

Phase Behavior of (1-Alkyl-3-methyl Imidazolium Tetrafluoroborate + 6-(Hydroxymethyl)oxane-2,3,4,5-tetrol + Water)

Yuhuan Chen[†] and Suojiang Zhang^{*,‡}

School of Chemical Engineering and Technology, Hebei University of Technology, Tianjin, 300130, China, and Research Laboratory of Green Chemistry and Technology, Institute of Process Engineering, Chinese Academy of Sciences, Beijing 100080, China

Phase behavior of 1-alkyl-3-methyl imidazolium tetrafluoroborate ($[C_n\text{mim}][\text{BF}_4]$, $n = 2$ to 10), 6-(hydroxymethyl)oxane-2,3,4,5-tetrol and water has been determined at temperatures in the range of (242.15 to 308.15) K. Binodal curves, tie-lines, and the slope of the tie-line (STL) for $[\text{C}_3\text{mim}][\text{BF}_4]/[\text{C}_4\text{mim}][\text{BF}_4] + \text{glucose} + \text{H}_2\text{O}$ systems were obtained at different temperatures of $T = (278.15, 288.15, 298.15, \text{ and } 308.15)$ K. Results show that, as the temperature decreases, the two-phase area expands and the STL increases. Binodal curves were correlated using an empirical equation, and tie-lines were correlated according to the Othmer–Tobias and Bancroft equations. These equations satisfactorily represented the experimental data. The molecular structure is used as an argument to describe the phase-forming mechanism.

Introduction

Aqueous biphasic systems (ABS's) are well-known as green separation systems and are potentially able to replace conventional organic compounds. ABS's are usually composed of aqueous solutions of two water-soluble polymers or by addition of an inorganic salt (e.g., sulfate or phosphate), at a high concentration, to a solution of a polymer. However, polymer–polymer ABS's have a relatively high cost, a high viscosity, and require a relatively long time to result in for phase splitting. For electrolyte–polymer systems, the properties strongly limit their applications in biotechnology owing to high salt concentrations, which may cause the denaturation of sensitive biological structures.

Ionic liquids (ILs) are the latest molecular class that has attracted attention for green chemistry applications owing to their unique properties: extremely low vapor pressure, non-flammability, excellent solvent power for organic and inorganic compounds, and relative ease of structure modification to elicit the desired physical properties. ILs have been applied to biocatalysis, electrochemistry, and separation. IL-based ABS's were reported by Rogers and co-workers in 2003¹ and more recent work reported in refs 2 to 6. However, these ABS's are based on IL with salt where the IL tends to be concentrated in the upper phase with some salt contamination, which makes the system more complex. Recently, alternative ABS's based on ILs, carbohydrate, and water have been reported.^{7–11} This system is more environmentally benign and is potentially used in biological engineering, pharmaceuticals, and polluted water treatment.

In this work, we report the phase behaviors of 1-alkyl-3-methyl imidazolium tetrafluoroborate ($[C_n\text{mim}][\text{BF}_4]$, $n = 2$ to 10), with 6-(hydroxymethyl)oxane-2,3,4,5-tetrol (glucose) and water. Binodal curves, tie-lines, and the slope of the tie-line

(STL) for $[\text{C}_3\text{mim}][\text{BF}_4]/[\text{C}_4\text{mim}][\text{BF}_4] + \text{glucose} + \text{H}_2\text{O}$ ABS's were obtained at $T = (278.15 \text{ to } 308.15)$ K. Binodal curves were correlated using an empirical equation, and the tie-lines were correlated according to the Othmer–Tobias and Bancroft equations. Results obtained from the correlations are in good agreement with the experimental data.

