

Further calculations on solubility of 2-chloro-3-(trifluoromethyl)pyridine in ethanol + 1-propanol solvent mixtures at various temperatures

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Abstract

The reported calculations on solubility data of 2-chloro-3-(trifluoromethyl)pyridine in binary ethanol + 1-propanol solvent mixtures at various temperatures have been reanalyzed and several additional points regarding the correlations were reported. In addition preferential solvation of 2-chloro-3-(trifluoromethyl)pyridine in ethanol + 1-propanol mixtures were investigated by means of the inverse Kirkwood-Buff integrals method. Apparently no preferential solvation of this compound by both organic solvents is observed because the respective parameters are lower than 0.01 in all the analyzed compositions.

Keywords: Solubility; Modelling; Jouyban-Acree model; Preferential solvation.

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In a recent paper appearing in this *Journal* [1], Wang and coworkers reported the experimental mole fraction solubilities of 2-chloro-3-(trifluoromethyl)pyridine dissolved in a number of mono-solvents and also in binary ethanol + 1-propanol mixtures at various temperatures ranging from 273.15 K to 303.15 K. The generated solubility data was mathematically represented by van't Hoff, Apelblat, λh and Wilson models. These models successfully correlated the solubility data in a given solvent and could be used to predict the solubility in the solvents at various temperatures. The aim of this communication is not to criticize the work of Wang et al. [1], but rather is to provide more computational results which are usually required in many practical applications.

The log-linear model of Yalkowsky employs the fractions of the solvents 1 and 2 and the solute's solubility in the mono-solvents to calculate the solubility at room temperature. It is presented as [2]:

$$\ln X_T = x_1^0 \ln X_1 + x_2^0 \ln X_2 \quad (1)$$

where x_1^0 and x_2^0 are mole fractions of solvents 1 and 2, X_1 and X_2 represent the solute's solubility in neat solvents 1 and 2, respectively. Using Eq. (1) and employing X_1 and X_2 values, the solubility in all possible compositions could be predicted. The obtained mean relative deviation (MRD) for the solubility of 2-chloro-3-(trifluoromethyl)pyridine in ethanol (1) + 1-propanol (2) mixtures is 8.4 ± 7.1 %. As noticed Eq. (1) requires X_1 and X_2 values at each temperature and to extend the applicability of the model to various temperatures, its combination with the van't Hoff model could be considered as:

$$\ln X_{m,T} = x_1^0 \left(A_1 + \frac{B_1}{T} \right) + x_2^0 \left(A_2 + \frac{B_2}{T} \right) \quad (2)$$

in which $X_{m,T}$ is the solubility of the solute in solvent mixtures at temperature T , A_1 , B_1 , A_2 and B_2 are the model constants [3]. When solubilities of 2-chloro-3-(trifluoromethyl)pyridine in ethanol and 1-propanol were used to train Eq. (2), the obtained model was:

$$\ln X_{m,T} = x_1^0 \left(16.821 - \frac{5146.967}{T} \right) + x_2^0 \left(16.675 - \frac{5283.212}{T} \right) \quad (3)$$

which predicted the solubility of 2-chloro-3-(trifluoromethyl)pyridine in ethanol (1) + 1-propanol (2) mixtures at various temperatures with the MRD of 9.2 ± 6.0 %. The log-linear model and its combined version with the van't Hoff model assume the ideal mixing behavior for the solubility of solutes in binary solvent mixtures which is not the case for solubility of polar or semi-polar solutes in relatively polar solvent mixtures.

The combined nearly ideal binary solvent/Redlich-Kister (CNIBS/R-K) model [4] possesses some additional parameters to represent non-ideal mixing behavior and is presented as:

$$\ln X_T = x_1^0 \ln X_1 + x_2^0 \ln X_2 + x_1^0 x_2^0 \sum_{i=0}^2 S_i (x_1^0 - x_2^0)^i \quad (4)$$

in which S_i terms are the model constants representing two-body and three-body interaction terms that could be calculated using a no-intercept least square analysis [5]. The model has provided accurate calculations for solubility of solutes in binary solvent mixtures [6,7]. Table 1 listed the numerical values of S_i terms and the MRD values.

