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Solubility Determination of Tris(hydroxymethyl)aminomethane in Water + Methanol Mixtures at Various Temperatures Using a Laser Monitoring Technique

Vahid Jouyban-Gharamaleki,[†] Karim Jouyban-Gharamaleki,[‡] Jafar Soleymani,[§] William E. Acree, Jr.,[∥] and Abolghasem Jouyban*[,⊥,#]

[†]Department of Mechatronic Engineering, International Campus, University of Tabriz, Tabriz, Iran

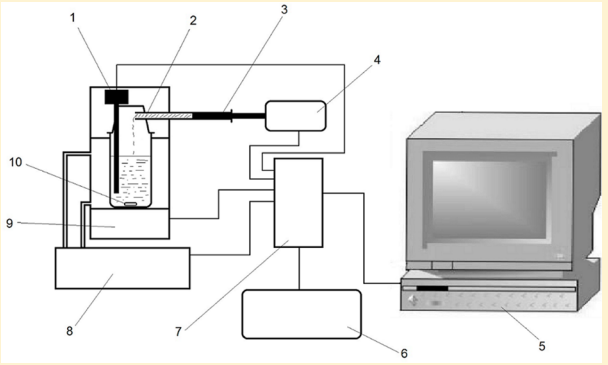
[‡]Tabriz Technical Training Center, No. 2, Tabriz, Iran

[§]Liver and Gastrointestinal Diseases Research Center and [⊥]Drug Applied Research Center and Faculty of Pharmacy, Tabriz University of Medical of Sciences, Tabriz 51664, Iran

[∥]Department of Chemistry, University of North Texas, Denton, Texas 76203-5070, United States

[#]Pharmaceutical Engineering Laboratory, School of Chemical Engineering, College of Engineering, University of Tehran, P.O. Box 11155/4563, Tehran, Iran

ABSTRACT: The solubility of tris(hydroxymethyl)-aminomethane (TRIS) in various mass fractions of water + methanol solvent mixtures at (293.2, 298.2, 303.2, 308.2, and 313.2) K was measured using a laser monitoring technique. The generated data were mathematically represented using the Jouyban−Acree model. The back-calculated mole fraction solubilities are in good agreement with the corresponding experimental values as documented by an overall mean percentage deviation of 3.2 %.



INTRODUCTION

Solubility data enable researchers to select the most appropriate solvent system for solubilization or crystallization of a solute. Mixed solvents provide "tunable polarity solvents" to alter the solubility of a given solute. These mixtures are also used as mobile phases and/or solvents for the background electrolytes in analytical separation methods such as high-performance liquid chromatography (HPLC) or capillary electrophoresis (CE) where the low solubility of electrolytes at higher concentrations of the organic solvent might be a limiting parameter. Mixed solvents applied in this context may improve the solubility of the analyte, the resolution of the peaks of various analytes, or determine other relevant analytical parameters like pK_a values, partition coefficients, or electrophoretic and electroosmotic mobilities.[1]

Tris(hydroxymethyl)aminomethane (TRIS) with the Chemical Abstract Service number of 77-86-1 and acid dissociation constant (pK_a) of 8.1 is a common buffering agent. The solubility of TRIS in water + methanol mixtures at (288.15, 298.15, and 308.15) K (measured by acidimeteric titration of the saturated solutions),[2] in water + 2-methoxyethanol mixtures at (288.15, 298.15, and 308.15) K (measured by acidimeteric titration of the saturated solutions),[3] in water + 1,4-dioxane mixtures at 298 K,[4] in water + ethanol mixtures at 298 K,[5] in methanol + propylene glycol at 298 K,[6] in ethylene glycol + water at 298 K,[7] in *N*-methylpropionamide + water at 298 K,[8] in acetonitrile + ethylene glycol at 298.15 K,[9] in water + 2-ethoxyethanol,[10] and in water + sulfolane[11] has been reported in the literature.

