CHAPTER 8

CONCLUSIONS

8.1 CONCLUSIONS

(a) This comprehensive study on the effect of hydrotropes on the solubility and mass transfer coefficient of a series of organic acids and alizarin under a wide range of hydrotrope concentrations at different temperatures gives rise to the following conclusions.

1. All hydrotropes used in this work enhance the solubility and mass transfer coefficient of organic acids and alizarin studied significantly.

2. A Minimum Hydrotrope Concentration (MHC) in the aqueous phase is found to be essential for the initiation of the hydrotropic solubilization of organic acids and alizarin.

3. On the same lines, a threshold value, which is nothing but MHC is found necessary to bring significant increase in the mass transfer coefficient of organic acids and alizarin.

4. MHC values of different hydrotropes used in this study range between 0.30 and 0.60 mol/L with respect to a
series of organic acids and alizarin. However such values of a particular hydrotrope are in the narrow range.

5. MHC values seem to depend on the hydrophilicity of a hydrotrope. However, for few acid-hydrotrope systems, the hydrophobicity of the solute also contributes to some extent in determining such values.

6. The maximum concentration of hydrotropes in most cases approaches the values between 2.00 and 2.50 mol/L and further increase in hydrotrope concentration does not bring any significant increase in the solubility of the organic acids studied.

7. Any change in system temperature has negligible effect on MHC and $C_{\text{max}}$ values of the hydrotrope.

8. Even though the hydrotropic solubilization exists in a region between MHC and the effect of hydrotropes is found to be predominant at hydrotropic concentrations close to $C_{\text{max}}$ in most cases.

9. The solubilization effect of hydrotrope increases with increase in hydrotrope concentration and also with system temperature.

10. Consequent to the increase in the solubility of acids and alizarin, the mass transfer coefficient of acids and alizarin was also found to increase with increase in hydrotrope concentration.
11. As the system temperature increases, lesser hydrotrope concentration is adequate in the aqueous phase to achieve the solubility of the acid and alizarin to a certain value, which was obtained with higher hydrotrope concentration at the lower temperature.

12. The solubilization effected by hydrotropes is not a linear function of the hydrotrope concentration.

13. The order of increase in the solubility and mass transfer coefficient of the organic acids studied is

   Alizarin > p-Hydroxybenzoic acid > p-Nitrobenzoic acid > Benzoic acid > Cinnamic acid.

14. The values of $K_s$, Setschenow constant determined for each acid and alizarin at different temperatures can be considered as a measure of the effectiveness of a hydrotrope. The order of effectiveness of various hydrotropes based on such values is,

   Sodium salicylate > Sodium benzoate > Nicotinamide > Urea for benzoic acid and p-hydroxybenzoic acid

   For p-nitrobenzoic acid and cinnamic acid, the order is
   Sodium benzoate > Sodium salicylate > Nicotinamide > Urea

   For alizarin, the order of effectiveness of various hydrotropes is
Potassium p-toluene sulfonate > Sodium salicylate > Sodium benzoate > Nicotinamide > Urea.

15. The values of hydrotrope-hydrotrope association constant \(K_2\) and hydrotrope-solute association constant \(K_{hs}\) for all acids under study and alizarin can be considered as a measure of the aggregation behavior of hydrotrope and the solubilization of solutes.

16. The association constants \((K_{hs}, K_2)\) effected by sodium salicylate is much higher for organic acids such as benzoic acid, p-hydroxybenzoic acid while for sodium benzoate association constants \((K_{hs}, K_2)\) for p-nitrobenzoic acid and cinnamic acid is higher.

17. For each acid studied, the best one among the four hydrotropes has been selected for obtaining maximum solubilization. Such data can also be used for effective separation of the particular organic acid from hydrotrope solution.

18. The deviation from linearity of solution properties of hydrotropes at MHC can be taken as an indication of an aggregate formation. Such a trend may also be considered as a characteristic of the hydrotrope solubilization.

19. The difference in surface tension and other allied solution properties of hydrotrope aggregates with respect to aqueous solution acquired at MHC may be the factor responsible for solubilization of the solute into the aqueous phase at this particular concentration.
20. The increase in solubilizing effect of hydrotropes with increase in hydrotrope concentration may be due to the availability of more aggregates for interaction with the solute molecules at the existing conditions of the aqueous phase.

21. The saturation of the solubilizing effect of hydrotropes beyond $C_{\text{max}}$ may be due to the non-availability of water molecules to form further aggregates comprising of additional MHC agglomerates.

22. An artificial neural network model was developed to predict the solubility of organic acids and alizarin in aqueous hydrotrope solutions.

23. A good agreement was found between the experimental and predicted solubility data with the applicable ANN approach.

24. The ANN model results yielded low root mean square error which indicates that the ANN model is suitable for estimating solubility of acids and alizarin in hydrotrope solutions with high accuracy.