Experimental Section

Reagents and Chemicals. $[C_n\text{mim}][\text{BF}_4]$ ($n = 2$ to 10) was synthesized according to procedures reported in the literature,¹² and the composition was verified by ¹H NMR. The IL was dried under vacuum at $T = 353.15$ K for a time of 48 h before use. The water content of IL after drying was measured by Karl Fischer titration (Metrohm KF 787) and was less than $2 \cdot 10^{-4}$. Residual chloride in IL was $2 \cdot 10^{-3} \text{ mol} \cdot \text{dm}^{-3}$, which was determined by the method reported by Seddon et al.¹³ Glucose was purchased from Beijing Chemistry Reagent Company, dried under vacuum at $T = 353.15$ K for 48 h, and used without further purification. The water used was twice-distilled.

Procedures. The binodal curves were determined by a titration method according to literature¹⁴ at $T = (278.15, 288.15, 298.15, \text{ and } 308.15)$ K. The experiment on tie-lines was conducted with the apparatus similar to the reported work.⁸ A glass vessel with a volume of 50 cm³ was used to conduct the phase equilibrium determinations. The glass vessel was fitted with an external jacket through which water or ethanol was circulated to form a thermostat with a temperature stability of ± 0.1 K. The fluid mixture was prepared gravimetrically in a sealed glass vessel that was stirred for 3 h and then was set in the thermostat with a desired temperature for a time of 24 h to permit thorough separation. Preliminary experiments¹⁵ showed that this time was sufficient to achieve the equilibrium of two transparent liquid phases with a well-defined interface. After separation

* Corresponding author. E-mail: sjzhang@home.ipe.ac.cn. Fax: (+86) 10-8262-7080.

[†] Hebei University of Technology.

[‡] Chinese Academy of Sciences.

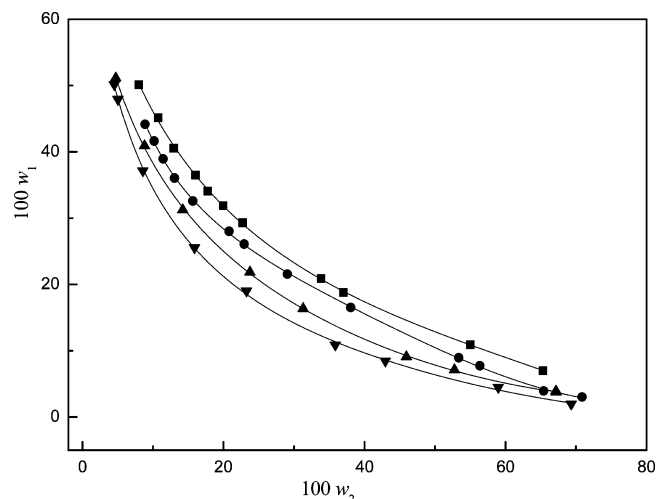


Figure 1. Binodal curves for {[C₃mim][BF₄] (1) + glucose (2) + H₂O (3)} as a function of mass fraction w_2 . ■, $T = 308.15$ K; ●, $T = 298.15$ K; ▲, $T = 288.15$ K; ▼, $T = 278.15$ K; —, eq 1.

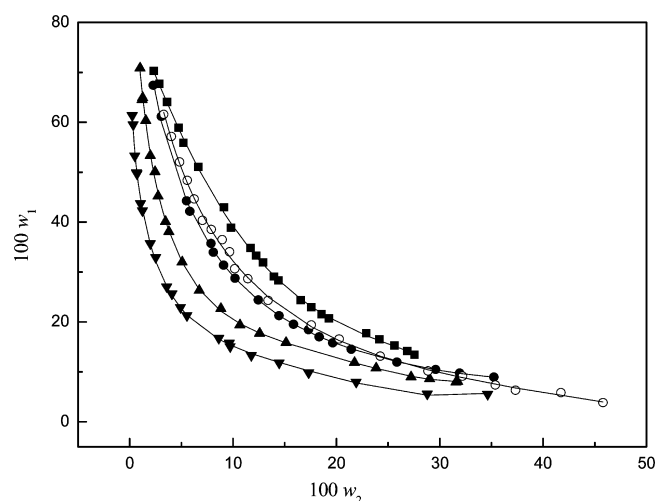


Figure 2. Binodal curves for {[C₄mim][BF₄] (1) + glucose (2) + H₂O (3)} as a function of mass fraction w_2 . ■, $T = 308.15$ K; ●, $T = 298.15$ K; ▲, $T = 288.15$ K; ▼, $T = 278.15$ K; ○, literature data;⁹ —, eq 1.

of the two phases, samples of both phases were collected with a long pinhead syringe and analyzed after dilution with water.