A quick survey on the published HPLC and CE methods for pharmaceutical analysis showed that TRIS buffer has been used primarily in the following binary solvent systems. The most frequently used mixed solvents are water + acetonitrile (55 %), followed by water + methanol (36 %), water + ethanol (4 %), methanol + acetonitrile (3 %), and water + 1-propanol (2 %).[12]

Because of this high practical importance, it was our intention to measure the solubility of TRIS in binary aqueous mixtures of methanol at different temperatures for validating a lab-made setup and to extend the available database of solubilities.[13] To enable the calculation of the solubility of TRIS at any composition of the binary solvent mixture and temperatures, we fitted the data to the Jouyban−Acree model and its combined version with the van't Hoff equation.

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Table 1. List of the Used Materials

material	purity/in mass fraction	company	country
TRIS: tris(hydroxymethyl)aminomethane (CASRN of 77-86-1)	0.999	Merck	Germany
MeOH	0.999	Scharlau	Spain
water	conductivity < 1.5 $\mu S \cdot cm^{-1}$	lab made	

EXPERIMENTAL SECTION

Materials. TRIS (with the stated purity of 0.999 in mass fraction) was purchased from Merck (Germany). MeOH (0.999 mass fraction purity) was purchased from Scharlau (Barcelona, Spain). Double-distilled water was used for the preparation of the solutions. All reagents were used as received from the company without further purification. The list of materials used is shown in Table 1.

Instrumentation. The most common method for determination of the thermodynamic solubility of a solute is the shake-flask method of Higuchi and Connors.[14] The synthetic method,[15,16] which is also called the laser monitoring technique,[17] the last crystal disappearance method,[18] and the dynamic method[19] is the second most common method for determination of thermodynamic solubility of a solute. The latter technique is based on the disappearance of the solid solute (from the mixture of solvent and solute) as monitored by a laser beam. The TRIS solubility in water + methanol mixtures is determined using a lab-made setup. In the constructed setup (see Figure 1 for schematic representation), a glass syringe was used to dispense the solute powder to the dissolution vessel. Small diameter syringes are suitable for solutes having low solubilities since they dispense a very small mass of the powder in each dispensing, whereas larger diameters are suitable for relatively soluble solutes where larger masses of solutes are required for the saturation of the solution. The filled tube with solute powder was weighed using an electronic balance (Sartorius, Germany) with uncertainty of 0.01 g before and after saturation of the solution, and the mass difference determines the mass of solute added to saturate the solution. It should be noted that the masses of the solvents varied between (115.84 and 148.83) g, and those of the solute + syringe varied between (0.10 and 4.00) g. The saturated concentration of the solution is calculated using the mass of the solvent added to the dissolution vessel. After reaching the experimental temperature, the setup adds a small amount of solute powder to the solution, and the contents were stirred continuously at a constant temperature with the uncertainty of ± 0.1 K. As the particles of the solute are dissolved, the signals indicating the number of particles decreases gradually and reaches to the minimum value when the solute is completely dissolved. Then another mass of the solute is dispensed to the vessel, and the procedure is repeated until the laser beam could not return to the minimum value which means the last added powder could not be dissolved. This cycle has been checked several times by the software, and then the system was stopped, and the total amount of the added drug is recorded and used to calculate the solubility value. The signals for neat solvents are considered as the minimum intensity of the signals detected by the photo convertor. Further details of the setup have been provided in an earlier work.[20] The setup was validated by measuring the solubility of acetaminophen in water, ethanol, and propylene glycol at various temperatures and comparing the data with available data from the literature in which the overall mean percentage of 14 % was obtained.[20]