Table 1. Calculated CNIBS/R-K model constants* based on Eq. (3) using a no intercept least squares analysis

T	S_0^*	S_1^{**}	MRD
273.15	0.359	-0.162	1.3
278.15	0.560	-0.160	2.9
283.15	0.716	-0.413	0.9
288.15	0.676	-0.534	0.8
293.15	0.705	-0.646	1.4
298.15	0.591	-0.709	0.5
303.15	0.637	-0.711	0.8
		Overall	1.2

* The S_2 constant is not statistically significant $p > 0.05$.

** All p values for these constants are < 0.05 .

The Jouyban-Acree model [8] which is an extended version of the CNIBS/R-K model provided a possibility of solubility calculations in binary solvent mixtures at various temperatures and is expressed as:

$$\ln X_{m,T} = x_1^0 \ln X_{1,T} + x_2^0 \ln X_{2,T} + \frac{x_1^0 x_2^0}{T} \sum_{i=0}^2 J_i (x_1^0 - x_2^0)^i \quad (5)$$

in which J_i denotes the constants of the model computed by a no intercept regression analysis.

The trained model for correlating the solubility of 2-chloro-3-(trifluoromethyl)pyridine in ethanol (1) + 1-propanol (2) mixtures is:

$$\ln X_{m,T} = x_1^0 \ln X_{1,T} + x_2^0 \ln X_{2,T} + \frac{173.584 x_1^0 x_2^0}{T} - \frac{134.813 x_1^0 x_2^0 (x_1^0 - x_2^0)}{T} \quad (6)$$

which correlated the solubility data the MRD of 2.1 ± 2.7 %. Using Eq. (5), it is possible to train the model at one temperature (e.g. 298.15 K) and predict the solubility of the solute at other temperatures of interest by employing the experimental X_1 and X_2 values [9-13].

Measuring X_1 and X_2 values is a limiting parameter in practical applications of the model and to cover this limitation, the Jouyban–Acree model could be combined with the van't Hoff model as [14,15]:

$$\ln X_{m,T} = x_1^0 \left(A_1 + \frac{B_1}{T} \right) + x_2^0 \left(A_2 + \frac{B_2}{T} \right) + \frac{x_1^0 x_2^0}{T} \sum_{i=0}^2 J_i (x_1^0 - x_2^0)^i \quad (7)$$

Combining the model constants of Eqs. (3) and (6) yields:

$$\begin{aligned} \ln X_{m,T} = & x_1^0 \left(16.821 - \frac{5146.967}{T} \right) + x_2^0 \left(16.675 - \frac{5283.212}{T} \right) \\ & + \frac{173.584 x_1^0 x_2^0}{T} - \frac{134.813 x_1^0 x_2^0 (x_1^0 - x_2^0)}{T} \end{aligned} \quad (8)$$

in which the solubility data of 2-chloro-3-(trifluoromethyl)pyridine in ethanol (1) + 1-propanol (2) at various temperatures is computed with the MRD of 2.2 ± 1.8 %.

On the other hand, equilibrium solubility data could be useful to evaluate if the solute is preferentially solvated by one of the components regarding the mixtures composition. In this way, the preferential solvation parameter of 2-chloro-3-(trifluoromethyl)pyridine (compound 3) by ethanol (compound 1) in the ethanol (1) + 1-propanol (2) mixtures is defined as [16, 17]:

$$\delta x_{1,3} = x_{1,3}^L - x_1^0 = -\delta x_{2,3} \quad (9)$$

where $x_{1,3}^L$ is the local mole fraction of ethanol (1) in the molecular environment near to 2-chloro-3-(trifluoromethyl)pyridine (3) and x_1 is the bulk mole fraction composition of ethanol (1) in the initial binary solvent mixture free of solute. If $\delta x_{1,3} > 0$ then the solute is preferentially solvated by ethanol (1); on the contrary, if this parameter is < 0 the solute is preferentially solvated by 1-propanol (2). Values of $\delta x_{1,3}$ are obtainable from the inverse Kirkwood-Buff integrals for the individual solvent components analyzed in terms of some thermodynamic quantities as shown in the following equations [16, 17]:

$$\delta x_{1,3} = \frac{x_1^o x_2^o (G_{1,3} - G_{2,3})}{x_1^o G_{1,3} + x_2^o G_{2,3} + V_{\text{cor}}} \quad (10)$$

with,

$$G_{1,3} = RT\kappa_T - \bar{V}_3 + x_2^o \bar{V}_2 D / Q \quad (11)$$

$$G_{2,3} = RT\kappa_T - \bar{V}_3 + x_1^o \bar{V}_1 D / Q \quad (12)$$

$$V_{\text{cor}} = 2522.5 \left(r_3 + 0.1363 (x_{1,3}^L \bar{V}_1 + x_{2,3}^L \bar{V}_2)^{1/3} - 0.085 \right)^3 \quad (13)$$