Analysis. The concentration of IL was determined by high performance liquid chromatography (HPLC), a Agilent 1100 series HPLC with cation exchange column⁸ (Zorbax Scx 250 \times 4.6 mm, inner diameter 5 μ m, Agilent). The concentration of water in both phases was determined by Karl Fischer titration (Metrohm KF 787). The concentration of glucose was obtained by the difference. The accuracy of the analysis method was verified by comparing this work with the published work.¹⁶ For example, the mass fraction solubility of [C₈mim][BF₄] in water at $T = 298.15$ K is 0.0133, which is consistent with the reported value of (0.018 ± 0.005) .¹⁶ All experiments were repeated twice, and the repeatability was about ± 0.001 .

Results and Discussion

In this work, it was found that ([C₃mim][BF₄]/[C₄mim][BF₄] + glucose + H₂O) forms ABS's in the temperature range of (242.15 to 373.15) K. ([C₂mim][BF₄] + glucose + H₂O) forms solid at a temperature of about 245 K and [C_{*n*}mim][BF₄] (with

Table 1. Binodal Curves Data for the {[C₃mim][BF₄]/[C₄mim][BF₄] (1) + Glucose (2) + H₂O (3)} System at Temperatures T

$T = 278.15$ K		$T = 288.15$ K		$T = 298.15$ K		$T = 308.15$ K	
100 w_1	100 w_2	100 w_1	100 w_2	100 w_1	100 w_2	100 w_1	100 w_2
[C ₃ mim]BF ₄ (1) + Glucose (2) + H ₂ O (3)							
58.98	4.47	67.16	3.92	65.42	3.94	8.01	50.13
42.95	8.48	45.95	9.09	56.39	7.74	10.76	45.14
35.85	10.88	31.30	16.34	38.04	16.55	12.95	40.55
23.28	19.01	23.76	21.86	11.45	38.93	16.04	36.51
15.91	25.53	8.80	40.90	22.92	26.10	17.80	34.07
8.56	37.14	52.77	7.11	15.65	32.60	19.95	31.88
5.02	47.92	14.23	31.24	13.05	36.04	22.72	29.30
4.52	50.14	67.21	3.71	70.86	3.03	33.85	20.88
69.35	1.98	4.72	51.13	10.17	41.66	65.33	7.01
				8.86	44.16	55.05	10.90
				29.08	21.55	37.02	18.81
				20.80	28.02		
				53.38	8.95		
[C ₄ mim]BF ₄ (1) + Glucose (2) + H ₂ O (3)							
5.55	34.63	7.95	31.58	8.92	35.22	13.43	27.55
5.61	28.80	8.09	31.73	9.73	31.92	14.14	26.87
7.97	21.92	8.58	29.03	10.45	29.60	15.27	25.62
9.82	17.31	8.98	27.23	11.96	25.84	16.54	24.17
11.79	14.46	10.75	23.85	14.54	21.43	17.74	22.88
13.34	11.77	11.84	21.75	15.82	19.64	20.74	19.26
15.11	9.71	15.83	15.14	16.98	18.33	21.54	18.56
15.80	9.66	17.70	12.57	18.44	17.29	22.91	17.56
16.79	8.62	19.40	10.67	19.55	15.84	24.33	16.55
21.31	5.54	22.69	8.84	21.25	14.45	28.30	14.39
22.90	4.91	26.30	6.73	24.38	12.44	29.06	13.96
25.66	4.09	31.98	5.08	28.74	10.18	31.89	12.90
27.09	3.57	38.12	3.79	31.37	9.07	33.26	12.24
32.93	2.52	40.10	3.47	33.94	8.09	34.79	11.67
35.73	1.99	45.19	2.75	35.71	7.87	38.84	9.80
42.32	1.22	50.10	2.46	42.15	5.81	42.97	9.13
43.71	1.05	53.34	2.00	44.25	5.49	51.08	6.63
49.69	0.71	60.33	1.55	61.16	3.06	55.87	5.19
49.92	0.66	64.55	1.20	67.42	2.26	58.88	4.70
53.30	0.49	64.90	1.26			64.05	3.60
59.53	0.33	70.82	1.00			67.67	2.87
61.37	0.25					70.24	2.32

