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RESEARCH ARTICLE

Enhanced Solubility and Reflection of Hydrotropy Technique in the Segregation of of *m*/*p*-Aminonitrobenze

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Abstract: The aqueous solubilities of *m*/*p* – amino nitrobenzene in different concentrations (0-3.0 mol/L) of hydrotropes such as sodium benzoate, sodium saccharin, dimethyl benzamide at different system temperatures (303 K to 333 K) were studied. The percentage extraction (%E) of *m*- amino nitrobenzene from m/*p* - amino nitrobenzene mixture increases with an increase in hydrotrope concentration. A minimum hydrotrope concentration (MHC) in the aqueous phase was required to initiate the significance of the %E of *m*- amino nitrobenzene. Percentage extraction (%E) is the ratio of moles of *m* - amino nitrobenzene extracted in presence and absence of a hydrotrope. The sensitivity and feasibility of the proposed process are examined by carrying out solubilization and equilibrium precipitation experiments with the mixtures of various compositions. The effectiveness of hydrotropes was measured in terms of Setschenow constant Ks and reported for all hydrotropes used in this study and determination of aggregation behavior of all hydrotropes were also studied.

Keywords: Hydrotropy, Solubilization, Enhanced solubility, Extraction

Introduction

A range of industrial mixtures having a close boiling point isomeric or non isomeric components present a challenging separation problem, as in most cases conventional separation methods cannot be successfully applied. These components usually have similar chemical properties and molecular sizes and comparable volatilities. A simple technique is employed, which involves either solubilization and precipitation, *i.e.*, the solubilization of the mixture in a hydrotrope solution and subsequent selective precipitation of a desired component by controlled dilution with water.

Hydrotropy is a unique and unprecedented solubilization technique in which specific chemical components termed as hydrotropes can be used to affect a number of fold increases in the solubility of sparingly soluble solutes under standard conditions[1-4].

Hydrotropic substances are a class of chemical combinations that are freely soluble in water. Hydrotropes are much effective at high concentrations which in turn enhance the aqueous solubility of organic compound, because of the opportunity of molecular solution

structures probably in the form of stack-type aggregates. The solubilized solute will therefore precipitate out on dilution with water from most hydrotropic solutions. This process may be used to recover the solute in a pure form and the remaining mother liquor may be used to concentrate the hydrotrope for recycle[5].

Even so, in modern age, we have established the aggregation behavior of common hydrotropes by several techniques[6-7]. The self-aggregation of the hydrotropes has been considered to be a pre-requisite for a number of applications in various meadows such as drug solubilization[8-10] and boswellic acids from Boswellia serrata resins[13].

The current work was commenced for the fundamental study of the global character of hydrotropes in the selective separation of a component from mixtures via solubilization and precipitation techniques[11-17]. With particular attention on both the theoretical understanding of the mechanistic action and the experimental studies which demonstrate the utility of hydrotropes in the separation of commercially prominent mixtures[18-21]. The system *m*/*p* – amino nitrobenzene (molecular weight M = 138.13) was selected, for enhancing its solubility using several commercially available hydrotropes. Since *m*- amino nitrobenzene serves as a raw material/intermediate for organic synthesis; *p*-phenylenediamine, azo dyes, antioxidants, fuel additives, corrosion inhibitors, pesticides, antiseptic agents, medicines for poultry and pharmaceutical synthesis and this makes its separation from any liquid mixture, which has been difficult, until now.

The separation of *m*/*p* – amino nitrobenzene through solubilization and selective precipitation is important as both these isomers have been not only close boiling points but also close melting points. The melting points of *m*/*p* – amino nitrobenzene are 114 °C and 149 °C, while the boiling points are 307 °C and 332 °C, respectively. All hydrotropes are non- reactive, non-toxic and do not produce any change in temperature effect when dissolved in water. The cheapness and easy availability are other factors considered in the selection of hydrotropes.

Experimental

All the chemicals used in this work were manufactured by the Loba Chemie Pvt. Ltd., Mumbai. With manufacturers stated purity of 99.9%. The hydrotropes used in this work *viz*., diethyl nicotinamide, sodium pseudocumene sulfonate and sodium thiocyanate are of analar grade. Double distilled water was used for the preparation of hydrotropic solutions.

Methods

The experimental setup for conducting a single-stage batch wise liquid-liquid extraction consisted of a thermostatic bath and a separating funnel. Measurement of the solubility of *m*- amino nitrobenzene was carried out at temperatures of 303, 313, 323 and 333 K.