As has been previously described [18], in these equations κ_T is the isothermal compressibility of the ethanol (1) + 1-propanol (2) solvent mixtures (which is calculated as an additive property by using the mixtures compositions expressed in mole fraction and the reported values for both neat solvents), \bar{V}_1 and \bar{V}_2 are the partial molar volumes of the alcohols in the mixtures, similarly, \bar{V}_3 is the partial molar volume of 2-chloro-3-(trifluoromethyl)pyridine in these mixtures. The function D (Eqn. (14)) is the derivative of the standard molar Gibbs energies of transfer of 2-chloro-3-(trifluoromethyl)pyridine from neat 1-propanol (2) to ethanol (1) + 1-propanol (2) mixtures with respect to the ethanol proportion in the mixtures. The function Q

(Eqn. (15)) involves the second derivative of the excess molar Gibbs energy of mixing of the two alcohols (G_{1+2}^{Exc}) with respect to the 1-propanol proportion in the mixtures [18]. V_{cor} is the correlation volume and r_3 is the molecular radius of 2-chloro-3-(trifluoromethyl)pyridine calculated by means of Eqn. (16) with N_{Av} as the Avogadro's number.

$$D = \left(\frac{\partial \Delta_{tr} G_{3,2 \rightarrow 1+2}^o}{\partial x_1^o} \right)_{T,p} \quad (14)$$

$$Q = RT + x_1 x_2 \left(\frac{\partial^2 G_{1+2}^{Exc}}{\partial x_2^{o2}} \right)_{T,p} \quad (15)$$

$$r_3 = \left(\frac{3 \cdot 10^{21} \bar{V}_3}{4\pi N_{Av}} \right)^{1/3} \quad (16)$$

Definitive correlation volume requires iteration because it depends on the local mole fractions around the solute. This iteration is done by replacing $\delta x_{1,3}$ and V_{cor} in the Eqns. (9), (10) and (13) to recalculate $x_{1,3}^L$ until a non-variant value of V_{cor} is obtained.

Figure 1 shows the Gibbs energy of transfer behavior of 2-chloro-3-(trifluoromethyl)pyridine (3) from neat 1-propanol (2) to all ethanol (1) + 1-propanol (2) mixtures at 298.15 K. These values were calculated from the mole fraction drug solubility data reported by Yang et al. [1], by using the following expression:

$$\Delta_{tr} G_{3,2 \rightarrow 1+2}^o = RT \ln \left(\frac{x_{3,2}}{x_{3,1+2}} \right) \quad (17)$$

Here, $x_{3,2}$ is the mole fraction solubility of the solute in neat 1-propanol (2) and $x_{3,1+2}$ is the solubility in the ethanol (1) + 1-propanol (2) mixtures. $\Delta_{tr} G_{3,2 \rightarrow 1+2}^o$ values were correlated according to polynomial presented as Eqn. (18) with $r^2 = 0.9990$.

$$\Delta_r G_{3,2 \rightarrow 1+2}^{\circ} = -0.01 - 4.63x_1^{\circ} + 6.69x_1^{\circ 2} - 3.50x_1^{\circ 3} \quad (18)$$