$n = 5$ to 9) is partially soluble with water at ambient temperature. The mutual solubility of IL and water can be lowered by the addition of glucose.

Binodal Curves. Binodal curves for ([C₃mim][BF₄]/[C₄mim][BF₄] (1) + glucose (2) + H₂O) were determined at temperatures of (278.15, 288.15, 298.15, and 308.15) K and are shown in Figures 1 and 2; the results are listed in Table 1. The data reported in the literature⁹ for ([C₄mim][BF₄] + glucose + H₂O) at room temperature are also shown in Figure 2. From Figure 2, it is clear that the results obtained in this work are consistent with the literature values.⁹ Figure 2 also shows that the two-phase area expands with decreasing temperature. This phenomenon has been observed for other ABS's composed of ([C₄mim][BF₄] + fructose + H₂O)^{8,10} and in aqueous two-polymer systems¹⁷ and is contrary to that observed in single-polymer systems.¹⁸ The two-phase area of ([C₃mim][BF₄] + glucose + H₂O) is less than ([C₄mim][BF₄] + glucose + H₂O). In the experiment, it was found that the top phase is not always glucose-rich and the bottom phase is not always IL-rich. As the concentration of glucose increases, phase inversion occurs so that the glucose-rich phase is beneath the IL-rich phase. This phenomenon is essential information for the design of separation process with phase tunable IL-based ABS's.

The binodal curves data for ([C₃mim][BF₄]/[C₄mim][BF₄] + glucose + H₂O) were correlated with a nonlinear empirical eq 1⁸

Table 2. Values of Parameters of Eq 1 for ([C₃mim][BF₄]/[C₄mim][BF₄] + Glucose + H₂O) at Temperatures *T*

<i>T</i> /K	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>	SD	<i>R</i> ²
[C ₃ mim][BF ₄] + Glucose + H ₂ O							
278.15	99.3223	−29.4337	2.9928	−0.01736	0.0001	0.4976	0.9996
288.15	90.6001	−21.9488	1.7971	−0.0094	0.0001	0.2910	0.9999
298.15	124.1526	−41.5259	5.3255	−0.04613	0.0002	0.2640	0.9998
308.15	96.3172	−19.4761	1.1311	0.0005	−0.0000	0.2964	0.9997
[C ₄ mim][BF ₄] + Glucose + H ₂ O							
278.15	80.5595	−43.8773	8.8339	−0.1696	0.0019	0.5819	0.9992
288.15	128.7286	−72.7347	14.3952	−0.2472	0.0025	0.6098	0.9994
298.15	136.4746	−57.8110	8.3436	−0.0857	0.0006	0.4458	0.9995
308.15	79.2740	4.94825	−7.6878	0.2411	−0.0030	0.4664	0.9995

$$w_1 = a + bw_2^{0.5} + cw_2 + dw_2^2 + ew_2^3 \quad (1)$$

where w_1 and w_2 represent the mass fraction of IL and glucose, respectively. In eq 1, a , b , c , d , and e are coefficients, and the numerical values, listed in Table 2, are obtained by adjustment to the measured values.