(b) The conclusions drawn from the study on extraction of mangiferin from mango leaves using hydrotrope solution.

1. The yield of mangiferin is maximum at higher sodium salicylate concentration (2 mol/L).

2. The sodium salicylate concentration and raw material loading has significant effect on extraction process
3. The extraction variables are optimized using Response Surface Method (RSM)

4. This method is cost effective and environmental friendly, since it eliminates the organic solvents.

8.2 TECHNICAL AND ECONOMICAL FEASIBILITY OF THE PRESENT STUDY

The study on hydrotropic phenomenon has the following practical implications at the industrial levels.

1. The solubility and mass transfer coefficient of sparingly soluble organic solutes has been increased significantly in the presence of hydrotropes. These characteristics of hydrotropes would be much useful in increasing the rate of output of the desired products made from such organic solutes.

2. The separation of such compound from any liquid mixture which is found to be difficult, until now can be carried out effectively.

3. This study provides the cheapest and most effective solubilization technique, since huge cost and energy normally involved in the separation of the solubilized material from its solution is totally eliminated.

8.3 SCOPE FOR FUTURE WORK

1. It would be worthwhile investigating the effect of hydrotropes towards other organic solutes such as alcohols, aldehydes and ketones, whose solubility in water is negligible and which are useful in process industries.
2. The purity of bioactive compounds can be improved by carrying out the experiments with various hydrotopes.

3. Crystallization studies can be carried in the presence of hydrotopes to increase the purity of bioactive compounds extracted.

4. This hydrotropic technique can be used to increase the kinetics of reactions.

8.4 SUMMARY OF THE CHAPTERS

The thesis is divided into eight chapters. Chapter 1 deals with the introductory remarks on the need for undertaking hydrotrope study and the scope of the present investigation.

Chapter 2 is concerned with the absence of data on the study of hydrotopes on a series of organic acids and alizarin. However a summary on the different types of hydrotopes used for the study of esters and other solutes was given. The literature review provides the background and guidance for the scope of the present work.

In chapter 3, the experimental procedures used for the determination of solubility and mass transfer coefficient of acids and alizarin in different hydrotrope solutions were described. The experimental procedures used for the measurement of various properties such as viscosity, specific gravity, surface tension, specific conductance and refractive index of hydrotrope solution were also discussed. The experimental procedure used for the extraction of mangiferin from mango leaves was also described.

Chapter 4 presents extraction studies of mangiferin from mango leaves using hydrotrope solutions. It has two sections. Section one explains
the mechanism of hydrotropic extraction and selection of hydrotropes. Section two discusses response surface methodology for experimental design to evaluate the combined effect of three variables such as hydrotropic concentration, system temperature and loading of raw material.

Chapter 5 discusses the application of the Artificial Neural Network (ANN) in predicting the solubility of organic solutes. It also explains about the mechanism of ANN model and its architecture for predicting the solubility. This procedure helps to predict the solubility of organic acids and alizarin in hydrotrope solutions using ANN with maximum accuracy.

Chapter 6 has four sections. In section one and two the minimum and maximum concentration range of hydrotropes used were discussed while in section three and four hydrotropic region and the effect of temperature were discussed.

Chapter 7 presents the results of the experimental investigation on the solubility and mass transfer coefficient of the solid-liquid systems studied. This chapter has seven sections.

Section one discusses the effect of hydrotropes on the solubility of solutes and the section two presents the effect of hydrotropes on the mass transfer coefficient of solutes. It was observed that the solubility increases with increase in hydrotrope concentration and also with system temperature. Consequent to the increase in the solubility of the solute, the mass transfer coefficient was also found to increase in hydrotrope concentration. The enhancement factor, $\phi$, which is the ratio of the value in the presence and absence of a hydrotrope is determined for both solubility and mass transfer coefficient.

Section three discusses the effectiveness of hydrotropes based on Setschenow constant ($K_s$) value of each hydrotrope towards solutes and its
significance. In section four association constant (K_{2} and K_{in}) determined from association model which are used to represent the solubilization of organic acids and alizarin in hydrotrope solutions were presented.

The influences of solution properties such as viscosity, specific gravity, surface tension, specific conductance and refractive index on the possible mechanism for the solubilizing effect of hydrotropes were discussed in the section five.

Section six presents the result obtained using artificial neural network model. The predicted results were compared with experimental values and statistically discussed.

Section seven discusses the extraction of mangiferin from mango leaves using hydrotrope solutions. In this section the experimental data obtained were statistically analyzed using response surface methodology.

In the concluding chapter 8, the salient feature drawn from the present study of hydrotropes on various organic compounds and extraction of mangiferin have been summarized and scope for future research is suggested.