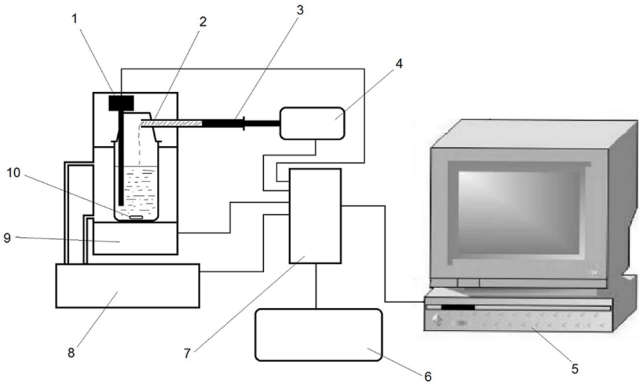

Figure 1. Schematic representation of the setup; 1: laser generator and photoelectronic convertor, 2: drug powder, 3: dispensing syringe, 4: syringe actuator, 5: display system, 6: power supply, 7: data processor and controller, 8: thermostate system, 9: magnetic stirrer, and 10: stir bar.

Calculations. The average of at least triplicate measurements was used to calculate the mole fraction solubility of TRIS. The solvents 1 and 2 masses (m_1 and m_2) were divided to their molar masses (MW_1 and MW_2) and then the mole fractions of solvents 1 and 2 in the absence of the solute (x_1^0 and x_2^0) were computed using

$$x_i^0 = \frac{m_i/MW_i}{(m_1/MW_1 + m_2/MW_2)} \quad (1)$$

The saturated mole fraction solubility of TRIS ($x_{m,T}$) in different compositions of the binary solvents at various temperatures was calculated using

$$x_{m,T} = \frac{m_{TRIS}/MW_{TRIS}}{(m_{TRIS}/MW_{TRIS} + m_1/MW_1 + m_2/MW_2)} \quad (2)$$

where m_{TRIS} and MW_{TRIS} are the mass of added TRIS to the solution and molar mass of TRIS (121.14 $g \cdot mol^{-1}$), respectively. Evaluation of the accuracy of the calculated data was performed by computing the mean percentage deviations (MPD) between calculated and experimental solubilities according to

$$MPD = \frac{100}{N} \sum \left[\frac{x_{m,T}^{calculated} - x_{m,T}^{exp\ erimental}}{x_{m,T}^{exp\ erimental}} \right] \quad (3)$$

where N is the number of data points in each set.

RESULTS AND DISCUSSION

Experimental Solubility Data. Table 2 lists the experimental mole fraction solubility of TRIS in various mole fractions of water (1) + methanol (2) mixtures at (293.2, 298.2, 303.2, 308.2, and 313.2) K. The generated aqueous solubilities of TRIS at (298.2 and 308.2) K are in good agreement with previously reported data of 0.0939 and 0.1141.[3] There is also excellent agreement between generated solubility data at (298.2

Table 2. Experimental Mole Fraction Solubility[a] of Tris(hydroxymethyl)aminomethane (TRIS) in Binary Mixtures of Water (1) + Methanol (2) at Various Temperatures and Atmospheric Pressure (0.1 MPa)

x_1^{0b}	293.2 K	SD	298.2 K	SD	303.2 K	SD	308.2 K	SD	313.2 K	SD
1.00	0.0831	0.0003	0.0920	0.0001	0.1013	0.0001	0.1099	0.0013	0.1228	0.0001
0.95	0.0766	0.0009	0.0860	0.0011	0.0954	0.0009	0.1077	0.0014	0.1186	0.0021
0.90	0.0721	0.0007	0.0824	0.0008	0.0930	0.0010	0.1042	0.0009	0.1157	0.0012
0.84	0.0672	0.0011	0.0759	0.0006	0.0874	0.0003	0.0978	0.0005	0.1101	0.0003
0.77	0.0613	0.0003	0.0710	0.0001	0.0814	0.0001	0.0928	0.0005	0.1039	0.0004
0.69	0.0539	0.0006	0.0622	0.0003	0.0712	0.0006	0.0826	0.0003	0.0945	0.0003
0.60	0.0469	0.0001	0.0539	0.0001	0.0633	0.0003	0.0727	0.0001	0.0846	0.0003
0.49	0.0351	0.0006	0.0426	0.0004	0.0501	0.0004	0.0594	0.0004	0.0690	0.0000
0.36	0.0259	0.0002	0.0318	0.0003	0.0373	0.0005	0.0453	0.0002	0.0551	0.0002
0.20	0.0169	0.0002	0.0203	0.0004	0.0257	0.0002	0.0299	0.0003	0.0359	0.0003
0.00	0.0076	0.0002	0.0092	0.0003	0.0106	0.0003	0.0124	0.0004	0.0158	0.0003