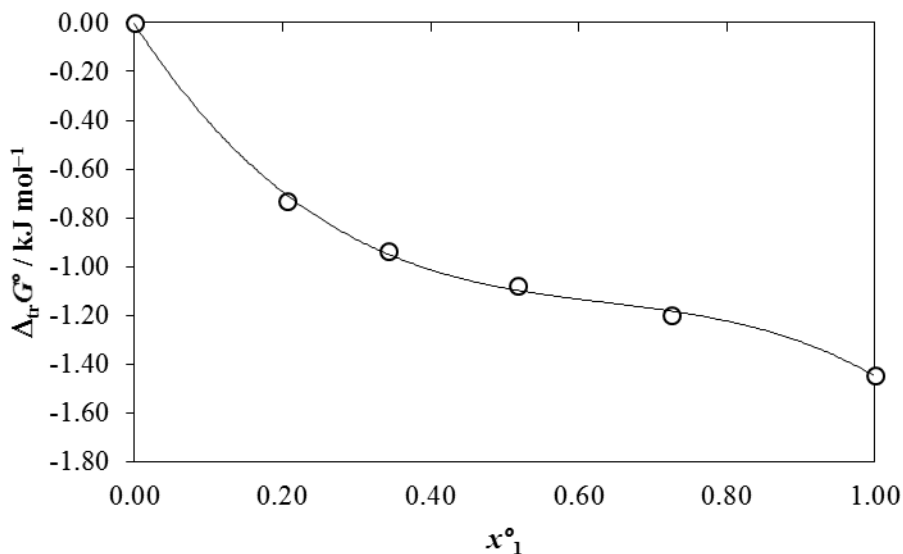


Figure 1. Gibbs energy of 2-chloro-3-(trifluoromethyl)pyridine (3) from neat 1-propanol (2) to ethanol (1) + 1-propanol (2) mixtures at 298.15 K.

Thus, D values reported in Table 2 were calculated from the first derivative of the respective polynomial model and solved according to the solvent mixtures composition. For ethanol (1) + 1-propanol (2) mixtures free of solute the values of Q were calculated from excess Gibbs energies (expressed in J mol^{-1}) at 298.15 K, which were in turn, calculated from values reported at 313.15 K by Oracz [19]. As described above, the $RT \cdot \kappa_T$ values were calculated by assuming additive mixing with the reported κ_T values for ethanol (1.153 GPa^{-1}) and 1-propanol (1.025 GPa^{-1}) at 298.15 K [20].

In similar way, the partial molar volumes of both alcohols in the mixtures were calculated from the reported density values of the ethanol (1) + 1-propanol (2) mixtures at 298.15 K [21],

by using Eqns. (17) and (18). In these equations V is the molar volume of the mixtures calculated as $V = (x_1.M_1 + x_2.M_2)/\rho$. Here, M_1 is 46.07 g mol^{-1} for ethanol and M_2 is 60.10 g mol^{-1} for 1-propanol [22].

$$\bar{V}_1 = V + x_2 \frac{dV}{dx_1} \quad (19)$$

$$\bar{V}_2 = V - x_1 \frac{dV}{dx_1} \quad (20)$$

The Q , $RT \cdot \kappa_T$, \bar{V}_1 and \bar{V}_2 values for ethanol (1) + 1-propanol (2) mixtures at 298.15 K are shown in Table 2.

Table 2. Some properties associated to preferential solvation of 2-chloro-3-(trifluoromethyl)pyridine (3) in ethanol (1) + 1-propanol (2) mixtures at 298.15 K.