For each solubility test, an equal volume (100 mL) of *m*/*p* – amino nitrobenzene was comprehensively mixed to make a single-phase solution using a mechanical shaker. The hydrotrope solutions of different known concentrations were prepared by dilution with distilled water. Following to this, 100 mL of *m*/*p* – amino nitrobenzene mixture was taken and added to 100 mL of hydrotrope solution of known concentration. The mixture was then made to mix consecutively for three hours. The mixture was then allowed to settle and was transferred to a separating funnel, which was immersed in a thermostatic bath with a temperature controller within ±0.1 °C. The setup was kept overnight for equilibration. After equilibrium was attained, the organic phase containing *m*- amino nitrobenzene was carefully separated and analyzed to determine the concentration using a high-performance liquid

chromatography (HPLC). The mobile phase as a 40% isopropanol /60% hexane isocratic, 1 mL /min and silica column is used. All the solubility trials were conducted in duplicate runs to check their reproducibility. The %E has been calculated from these solubility data. The observed error was <2%.

Results and Discussion

Experimental data on the effect of hydrotropes, *i.e* diethyl nicotinamide, sodium pseudocumene sulfonate and sodium thiocyanate on the percentage extractions (%E) of *m*- amino nitrobenzene is displayed in Figures 1–3 and solubility of *m*- amino nitrobenzene is shown in Figures 4-6. Percentage extraction (%E) is the ratio of extraction of m- amino nitrobenzene in the presence and absence of hydrotrope, respectively.

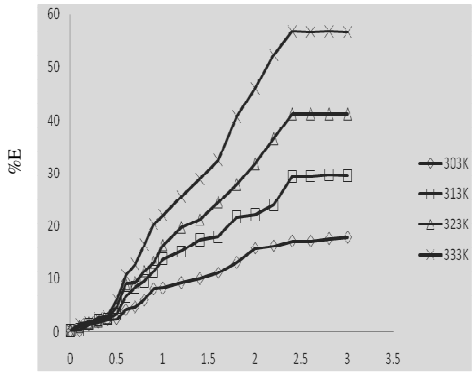

Figure 1. Effect of diethyl nicotinamide concentration (C) on percentage extractions (%E) of *m*- amino nitrobenzene

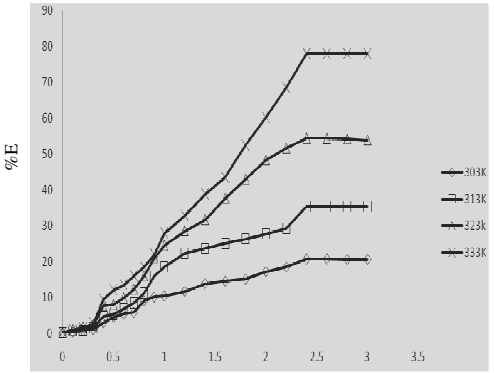

Figure 2. Effect of sodium pseudocumene sulfonate concentration (C) on percentage extractions (%E) of *m*- amino nitrobenzene

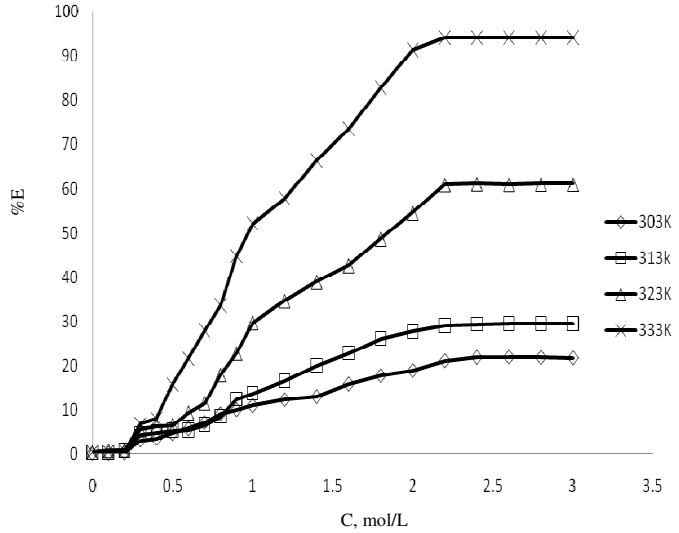

Figure 3. Effect of sodium thiocyanate concentration (C) on percentage extractions (%E) of *m*- amino nitrobenzene