[a]Data are the mean of three measurements. SD: standard deviation. The relative standard uncertainty for the solubilities is 1 % or $u_r(x) = 0.01$, the standard uncertainty for temperature is 0.1 K, and the measurements were made at atmospheric pressure. [b]x_1^0 is the mole fraction of solvent 1 in the absence of the solute.

and 308.2) K and the corresponding data taken from the literature[2] as shown in Figure 2. The good agreements reconfirm the validity of the developed setup in our laboratory for solubility determinations.

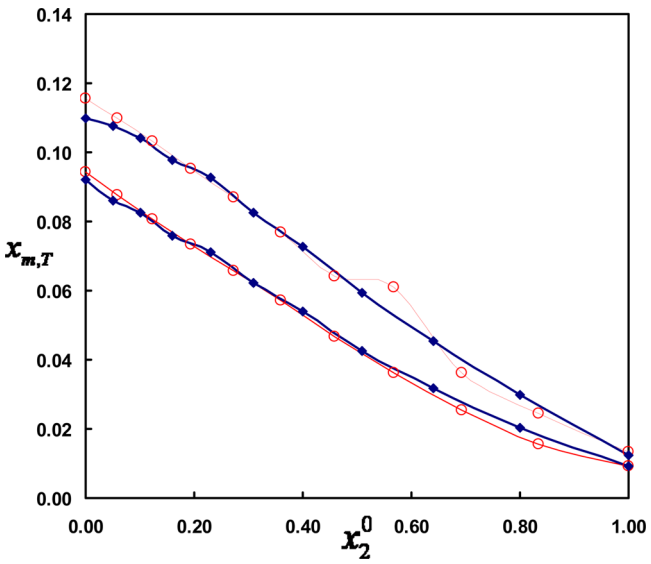

Figure 2. Comparison of measured mole fraction solubility of TRIS in various fractions of water + methanol mixtures (blue ◆) at (298 and 308) K versus data taken from the published literature[2] (red ○).

As expected, the solubility of TRIS in each solvent composition and also in the monosolvents increased with increasing temperature. The solubility data of TRIS in each solvent system at various temperatures (x_T) could be mathematically represented using the van't Hoff equation[21]

$$\ln x_T = A + \frac{B}{T} \tag{4}$$

where A and B are the model constants calculated using a least-square method. Table 3 lists the model constant and the MPD values for the back-calculated data using eq 4. Figure 3 shows the van't Hoff plot of the measured solubilities in the investigated solvent systems at different temperatures. There are very good linear relationships between ln x_T and $1/T$ as expected for the temperature range in this study.

Table 3. Model Constants for van't Hoff Equation for Various Mole Fractions of Water (x_1^0) and the Obtained Mean Percentage Deviation (MPD) for Back-Calculated Solubilities Using eq 4

x_1^0	A	B	MPD
1.00	3.52	−1759.98	0.5
0.95	4.30	−2015.17	0.4
0.90	4.77	−2167.62	0.4
0.84	5.08	−2280.49	0.4
0.77	5.51	−2433.46	0.6
0.69	5.89	−2582.76	0.4
0.60	6.19	−2713.86	0.6
0.49	7.21	−3093.93	0.6
0.36	7.99	−3412.60	1.0
0.20	7.82	−3489.20	1.1
0.00	6.07	−3211.66	2.4
		overall	0.7