$x_1^{\circ a}$	$D /$ kJ mol^{-1}	$Q /$ kJ mol^{-1}	$RT \cdot \kappa_T /$ $\text{cm}^3 \text{ mol}^{-1}$	$\bar{V}_1 /$ $\text{cm}^3 \text{ mol}^{-1}$	$\bar{V}_2 /$ $\text{cm}^3 \text{ mol}^{-1}$	$G_{1,3} /$ $\text{cm}^3 \text{ mol}^{-1}$	$G_{2,3} /$ $\text{cm}^3 \text{ mol}^{-1}$	$V_{\text{cor}} /$ $\text{cm}^3 \text{ mol}^{-1}$	100 $\delta x_{1,3}$
0.00	-4.63	2.487	2.541	58.78	75.18	-252.1	-112.2	1534	0.000
0.05	-3.99	2.480	2.557	58.76	75.18	-227.0	-116.9	1523	-0.373
0.10	-3.40	2.475	2.573	58.75	75.18	-205.0	-120.2	1512	-0.552
0.15	-2.86	2.469	2.588	58.74	75.18	-186.1	-122.3	1501	-0.594
0.20	-2.38	2.465	2.604	58.72	75.18	-170.1	-123.4	1489	-0.550
0.25	-1.94	2.461	2.620	58.71	75.18	-156.6	-123.7	1478	-0.459
0.30	-1.56	2.458	2.636	58.70	75.19	-145.5	-123.3	1466	-0.350
0.35	-1.24	2.455	2.652	58.69	75.19	-136.6	-122.4	1454	-0.245
0.40	-0.96	2.454	2.668	58.68	75.20	-129.7	-121.2	1442	-0.154
0.45	-0.74	2.453	2.684	58.67	75.20	-124.5	-120.0	1430	-0.085
0.50	-0.57	2.452	2.699	58.67	75.21	-120.7	-118.8	1418	-0.037
0.55	-0.45	2.453	2.715	58.66	75.22	-118.2	-117.9	1406	-0.006
0.60	-0.38	2.454	2.731	58.65	75.23	-116.7	-117.5	1395	0.015
0.65	-0.37	2.455	2.747	58.65	75.24	-115.9	-117.7	1383	0.032
0.70	-0.41	2.458	2.763	58.64	75.25	-115.7	-118.8	1371	0.052
0.75	-0.50	2.461	2.779	58.64	75.26	-115.8	-120.9	1359	0.078
0.80	-0.65	2.465	2.795	58.64	75.27	-115.9	-124.2	1347	0.109
0.85	-0.84	2.469	2.810	58.63	75.28	-115.7	-128.9	1335	0.138
0.90	-1.09	2.475	2.826	58.63	75.29	-115.2	-135.2	1322	0.149
0.95	-1.39	2.480	2.842	58.63	75.31	-114.0	-143.2	1310	0.116
1.00	-1.75	2.487	2.858	58.63	75.32	-111.8	-153.1	1298	0.000

^a x_1° is the mole fraction of ethanol (1) in the ethanol (1) + 1-propanol (2) mixtures free of 2-chloro-3-(trifluoromethyl)pyridine (3).

Because no partial molar volumes of 2-chloro-3-(trifluoromethyl)pyridine (3) in these mixtures are reported in the literature, this property is considered in this research as similar to that calculated for the pure compound. In this way, the molar volume of this solute (3) was calculated by means of the Fedors' method [23] as: $114.7 \text{ cm}^3 \text{ mol}^{-1}$ (Table 3). $G_{1,3}$ and $G_{2,3}$ values shown in Tables 2 are negative in all cases indicating that 2-chloro-3-(trifluoromethyl)pyridine exhibits affinity for both alcohols in all the mixtures. The molecular solute radius value (r_3) was calculated as 0.357 nm. The correlation volume was iterated three times by using Eqns. (5), (6) and (9) to obtain the values reported in Table 2. This table also shows the preferential solvation parameters of this solute (3) by ethanol (1), $\delta x_{1,3}$.

Table 3. Application of the Fedors' method to estimate internal energy, molar volume, and Hildebrand solubility parameter of 2-chloro-3-(trifluoromethyl)pyridine (3).

Group	Group number	$\Delta U^\circ / \text{kJ mol}^{-1}$	$V / \text{cm}^3 \text{ mol}^{-1}$
>C<	1	1.47	-19.2
>C=	2	2 x 4.31 = 8.62	2 x -5.5 = -11.0
-CH=	3	3 x 4.31 = 12.93	3 x 13.5 = 40.5
-N=	1	11.7	5.0
-F trisubstituted	3	3 x 2.30 = 6.90	3 x 22.0 = 66.0
-Cl attached to C with double bond	1	11.55 x 0.80 = 9.24	24.0
Ring closure 6 atoms	1	1.05	16.0
Conjugated double bond in ring	3	3 x 1.67 = 5.01	3 x -2.2 = -6.6
		$\Sigma \Delta U^\circ = 56.92$	$\Sigma V = 114.7$
		$\delta_3 = (56,920/114.7)^{1/2} = 22.3 \text{ MPa}^{1/2}$	

Figure 2 shows that the values of $\delta x_{1,3}$ vary non-linearly with the ethanol (1) proportion in all the mixtures. Addition of ethanol (1) makes negative the $\delta x_{1,3}$ values of this solute (3) from the pure 1-propanol to the mixture $x_1 = 0.55$. Maximum negative value is obtained in the mixture

