conductometric technique for the system involving ionic liquid in presence of 0.10, 0.25, and 0.50 wt. % of drug Chloramphenicol at various temperatures (i.e., 298.15, 308.15, and 318.15) K. On examining the data, it was found that the value of cmc decreases on increasing the concentration of drug Chloramphenicol and increases with increase in temperature. This indicates that micellization behavior of ionic liquid [C$_{14}$mim][Br] gets modified upon addition of drug Chloramphenicol. Also upon analysis of thermodynamic parameters, it was observed that micelle formation of ionic liquid is entropy driven at lower temperatures and enthalpy-driven when going to higher temperatures. Also, negative values obtained for $\Delta G_{m}^{0}$ and $\Delta H_{m}^{0}$ signifies that micellization process is spontaneous and exothermic in nature. Hence, it can be concluded that micellization tendency of ionic liquid [C$_{14}$mim][Br] is promoted in the presence of drug additive as shown in figure 7.

![Figure 7](image-url)
5. References

[1] Welton T 1999 Chem. Rev. 99 2071.
[2] Earle M J, Esperanca J M S S, Gilea M A, Canongia Lopes J N, Rebelo L P N, Magee J W, Seddon K R and Widegren J A 2006 Nature 439 831.
[3] Łuczak J, Jungnickel C, Łącka I, Stolte S and Hupka J 2010 Green Chem. 12 593.
[4] Harjani J R, Farrell J, García M T, Singer R D and Scammells P J 2009 Green Chem. 11 821.
[5] Zhang Q, Zhang S and Deng Y 2011 Green Chem. 13 2619.
[6] Neves C M S S, Granjo J F O, Freire M G, Robertson Al, Oliveira N M C and Coutinho J A P 2011 Green Chem. 13 1517.
[7] Passos H, Luis A, Coutinho J A P and Freire M G 2015 Sci. Rep. 6 20276.
[8] Swatloski R P, Spear S K, Holbrey J D and Rogers R D 2002 J. Am. Chem. Soc. 124 4974.
[9] Singh T, Trivedi T J and Kumar A 2010 Green Chem. 12 1029.
[10] Wang H, Gurau G and Rogers R D 2012 Chem. Soc. Rev. 41 1519.
[11] Wasserscheid P and Welton T (Eds.) 2003 Ionic Liquids in Synthesis, Wiley-VCH Weinheim,
[12] El Seoud O A, Pires P A R and Abdel-Moghny T, Bastos E L 2007 J. Colloid Interface Sci. 313 296.
[13] Singh T and Kumar A 2007 J. Phys. Chem. B 111 7843.
[14] Dong B, Li N, Zheng L, Yu L and Inoue T 2007 Langmuir 23 4178.
[15] Wang J, Wang H, Zhang S, Zhang H and Zhao Y 2007 J. Phys. Chem. B 111 6181.
[16] Kumar D, Hidayathulla S and Rub M A 2018 J. Mol. Liq. 271 254.
[17] Patel R, Khan A B, Dohare N, Ali M M and Rajor H K 2015 J. Surfact. Deterg. 18 719.
[18] Harutyunyan L R and Harutyunyan R S 2017 Tenside Surfactant Deterg. 54 141.
[19] Inoue T, Ebina H, Dong B and Zheng L 2007 J. Colloid Interface Sci. 314 236.
[20] Pal A and Pillania A 2015 Fluid Phase Equilib. 389 67.
[21] Rosen M J 2004 Surfactants and Interfacial Phenomena (New York: John Wiley & Sons).
[22] Holbrey J D and Seddon K R J 1999 Chem. Soc., Dalton Trans. 13 2133.

Acknowledgments

The authors are grateful for the research grant funded by Science and Engineering Research Board (SERB), New Delhi through sanction order number EMR/2015/002059. One of the authors, Ramanjeet Kaur is thankful to University Grants Commission (UGC), Government of India for research fellowship. The authors also wish to thank Department of Chemistry, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, Punjab, India for providing necessary facilities.