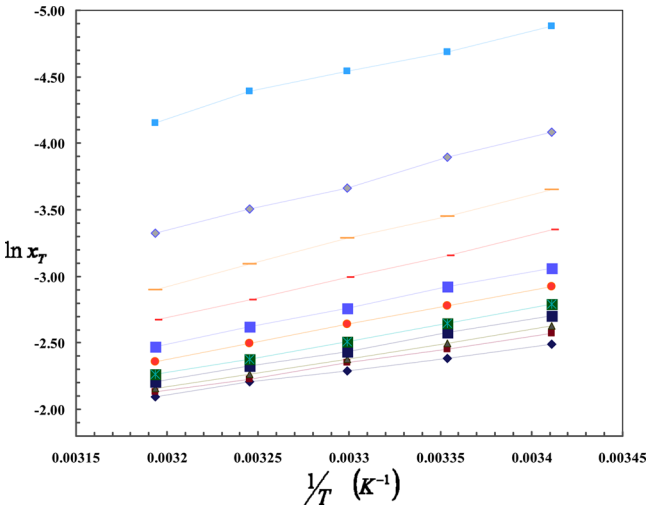

Figure 3. Logarithm of the experimental mole fraction solubility of TRIS in water + methanol mixtures as a function of temperature (the mole fraction of water is blue ◆, 0.00; red ■, 0.20; green ▲, 0.36; dark purple ■, 0.49; green ∗ in ■, 0.60; orange ●, 0.69; light purple ■, 0.77; orange —, 0.84; yellow —, 0.90; light purple ◆, 0.95; light blue ■, 1.00).

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Using the combined nearly ideal binary solvent/Redlich–Kister equation,[22] the solubility of TRIS in various compositions of the binary solvent mixtures at a given temperature could be represented as

$$\ln x_m = x_1^0 \ln x_1 + x_2^0 \ln x_2 + [x_1^0 x_2^0 \sum_{i=0}^{2} S_i (x_1^0 - x_2^0)^i] \quad (5)$$

where x_m and x_1 and x_2 are the mole fraction solubility of TRIS in the solvent mixtures and the monosolvents 1 and 2 at a given temperature, and S_i are the constants of the model calculated using a no-intercept least-square analysis. Table 4 lists the numerical values of the model constants of eq 5 and the obtained MPD values for the back-calculated solubility data.

Table 4. Model Constants of eq 5 and the MPD and OMPD Values for Back-Calculated Solubilities in Water + Methanol Mixtures at Various Temperatures (K)

T/K	S_0	S_1	S_2	MPD
293.2	457.38	−123.56		1.5
298.2	499.12	−138.46		0.8
303.2	548.07	−230.2	218.80	1.5
308.2	616.69	−234.51	232.96	0.6
313.2	607.96	−240.01	151.64	0.6
			OMPD	1.0

The model has been extended to represent both solvent composition and temperature effects on solubility as[23]

$$\ln x_{m,T} = x_1^0 \ln x_{1,T} + x_2^0 \ln x_{2,T} + \left[\frac{x_1^0 x_2^0}{T} \sum_{i=0}^{2} J_i (x_1^0 - x_2^0)^i\right] \quad (6)$$

where $x_{m,T}$ is the molar solute solubility in the solvent mixtures at absolute temperature T, $x_{1,T}$ and $x_{2,T}$ denote the mole fraction solubility of TRIS in the monosolvents 1 and 2, respectively, and J_i are the constants (expressed in K units) of the model computed by a regression analysis. The model has been used to represent other physicochemical properties and renamed as the Jouyban–Acree model.[24] Equation 6 is able to predict the solubility of a solute in mixed solvents at various T once the equation coefficients are obtained from a training process. The only required input data are the $x_{1,T}$ and $x_{2,T}$ values. The solubility data at all temperatures were fitted to eq 6, and the obtained model is

$$\ln x_{m,T} = x_1^0 \ln x_{1,T} + x_2^0 \ln x_{2,T} + \frac{x_1^0 x_2^0}{T} \cdot [540.780 - 193.896(x_1^0 - x_2^0) + 133.545(x_1^0 - x_2^0)^2] \quad (7)$$

which correlated the data with the correlation coefficient of 0.99 which is a significant correlation with $p < 0.0005$. The obtained MPD value for the back-calculated solubility data was 3.2 ± 2.8 % (N = 55). As it has been shown in earlier works, eq 6 could be trained using solubility data at 298 K, and the solubility at other temperatures could be predicted employing the experimental solubility data in the monosolvents at other temperatures.[25−27] The obtained MPD for predicted solubility data was 4.3 ± 3.7 % (N = 36).