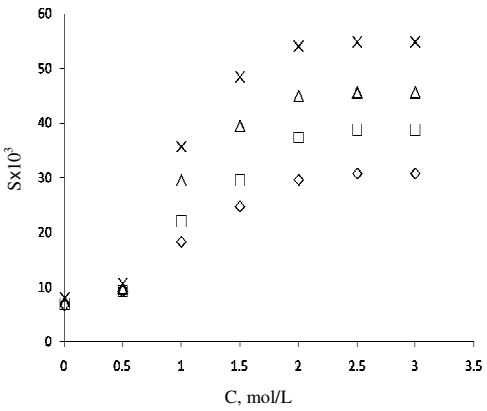

Figure 4. Effect of diethyl nicotinamide concentration (C) on solubility of *m*- amino nitrobenzene

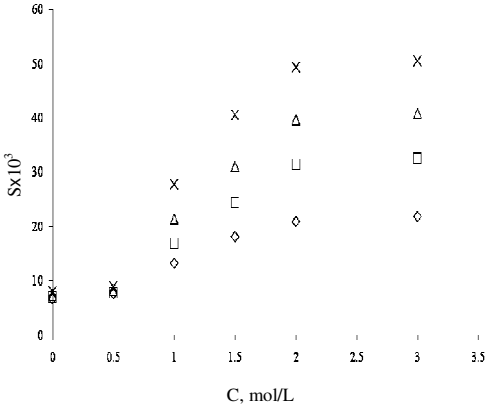

Figure 5. Effect of sodium pseudocumene sulfonate concentration (C) on solubility of *m*- amino nitrobenzene

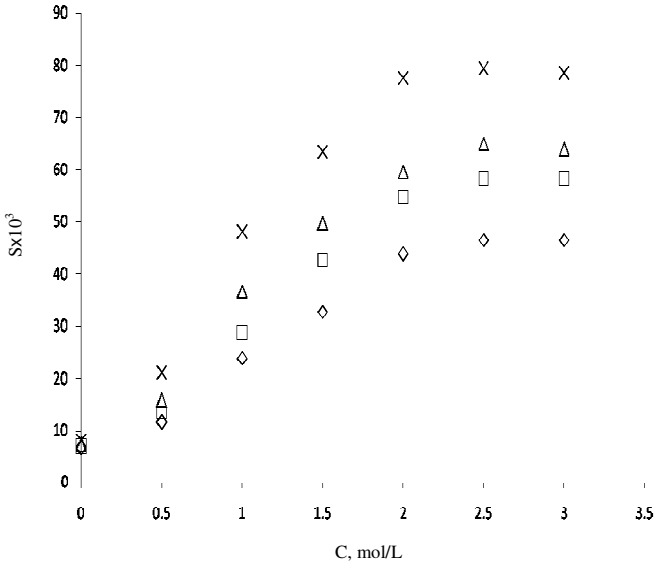

Figure 6. Effect of sodium thiocyanate concentration (C) on solubility of *m*- amino nitrobenzene

Sodium thiocyanate is one of the hydrotropes used in this research. It was observed that the %E of *m*- amino nitrobenzene did not indicate any appreciable increase until 0.20 mol/L of sodium thiocyanate. However, upon a subsequent increase in the concentration of sodium thiocyanate, *i.e*., 0.30 mol/L, the %E of *m*- amino nitrobenzene was found to increase significantly. This concentration of sodium thiocyanate in the aqueous phase, *i.e*., 0.30 mol/L, is termed as the minimum hydrotrope concentration (MHC), which is the minimum required amount of dimethyl benzamide in the aqueous phase to commence a significant increase in the percentage extraction of *m*- amino nitrobenzene. It was observed that the MHC of sodium thiocyanate in the aqueous phase does not modify even at increased system temperatures, *i.e*., 313, 323 and 333 K.

A related tendency in the MHC requirement has also been observed for other hydrotropes. Accordingly, it is manifest that hydrotropic separation is displayed only above MHC, irrespective of the system temperature. Hydrotropey does not seem to be functioning below the MHC, which may be a distinctive of a particular hydrotrope with respect to each solute. The percentage extraction effect changes with concentration of the hydrotropes. In this case, a clear increasing trend in the percentage extraction of *m*- amino nitrobenzene was observed above the MHC of sodium thiocyanate. This increase is affirmed only up to a certain concentration of sodium thiocyanate in the aqueous phase, *i.e*, 2.20 mol/L further than which there is no appreciable increase in the percentage extraction of *m*- amino nitrobenzene. This concentration of sodium thiocyanate in the aqueous phase is referred to as the maximum hydrotrope concentration (C_{max}). From the analysis of the experimental data, it is observed that further increase in the hydrotrope concentration beyond C_{max} does not cause any considerable increase in the percentage extraction even up to 3.0 mol/L in the aqueous phase. Similar to the MHC values, the C_{max} values of the hydrotropes also remained unaltered with the increase in system temperature. (Table.1) The maximum effectiveness of hydrotrope (φ) which is the ratio of the percentage extraction value in the presence and absence of a hydrotrope respectively. It was determined and the highest value of(φ) 93.95 in the case of sodium thiocyanate at a system temperature of 333 K (Table 2).