Tie-Lines. Tie-lines data for ([C₃mim][BF₄]/[C₄mim][BF₄] (1) + glucose (2) + H₂O) are listed in Table 3 and, at $T = 298.15$ K, shown in Figure 3. The tie-line compositions were fit to equations given by Othmer–Tobias, eq 2, and Bancroft, eq 3.^{7,19–21}

$$\frac{1 - w_1^I}{w_1^I} = k_1 \left(\frac{1 - w_2^G}{w_2^G} \right)^n \quad (2)$$

and

$$\frac{w_3^G}{w_2^G} = k_2 \left(\frac{w_3^I}{w_1^I} \right)^r \quad (3)$$

where k_1 , k_2 , n , and r are adjustable parameters obtained by regression analyses. In eqs 1 and 2, w_1^I is the mass fraction of IL in the IL-rich phase and w_2^G the mass fraction of glucose in the glucose-rich phase, and w_3^G and w_3^I are the mass fractions of water in the glucose-rich phase and IL-rich phase, respectively. Linearized forms of eqs 2 and 3 were used to determine the adjustable parameters, and these are listed in Table 4 where the subscripts 1 and 2 refer to the use of eqs 2 and 3, respectively.

STL was determined from

$$\text{STL} = \Delta w(\text{glucose})/\Delta w(\text{IL}) \quad (4)$$

where $\Delta w(\text{glucose})$ and $\Delta w(\text{IL})$ are the differences in the mass fraction of glucose and IL between the two phases, respectively. STLs obtained as a function of temperatures are shown in Figure 4 and the data listed in Table 3. Figure 4 shows that STL decreases with increasing temperature. From Figure 4, it can be seen that STL of ([C₃mim][BF₄] + glucose + H₂O) is less than that of the [C₄mim][BF₄] ABS; that is, the mutual solubility of the [C₃mim][BF₄]-rich phase and glucose-rich phase is better. This phenomena concurs with the two-phase area of ([C₃mim][BF₄] + glucose + H₂O) that is less than that of ([C₄mim][BF₄] + glucose + H₂O).

Phase-Forming Mechanism. At infinite dilution the IL dissociates in H₂O albeit with weak hydration. As the concentration of IL increases, the ions attract to form H₂O-mediated clusters,²² and when the cluster size is sufficiently large, that is, the case for ILs (with $n > 4$), they phase-separate.

Raman spectroscopy has been used to study the hydrogen interactions between glucose and water.²³ At high concentrations sugar and water dissociate owing to interactions between sugar and sugar although the tendency for glucose molecules

Table 3. Tie-lines Data and STLs for {[C₃mim][BF₄]/[C₄mim][BF₄] (1) + Glucose (2) + H₂O (3)} at Temperatures *T*