The Jouyban–Acree model could be combined with the van't Hoff model as[28,29]

$$\ln x_{m,T} = x_1^0\left(A_1 + \frac{B_1}{T}\right) + x_2^0\left(A_2 + \frac{B_2}{T}\right) + \left[\frac{x_1^0 x_2^0}{T} \sum_{i=0}^{2} J_i (x_1^0 - x_2^0)^i\right] \quad (8)$$

to provide a more versatile predictive equation where no further experimental data are required after training process of the model. The trained model from combining trained van't Hoff equations using x_1^0 = 0.00 and x_1^0 = 1.00 and J terms from eq 7 is

$$\ln x_{m,T} = x_1^0\left(3.515 - \frac{1759.978}{T}\right) + x_2^0\left(6.070 - \frac{3211.659}{T}\right) + \frac{x_1^0 x_2^0}{T}[540.780 - 193.896(x_1^0 - x_2^0) + 133.545(x_1^0 - x_2^0)^2] \quad (9)$$

which back-calculates the solubility data with the MPD of 3.2 ± 2.6 % (N = 55). Equation 8 could be trained using the solubility data at two temperatures (the lowest and highest temperatures of interest) and then be used to predict the solubility of other temperatures and solvent compositions using an interpolation technique. The obtained MPD value for this predictive analysis is 2.2 ± 1.7 % (N = 33). Graphical representation of the predicted solubility data at three temperatures by eq 8 trained using the solubility data at two temperatures has been shown in Figure 4.

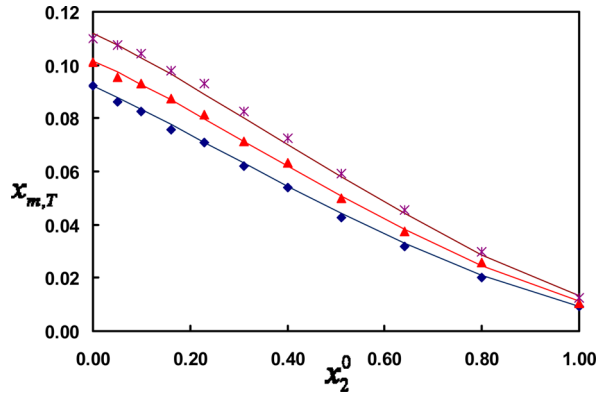

Figure 4. Comparison of predicted solubility data of TRIS in water + methanol mixtures (lines) at (298.2, 303.2, and 308) K with the corresponding experimental data (blue ◆, red ▲, or purple ∗).

CONCLUSIONS

We have reported the experimental apparent solubilities of TRIS in water + methanol mixtures at (293.2, 298.2, 303.2, 308.2, and 313.2) K and provided a trained version of the Jouyban–Acree model combined with the van't Hoff equation to predict the solubility of TRIS at any composition of the water + methanol mixtures at a temperature of interest. This work extends the available solubility database of solutes in mixed solvents,[13] and also the results could be employed for practical purposes, e.g., for crystallization procedures in the chemical industry or for methods like liquid chromatography or

capillary electrophoresis. TRIS buffer plays an important role in these analytical techniques.

AUTHOR INFORMATION

Corresponding Author

*E-mail: ajouyban@hotmail.com and jouyban@ut.ac.ir. Fax: +98 4113363231.

Notes

The authors declare no competing financial interest.