Table 1. MHC and C_{max} values

Hydrotrops	MHC	C_{max}
Diethyl nicotinamide	0.5	2.4
Sodium pseudocumene sulfonate	0.4	2.4
Sodium thiocyanate	0.3	2.2

Table 2. Maximum enhancement factor

Hydrotrops	Maximum enhancement factor (Φs)			
	T = 303 K	T = 313 K	T = 323 K	T = 333 K
Diethyl nicotinamide	17.02	28.1	40.93	56.6
Sodium pseudocumene sulfonate	20.61	32.19	54.18	74.64
Sodium thiocyanate	21.01	29.01	60.75	93.95

Effectiveness of hydrotrope

The effectiveness factor for each hydrotrope with respect to the percentage extraction of *m*- amino nitrobenzene at different system temperatures was determined by applying the model suggested by Setschenow and later modified by Phatak and Gaikar as given by the equation:

$$log\ (E/Em) = Ks(Cs - C\ m) \quad (1)$$

Where E and Em are the %E values of *m*- amino nitrobenzene maximum hydrotrope concentration Cs (same as C_{max}) and the minimum hydrotrope concentration Cm (same as MHC) respectively. The Setschenow constant (Ks) can be considered as a measure of the effectiveness of a hydrotrope at any given conditions of hydrotrope concentration and system temperature. The Setschenow constant values of hydrotropes, namely, diethyl nicotinamide, sodium pseudocumene sulfonate, sodium thiocyanate for percentage extractions of *m*- amino nitrobenzene different system temperatures are listed in Table 3. The highest value was observed as 0.59 in the case of sodium thiocyanate as the hydrotrope at temperature 333 K.

Table 3. Setschenow constant (Ks)

S.No.	Hydrotrop	303 K	313 K	323 K	333 K
1	Diethyl nicotinamide	0.41	0.49	0.50	0.51
2	Sodium pseudocumene sulfonate	0.41	0.43	0.44	0.46
3	Sodium thiocyanate	0.43	0.47	0.55	0.59

Association model

The solubility values were fitted into an association model for the hydrotropic solubilization which shows the aggregation behavior of hydrotrope and succeeding interaction of a solute with the hydrotrope assemblies. The model describes the hydrotrope-hydrotrope and hydrotrope-solute interactions with the mass-action law,

$$H1 + H1 \overset{K2}{\rightarrow} H2\,, H2 + H1 \overset{K3}{\rightarrow} H3\,, H3 + H1 \overset{K4}{\rightarrow} H4\,,\ Hn-1 + H1 \overset{Kn}{\rightarrow} Hn \tag{2}$$

Through the hypothesis that hydrotrope molecules associate in a step-by-step manner to form oligomers and multimers such that the association constant gets to be weaker on addition of succeeding hydrotrope molecules. The association constant for an *n*-mer of hydrotrope with a monomer is related to the dimerization constant (K_2, L/mol), *i.e*., Kn = K_2/n. The concentration of a monomeric hydrotrope molecule, [H1], is related to the total hydrotrope concentration (CS, mol/L) through the following equations.

$$Cs = \sum_{n=1}^{\infty} n[Hn]. \text{ or } Cs = [H1]\{2\exp(K2[H1]) - 1 \tag{3}$$

Moreover, the model adopts that the hydrotrope assemblies co solubilize the solute, where an *n*-mer is capable of take up a maximum of "(n - 1)" solute molecules and that the solutes association with the hydrotrope assemblies gets to be weaker on addition of an extra solute molecule in the same manner as the hydrotrope aggregation method. The total solute concentration associated with all hydrotrope aggregates is given by eq 4.

$$S_T = 2[S_1]\left(\frac{Ks}{K2}\right)\left(e^{K2}[H] - \langle 1 + K2[K1]\rangle\right) \tag{4}$$