<i>T</i>	IL-rich phase		glucose-rich phase		STL	average of STL
K	100 w_1	100 w_2	100 w_1	100 w_2		
[C ₃ mim][BF ₄] (1) + Glucose (2) + H ₂ O (3)						
278.15	89.70	0.50	5.24	44.39	−0.5197	
	86.81	0.63	5.54	41.19	−0.4991	
	84.20	1.08	6.18	39.61	−0.4938	
	78.11	1.10	8.22	35.40	−0.4908	
	72.30	1.57	10.45	31.83	−0.4892	−0.4985
288.15	85.40	1.07	8.52	43.01	−0.5455	
	82.11	1.17	9.34	40.45	−0.5398	
	77.10	1.45	11.68	37.36	−0.5489	
	71.64	1.69	12.95	34.06	−0.5515	
	61.54	4.60	16.63	29.38	−0.5518	−0.5475
298.15	84.32	1.22	7.60	45.27	−0.5742	
	79.22	1.83	9.12	41.68	−0.5684	
	74.23	2.36	11.63	38.12	−0.5712	
	68.83	3.58	13.19	34.85	−0.5620	
	63.64	4.01	17.72	31.66	−0.6021	−0.5756
308.15	82.33	5.62	5.55	53.86	−0.6283	
	74.72	6.13	10.71	44.90	−0.6057	
	66.62	7.23	12.83	38.31	−0.5778	
	60.03	8.14	19.93	32.24	−0.6259	−0.6094
[C ₄ mim][BF ₄] (1) + Glucose (2) + H ₂ O (3)						
278.15	56.34	0.39	10.08	19.60	−0.4152	
	68.04	0.14	8.43	22.50	−0.3752	
	76.40	0.10	7.14	25.20	−0.3624	
	79.95	0.13	6.52	26.80	−0.3633	
	87.83	0.14	5.86	31.20	−0.3789	
288.15	92.14	0.13	5.51	34.95	−0.4019	−0.3828
	60.63	1.00	11.70	22.30	−0.4354	
	73.40	0.96	9.25	26.80	−0.4028	
	76.80	0.89	8.45	28.60	−0.4055	
	81.20	0.72	8.22	30.90	−0.4136	
298.15	86.40	0.62	7.03	34.10	−0.4218	
	91.75	0.71	5.24	39.88	−0.4528	−0.4220
	60.90	2.76	12.40	25.01	−0.4588	
	71.30	2.02	10.37	29.80	−0.4559	
	77.50	1.92	8.95	33.24	−0.4569	
308.15	85.70	1.91	7.01	39.72	−0.4805	
	89.14	1.90	6.22	42.87	−0.4941	−0.4692
	56.44	4.93	15.00	25.20	−0.4891	
	65.57	3.48	11.80	29.70	−0.4876	
	70.70	2.28	9.90	32.57	−0.4981	
	81.09	1.76	8.07	39.64	−0.5188	
	87.60	1.65	5.51	45.14	−0.5298	
	91.48	1.49	5.36	50.87	−0.5734	−0.5161

to aggregate is not very significant.²⁴ The water molecules may be structured around the glucose and the hydrogen-bond between water reinforced. The interaction of first-shell water molecules with solute primarily is with glucose hydroxyl groups.

On the basis of this information, we speculate that, with the addition of glucose to homogeneous IL solution, a different water structure is formed owing to structural changes in the

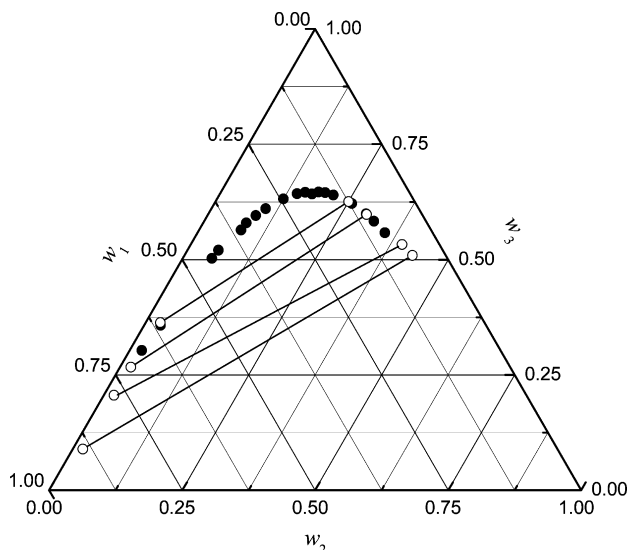


Figure 3. Ternary diagrams of {[C₄mim][BF₄] (1) + glucose (2) + H₂O (3)} at $T = 298.15$ K: ●, binodal curve; ○, tie-line; —, tie-lines.

Table 4. Values of Parameters of Eqs 2 and 3 for ([C₃mim][BF₄]/[C₄mim][BF₄] + Glucose + H₂O) at Temperatures T