REFERENCES

(1) Jouyban, A.; Kenndler, E. Capillary Electrophoresis with Organic Solvents in Pharmaceutical Analysis: A Systematic Guide Through the Background. *Curr. Anal. Chem.* **2014**, *10*, 248−266.

(2) Schindler, P.; Robinson, R. A.; Bates, R. G. Solubility of Tris(hydroxymethyl)aminomethane in Water − Methanol Solvent Mixtures and Medium Effects in the Dissociation of the Protonated Base. *J. Res. Natl. Bur. Stand.* **1968**, *72A*, 141−148.

(3) El-Harakany, A. A.; Barakat, A. O. Solubility of Tris-(hydroxymethyl)aminomethane in Water − 2-Methoxyethanol Solvent Mixtures and the Solvent Effect on the Dissociation of the Protonated Base. *J. Solution Chem.* **1985**, *14*, 263−269.

(4) Taha, M.; Lee, M. Buffer Interactions: Densities and Solubilities of Some Selected Biological Buffers in Water and in Aqueous 1,4-Dioxane Solutions. *Biochem. Eng. J.* **2009**, *46*, 334−344.

(5) Taha, M.; Lee, M. Buffer Interactions: Solubilities and Transfer Free Energies of TRIS, TAPS, TAPSO, and TABS from Water to Aqueous Ethanol Solutions. *Fluid Phase Equilib.* **2010**, *289*, 122−128.

(6) Kund, K. K.; De, A. L.; Das, M. N. Studies in Some "Isodielectric" Media. Part IV. Solvent Effect on the Proton Transfer Equilibria of Some Acids in Methanol − Propylene Glycol at 25 °C. *J. Chem. Soc., Dalton Trans.* **1972**, *3*, 386−391.

(7) Kund, K. K.; Das, M. N. Solvent Effect on the Dissociation of Protonated Tris(hydroxymethy1)-methylamine and p-Nitroanilinium Ion in Water −Ethylene Glycol Media at 25 °C. *J. Chem. Soc., Dalton Trans.* **1972**, 2063−2069.

(8) Bates, R. G.; Falcone, J. S., Jr.; Ho, A. Y. W. Transfer Energies and Solute-Solvent Effects in the Dissociation of Protonated Tris in N-Methylpropionamide−water solvents. *Anal. Chem.* **1974**, *46*, 2004−2008.

(9) Bose, K.; Kundu, K. K. Proton-Transfer Equilibria in Isodielectric Acetonitrile−Ethylene Glycol Mixtures at 298.15 K. *J. Chem. Soc., Dalton Trans.* **1979**, 1208−1213.

(10) Barakat, A. O.; El-Harakany, A. A.; Adel-Maboud, A. A. Solvent Effects on the Thermodynamics of Transfer of Tris(hydroxymethyl)-aminomethane in Water − 2-Ethoxyethanol Mixtures. *Alexandria J. Pharm. Sci.* **1994**, *8*, 121−124.

(11) El-Harakany, A. A.; El-Dessouky, M. A.; Taha, A. A.; Bassiony, A. F. Solubilities and Thermodynamics Functions of Transfer of Substituted Benzoic Acids and Aliphatic Amine Derviatives from Water to Water-Sulfolane Mixtures at Different Temperatures. *Egyp. J. Chem.* **2002**, *45*, 1−32.

(12) Lunn, G. *HPLC Methods for Pharmaceutical Analysis*; John Wiley and Sons, Inc.: New York, 2000.

(13) Jouyban, A. *Handbook of Solubility Data for Pharmaceuticals*; CRC Press: Boca Raton, FL, 2010.

(14) Higuchi, T.; Connors, K. A. Phase Solubility Diagram. *Adv. Anal. Chem. Instrum.* **1965**, *4*, 117−212.

(15) Hankinson, R. W.; Thompson, D. Equilibria and Solubility Data for Methanol−Water-1-Nitropropane Ternary Liquid System. *J. Chem. Eng. Data* **1965**, *10*, 18−19.