$x_1^o = 0.15$ (with $\delta x_{1,3} = -5.94 \times 10^{-2}$). In this way, in this composition region apparently 2-chloro-3-(trifluoromethyl)pyridine is preferentially solvated by 1-propanol although the $\delta x_{1,3}$ values are lower than 1.0×10^{-2} and therefore, they could be attributed to uncertainties propagation rather than solvation effects [24, 25]. On the other hand, in the interval $0.55 < x_1^o < 1.00$ the $\delta x_{1,3}$ values are positive but with a maximal in the mixture $x_1^o = 0.90$ (1.49×10^{-3}), which could be interpreted as no preferential solvation effects. This result dealing with no preferential solvation effects could be a consequence of the chemical similarity exhibited by ethanol and 1-propanol as observed in the very small positive excess Gibbs energies of mixing and also because of the similar solubilities exhibited by this compound in both solvents, i.e. $x_{3,2} = 0.3546$ in neat 1-propanol (2) and $x_{3,1} = 0.6350$ in neat ethanol (1) [1]. Thus, this result is very different regarding the behavior of other compounds in several cosolvent (1) + water (2) mixtures [26-33] and also in binary mixtures of organic solvents [34,35], where $\delta x_{1,3}$ values higher than 1.0×10^{-2} have been reported and therefore, preferential solvation by the mixtures components on the solutes have been discussed in terms of solute-solvents interactions.

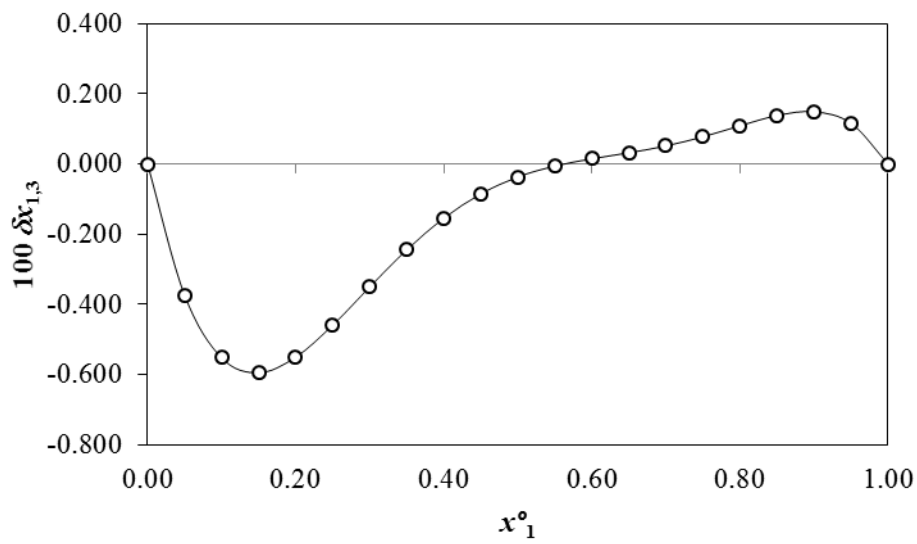


Figure 2. $\delta x_{1,3}$ values of 2-chloro-3-(trifluoromethyl)pyridine (3) in ethanol (1) + 1-propanol (2) mixtures at 298.15 K.

References

- [1] L. Wang, C. Xing, L. Zhao, L. Xu, G. Liu, Measurement and correlation of solubility of 2-chloro-3-(trifluoromethyl)pyridine in pure solvents and ethanol + *n*-propanol mixtures, *J. Mol. Liq.* 238 (2017) 470-477.
- [2] S. H. Yalkowsky, T. J. Roseman, Solubilization of drugs by cosolvents, in: S.H. Yalkowsky (Ed.), *Techniques of Solubilization of Drugs*, Marcel Dekker, New York, 1981.
- [3] F. Shakeel, M.A. Bhat, N. Haq, A. Fathi-Azarbayjani, A. Jouyban, Solubility and thermodynamic parameters of a novel anti-cancer drug (DHP-5) in polyethylene glycol 400 + water mixtures, *J. Mol. Liq.* 229 (2017) 241–245.
- [4] W.E. Acree Jr., Mathematical representation of thermodynamic properties: Part 2. 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* 198 (1992) 71–79.
- [5] A. Jouyban-Gharamaleki, J. Hanaee, A novel method for improvement of predictability of the CNIBS/RK equation, *Int. J. Pharm.* 154 (1997) 245–247.
- [6] A. Jouyban-Gharamaleki, L. Valaee, M. Barzegar-Jalali, B.J. Clark, W.E. Acree Jr., Comparison of various cosolvency models for calculating solute solubility in water-cosolvent mixtures, *Int. J. Pharm.* 177 (1999) 93–101.
- [7] A. Jouyban, Review of the cosolvency models for predicting solubility of drugs in water-cosolvent mixtures, *J. Pharm. Pharm. Sci* 11 (2008) 32–57.