T/K	k_1	n	k_2	r	R_1	R_2	SD_1	SD_2
[C ₃ mim][BF ₄] + Glucose + H ₂ O								
278.15	3.2210	0.4379	2.6639	0.3815	0.9982	0.9985	0.0064	0.0050
288.15	2.9682	0.4605	2.2957	0.3904	0.9995	0.9977	0.0038	0.0065
298.15	2.8354	0.5166	2.1210	0.4055	0.9977	0.9979	0.0077	0.0056
308.15	2.7196	0.7467	1.9730	0.5000	0.9996	0.9969	0.0052	0.0118
[C ₄ mim][BF ₄] + Glucose + H ₂ O								
278.15	4.5086	0.3600	3.9604	0.3382	0.9999	0.9996	0.0018	0.0035
288.15	4.171	0.4217	3.5128	0.3763	0.9997	0.9996	0.0034	0.0036
298.15	3.640	0.4911	3.1160	0.4381	0.9996	0.9996	0.0049	0.0038
308.15	3.320	0.5236	2.7686	0.4559	0.9993	0.9984	0.0079	0.0104

hydration shells of both IL and glucose. Therefore, two differently structured microphases of water originate in the homogeneous mixture (below the binodal). An increase in the amount of IL or glucose or both upsets the stability of this microemulsion and leads to coagulation of the droplets (turbidity) resulting in phase separation.

Conclusions

Phase diagrams for ([C₃mim][BF₄]/[C₄mim][BF₄] + glucose + H₂O) were reported at temperatures ranging from (278.15 to

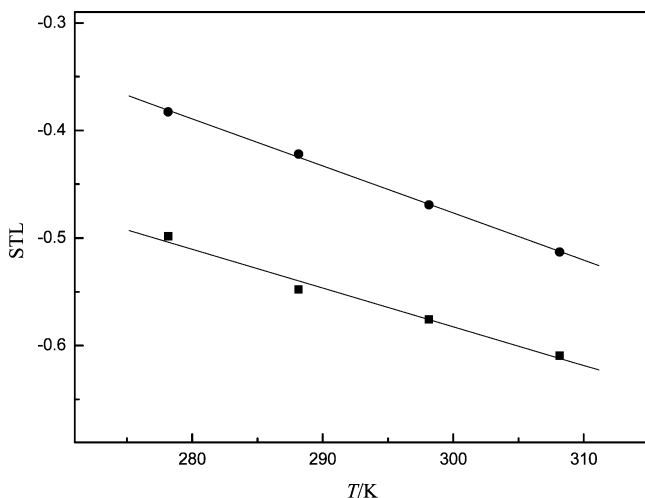


Figure 4. STLs for (IL + glucose + H₂O) as a function of temperatures T . ■, ([C₃mim][BF₄] + glucose + H₂O); ●, ([C₄mim][BF₄] + glucose + H₂O).

308.15) K, including binodal curves, tie-lines, and STL. It was found that with decreasing temperature the two-phase areas expanded and the STL increased. Binodal curves were correlated using an empirical equation, and the tie-lines were correlated according to both the Othmer–Tobias and the Bancroft equations. Results show that these equations can be satisfactorily represented in the experimental data of the systems investigated over the given temperatures studied.

Acknowledgment

The support of the Science and Technology Research and Development Program of Hebei Province (07216726) is gratefully acknowledged.