The hydrotrope-solute interaction constant (K_S, L/mol) and hydrotrope-hydrotrope interaction constant (K_2) were consequently, calculated for each pair of amino nitrobenzene and hydrotrope by fitting the experimental solubility data in eq 3 and 4. The solubility data of *m*- amino nitrobenzene, above the MHC of each hydrotrope, was fitted into the aforesaid modified association model. The equations are nonlinear and a nonlinear least-squares approach had to be adopted. The free solute concentration in the solution [S_1], mol/L) was taken equal to the solubility of *m*- amino nitrobenzene and *p*- amino nitrobenzene in water, at the corresponding temperatures. The values of K_S and K_2 for hydrotropes at different temperatures are given in Table 4. The Association model essentially predicts an increase in the solubility of the solute. Table 4 shows that hydrotrope-hydrotrope association constant (K_2) to be much smaller than that of the hydrotrope- solute interaction constant (K_S) for all hydrotropes. While the hydrotrope aggregates are shaped in aqueous solutions, their aggregation trend is much weaker than that of solute-hydrotrope co aggregation. With the increase in temperature, the interaction constants K_S and K_2 also increase. Probably, temperature causes a significant modification in the aggregate structures, thereby causing more solutes to be solubilized in the hydrotrope solutions. It indicates that *m*- amino nitrobenzene - dimethylbenzamide interactions are clearly the strongest compare to other hydrotrops.

Table 4. Hydrotrope-Solute (K_s), Hydrotrope-Hydrotrope (K_2) Association Constants

Hydrotrops	T, K	K_2, L/mol	Ks, L/mol
Diethyl nicotinamide	303	0.071	44.8
	313	0.076	44.6
	323	0.079	44.9
	333	0.079	44.2
Sodium pseudocumene sulfonate	303	0.142	60.2
	313	0.144	60.4
	323	0.144	60.6
	333	0.146	60.3
Sodium thiocyanate	303	0.235	88.3
	313	0.269	88.9
	323	0.302	87.5
	333	0.325	88.4

Mass-transfer coefficient

The mass transfer coefficient of the m- amino nitrobenzene + water system in the absence of any hydrotrope is 8.6 x 10-3 s^{-1} at 303 K (Table 5). The effect of different hydrotropes on the mass transfer coefficient of *m*- amino nitrobenzene at different hydrotrope concentrations is also given in the same table. It can be seen that a threshold value of 0.30 mol/L is needed to affect significant enhancement in the mass transfer coefficient of *m*- amino nitrobenzene + water system, as observed in the case of solubility determinations. The mass transfer coefficient of *m*- amino nitrobenzene + water system increases with increase in sodium thiocyanate concentration. A similar tendency in the mass transfer coefficient of *m*- amino nitrobenzene has been observed for other hydrotropes also, namely, diethyl nicotinamide and sodium pseudocumene sulfonate.

Table 5. Effect of hydrotrope concentration (C) on the mass-transfer coefficient (k_La) of *m*- amino nitrobenzene

Hydrotropes	C, mol/L	10^3K_La, S^{-1}
Diethyl nicotinamide	0	8.6±0.15
	0.2	9.7±0.16
	0.5*	12.6±0.22
	1	18.4±0.35
	1.4	23.5±0.47
	1.8	30.5±0.61
	2.4**	40.7±0.77
Sodium pseudocumene sulfonate	0	8.6±0.15
	0.2	9.3±0.16
	0.4*	10.3±0.20
	0.8	24.7±0.47
	1.4	33.4±0.64
	1.8	42.15±0.80
	2.40**	48.7±0.95
Sodium thiocyanate	0	8.6±0.15
	0.1	10.2±0.16
	0.3*	14.4±0.24
	1.4	25.81±0.45
	1.8	41.1±0.78
	2	49.8±0.97
	2.2**	60.2±0.21

*-- *MHC*; **--C_{max}

Conclusion

Selective solubilization of isomeric combinations of m/*p*- amino nitrobenzene was determined in aqueous solutions of a number of hydrotropes at different hydrotrope concentrations and temperatures. The MHC and C_{max} values of hydrotropes with respect to *m*- amino nitrobenzene can be used for the recovery of the dissolved *m*- amino nitrobenzene and hydrotrope solutions at any hydrotrope concentration between MHC and C_{max} by simple dilution with distilled water. It was potential to extract 81% of the material and the technique was optimized with respect to concentration of hydrotrope solution. From the data obtained by this research to be found that individual components using a step-by-step aggregation model indicated a weaker hydrotrope aggregation process but a much stronger hydrotrope–solute association. The association model predicted the trend in the solubility of the isomers, including selectivity in the solubilization of a particular isomer from the mixture. These sigmoidal-type solubility deviations are controlled by molecular structures. The differences in solubilities with hydrotrope concentration and temperature can be employed for the separation of closely related compounds. This will eliminate the huge cost and energy normally concerned in the separation of solubilized *m*- amino nitrobenzene from its solution. Hence sodium thiocyanate is found to be the best suitable hydrotrope for the enhancement of solubility of poorly soluble *m*- amino nitrobenzene within the framework of the current research.

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