- [8] A. Jouyban-Gharamaleki, W.E. Acree Jr., Comparison of models for describing multiple peaks in solubility profiles, *Int. J. Pharm.* 167 (1998) 177–182.
- [9] A. Jouyban, M.A.A. Fakhree, S.h. Mirzaei, T. Ghafourian, S.h. Soltanpour, A. Nokhodchi, Solubility prediction of paracetamol in water–glycerol mixtures at 25 and 30 C using the Jouyban–Acree model, *Asian J. Chem.* 21 (2009) 7249–7253.
- [10] A. Jouyban, J. Shokri, M. Barzegar-Jalali, D. Hassanzadeh, W.E. Acree Jr, T. Ghafourian, A. Nokhodchi, Solubility of chlordiazepoxide, diazepam, and lorazepam in ethanol+ water mixtures at 303.2 K, *J. Chem. Eng. Data* 54 (2009) 2142–2145.
- [11] A. Jouyban, W.E. Acree Jr, Comments on “Solubility of Ethyl Maltol in Aqueous Ethanol Mixtures” (Liu, B.-S.; Liu, R.-J.; Hu, Y.-Q.; Hu, Q.-F. *J. Chem. Eng. Data* 2008, 53, 2712–2714), *J. Chem. Eng. Data* 54 (2009) 1168–1170.
- [12] S. Ahmadian, J. Soleymani, V. Panahi-Azar, M.A.A. Fakhree, W.E. Acree Jr, A. Jouyban, 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* 56 (2011) 4352–4355.
- [13] S.H. Eghrary, R. Zarghami, F. Martinez, A. Jouyban, Solubility of 2-butyl-3-benzofuranyl 4-(2-(diethylamino) ethoxy)-3, 5-diiodophenyl ketone hydrochloride (amiodarone HCl) in ethanol+ water and N-methyl-2-pyrrolidone+ water mixtures at various temperatures, *J. Chem. Eng. Data* 57 (2012) 1544–1550.
- [14] F. Sardari, A. Jouyban, Solubility of nifedipine in ethanol + water and propylene glycol + water mixtures at 293.2 to 313.2 K, *Ind. Eng. Chem. Res.* 52 (2013) 14353–14358.
- [15] A. Jouyban, M.A. Fakhree, W.E. Acree Jr, Comment on “Measurement and Correlation of Solubilities of (Z)-2-(2-Aminothiazol-4-yl)-2-methoxyiminoacetic Acid in Different