(16) Ren, B. Z.; Chong, H. G.; Li, W. R.; Wang, F. A. Solubility of Potassium p-Chlorophenoxyacetate in Ethanol + Water from (295.61 to 358.16) K. J. *J. Chem. Eng. Data* **2005**, *50*, 907−909.

(17) Li, X.; Yin, Q.; Chen, W.; Wang, J. Solubility of Hydroquinone in Different Solvents from 276.65 to 345.10 K. *J. Chem. Eng. Data* **2006**, *51*, 127−129.

(18) Hao, H. X.; Hou, B. H.; Wang, J. K.; Zhang, M. J. Solubility of Erythriol in Different Solvents. *J. Chem. Eng. Data* **2005**, *50*, 1454−1456.

(19) Peisheng, M. A.; Qing, X. Determination and Correlation for Solubility of Aromatic Acids in Solvents. *Chin. J. Chem. Eng.* **2001**, *9*, 39−44.

(20) Jouyban-Gharamaleki, V.; Jouyban-Gharamaleki, K.; Shayanfar, A.; Khoubnasabjafari, M.; Jouyban, A. An Automated System for Determination of Drug Solubility Based on Laser Monitoring Technique. *J. Lab. Auto.* **2013**, submitted.

(21) Grant, D. J. W.; Mehdizadeh, M.; Chow, A. H. L.; Fairbrother, J. E. Non-Linear Van't Hoff Solubility-Temperature Plots and Their Pharmaceutical Interpretation. *Int. J. Pharmaceutics* **1984**, *18*, 25−38.

(22) Acree, W. E., Jr. Mathematical Representation of Thermodynamic Properties. Part II. Derivation of the Combined Nearly Ideal Binary Solvent (NIBS)/Redlich-Kister Mathematical Representation from a Two-Body and Three-Body Interactional Mixing Model. *Thermochim. Acta* **1992**, *198*, 71−79.

(23) Jouyban-Gharamaleki, A.; Acree, W. E., Jr. Comparison of Models for Describing Multiple Peaks in Solubility Profiles. *Int. J. Pharmaceutics* **1998**, *167*, 177−182.

(24) Jouyban, A. Review of the Cosolvency Models for Predicting Solubility of Drugs in Water-Cosolvent Mixtures. *J. Pharm. Pharmaceut. Sci.* **2008**, *11*, 32−58.

(25) Jouyban, A.; Acree, W. E., Jr. Comments on "Solubility of Ethyl Maltol in Aqueous Ethanol Mixtures". *J. Chem. Eng. Data* **2009**, *54*, 1168−1170.

(26) Ahmadian, S.; Panahi-Azar, V.; Fakhree, M. A. A.; Acree, W. E., Jr.; Jouyban, A. Solubility of Phenothiazine in Water, Ethanol, and Propylene Glycol at 298.2 to 338.2 K and Their Binary and Ternary Mixtures at 298.2 K. *J. Chem. Eng. Data* **2011**, *56*, 4352−4355.

(27) Fakhree, M. A. A.; Ahmadian, S.; Panahi-Azar, V.; Acree, W. E., Jr.; Jouyban, A. Solubility of 2-Hydroxybenzoic Acid in Water, 1-Propanol, 2-Propanol, and 2-Propanone at 298.2 to 338.2 K and Their Aqueous Binary Mixtures at 298.2 K. *J. Chem. Eng. Data* **2012**, *57*, 3303−3307.

(28) Jouyban, A.; Shayanfar, A.; Acree, W. E., Jr. Solubility Prediction of Polycyclic Aromatic Hydrocarbons in Non-Aqueous Solvent Mixtures. *Fluid Phase Equilib.* **2010**, *293*, 47−58.

(29) Shayanfar, A.; Eghrary, S. H.; Sardari, F.; Acree, W. E., Jr.; Jouyban, A. Solubility of Anthracene and Phenanthrene in Ethanol + 2,2,4-Trimethylpentane Mixtures at Different Temperatures. *J. Chem. Eng. Data* **2011**, *56*, 2290−2294.