- Pure Solvents and Binary Mixtures of Water + (Ethanol, Methanol, or Glycol)”, *J. Chem. Eng. Data* 57 (2012) 1344–1346.
- [16] Y. Marcus, On the preferential solvation of drugs and PAHs in binary solvent mixtures, *J. Mol. Liq.* 140 (2008) 61–67.
- [17] Y. Marcus, Preferential solvation of drugs in binary solvent mixtures, *Pharm. Anal. Acta* 8 (2017) 1000537.
- [18] D.R. Delgado, A. Jouyban, F. Martínez, Solubility and preferential solvation of meloxicam in methanol + water mixtures at 298.15 K, *J. Mol. Liq.* 197 (2014) 368–373.
- [19] P. Oracz, International DATA Series: Selected Data on Mixtures: Thermodynamic properties of non-reacting binary systems of organic substances, Texas A & M University, 1986, p. 80.
- [20] Y. Marcus, *The Properties of Solvents*, John Wiley & Sons, Chichester, 1998, p. 145–152.
- [21] J.J. Cano-Gómez, G.A. Iglesias-Silva, M. Ramos-Estrada, K.R. Hall, Densities and viscosities for binary liquid mixtures of ethanol + 1-propanol, 1-butanol, and 1-pentanol from (293.15 to 328.15) K at 0.1 MPa, *J. Chem. Eng. Data* 57 (2012) 2560–2567.
- [22] S. Budavari, M.J. O’Neil, A. Smith, P.E. Heckelman, J.R. Obenchain Jr., J.A.R. Gallipeau, M.A. D’Arecea, *The Merck Index, An Encyclopedia of Chemicals, Drugs, and Biologicals*, 13th ed., Merck & Co., Inc., Whitehouse Station, NJ, 2001.
- [23] R.F. Fedors, A method for estimating both the solubility parameters and molar volumes of liquids, *Polym. Eng. Sci.* 14 (1974) 147–154.
- [24] A. Ben-Naim, Preferential solvation in two- and in three-component systems, *Pure Appl. Chem.* 62 (1990) 25–34.

- [25] Y. Marcus, Solubility and solvation in mixed solvent systems, *Pure Appl. Chem.* 62 (1990) 2069–2076.
- [26] D.M. Jiménez, Z.J. Cárdenas, D.R. Delgado, F. Martínez, A. Jouyban, Preferential solvation of methocarbamol in aqueous binary cosolvent mixtures at 298.15 K, *Phys. Chem. Liq.* 52 (2014) 726–737.
- [27] F. Martínez, A. Jouyban, W.E. Acree Jr., Modelling the solubility and preferential solvation of bergenin in DMSO + water mixtures, *Lat. Am. J. Pharm.* 35 (2016) 2185–2190.
- [28] A. Jouyban, W.E. Acree Jr., F. Martínez, Modelling the solubility and preferential solvation of gallic acid in cosolvent + water mixtures, *J. Mol. Liq.* 224 (2016) 502–506.
- [29] M.Á. Peña, D.R. Delgado, F. Martínez, Preferential solvation of indomethacin in 1,4-dioxane + water mixtures according to the inverse Kirkwood-Buff integrals method, *Phys. Chem. Liq.* 54 (2016) 462–474.
- [30] F. Martínez, A. Jouyban, W.E. Acree Jr., Comments on “Solubility and thermodynamic function of a new anticancer drug ibrutinib in {2-(2-ethoxyethoxy)ethanol + water} mixtures at different temperatures”, *J. Chem. Thermodyn.* 95 (2016) 180–182.
- [31] S. Nozohouri, A. Shayanfar, Z.J. Cárdenas, F. Martinez, A. Jouyban, Solubility of celecoxib in N-methyl-2-pyrrolidone + water mixtures at various temperatures: Experimental data and thermodynamic analysis, *Kor. J. Chem. Eng.* 34 (2017) 1435–1443.
- [32] F. Martínez, A. Jouyban, W.E. Acree Jr., Solubility of phenobarbital in aqueous cosolvent mixtures revisited: IKBI preferential solvation analysis, *Phys. Chem. Liq.* 55 (2017) 432–443.

- [33] F. Martínez, A. Jouyban, W.E. Acree Jr., Preferential solvation of etoricoxib in some aqueous binary cosolvent mixtures at 298.15 K, *Phys. Chem. Liq.* 55 (2017) 291–303.
- [34] A. Jouyban, F. Martinez, W.E. Acree Jr., Comments on “Solubility and solution thermodynamics of 2,3,4,5-tetrabromothiophene in (ethanol + trichloromethane) binary solvent mixtures”, *Fluid Phase Equilib.* 421 (2016) 88–92.
- [35] G.A. Rodríguez, D.R. Delgado, F. Martínez, Preferential solvation of indomethacin and naproxen in ethyl acetate + ethanol mixtures according to the IKBI method, *Phys. Chem. Liq.* 52 (2014) 533–545.

HIGHLIGHTS

- CNIBS/R-K describes observed solubility data to average MRD of 1.2 %
- Combined Jouyban-Acree and van't Hoff model describes solubility data to average MRD of 2.1 %
- Inverse Kirkwood-Buff treatment shows no preferential solvation of solvents around dissolved solute