Literature Cited

- Gutowski, K. E.; Broker, G. A.; Willauer, H. D.; Huddleston, J. G.; Swatoski, R. P.; Holbrey, J. D.; Rogers, R. D. Controlling the Aqueous Miscibility of Ionic Liquids: Aqueous Biphasic Systems of Water-Miscible Ionic Liquids and Water-Structuring Salts for Recycle, Metathesis, and Separations. *J. Am. Chem. Soc.* **2003**, *125*, 6632–6633.
- Zafarani-Moattar, M. T.; Hamzehzadeh, S. Liquid-Liquid Equilibria of Aqueous Two-Phase Systems Containing 1-Butyl-3-Methylimidazolium Bromide and Potassium Phosphate or Dipotassium Hydrogen Phosphate at 298.15 K. *J. Chem. Eng. Data* **2007**, *52*, 1686–1692.
- Deng, Y. F.; Chen, J.; Zhang, D. L. Phase Diagram Data for Several Salt + Salt Aqueous Biphasic Systems at 298.15 K. *J. Chem. Eng. Data* **2007**, *52*, 1332–1335.
- Bridges, N. J.; Gutowski, K. E.; Rogers, R. D. Investigation of Aqueous Biphasic Systems Formed from Solutions of Chaotropic Salts with Kosmotropic Salts (Salt-Salt ABS). *Green Chem.* **2007**, *9*, 177–183.
- He, C.; Li, S.; Liu, H.; Li, K.; Liu, F. Extraction of Testosterone and Epitestosterone in Human Urine Using Aqueous Two-Phase Systems of Ionic Liquid and Salt. *J. Chromatogr., A* **2005**, *1082*, 143–149.
- Pei, Y.; Wang, J.; Wu, K.; Xuan, X.; Lu, X. Ionic Liquid-Based Aqueous Two-Phase Extraction of Selected Proteins. *Sep. Purif. Technol.* **2009**, *64*, 288–295.
- Chen, Y. H.; Wang, Y. G.; Cheng, Q. Y.; Zhang, S. J. Carbohydrates-tailored Phase Tunable Systems Composed of Ionic Liquids and Water. *J. Chem. Thermodyn.* **2009**, *41*, 1056–1059.
- Zhang, Y. Q.; Zhang, S. J.; Chen, Y. H.; Zhang, J. M. Aqueous biphasic systems composed of ionic liquid and fructose. *Fluid Phase Equilib.* **2007**, *257*, 173–176.
- Wu, B.; Zhang, Y.; Wang, H. Phase Behavior for Ternary Systems Composed of Ionic Liquid + Saccharides + Water. *J. Phys. Chem. B* **2008**, *112*, 6426–6429.
- Wu, B.; Zhang, Y.; Wang, H.; Yang, L. Temperature Dependence of Phase Behavior for Ternary Systems Composed of Ionic Liquid + Sucrose + Water. *J. Phys. Chem. B* **2008**, *112*, 13163–13165.
- Wu, B.; Zhang, Y. M.; Wang, H. P. Aqueous Biphasic Systems of Hydrophilic Ionic Liquids + Sucrose for Separation. *J. Chem. Eng. Data* **2008**, *53*, 983–985.
- Bonhôte, P.; Dias, A.-P.; Papageorgiou, N.; Kalyanasundaram, K.; Grätzel, M. Hydrophobic, Highly Conductive Ambient-Temperature Molten Salts. *Inorg. Chem.* **1996**, *35*, 1168–1178.
- Seddon, K. R.; Stark, A.; Torres, M. J. Influence of Chloride, Water, and Organic Solvents on the Physical Properties of Ionic Liquids. *Pure Appl. Chem.* **2000**, *72*, 2275–2287.
- Wu, C. T.; Marsh, K. N.; Deev, A. V.; Boxall, J. A. Liquid-Liquid Equilibria of Room-Temperature Ionic Liquids and Butan-1-ol. *J. Chem. Eng. Data* **2003**, *48*, 486–491.
- Haddou, B.; Canselier, J. P.; Gourdon, C. Cloud Point Extraction of Phenol and Benzyl Alcohol from Aqueous Stream. *Sep. Purif. Technol.* **2006**, *50*, 114–121.
- Anthony, J. L.; Maginn, E. J.; Brennecke, J. F. Solution Thermodynamics of Imidazolium-Based Ionic Liquids and Water. *J. Phys. Chem. B* **2001**, *105*, 10942–10949.
- Forciniti, D.; Hall, C. K.; Kula, M.-R. Influence of Polymer Molecular Weight and Temperature on Phase Composition in Aqueous Two-Phase Systems. *Fluid Phase Equilib.* **1991**, *61*, 243–262.
- Zafarani-Moattar, M. T.; Sadeghi, R.; Hamidi, A. A. Liquid-Liquid Equilibria of an Aqueous Two-phase System Containing Polyethylene Glycol and Sodium Citrate: Experiment and Correlation. *Fluid Phase Equilib.* **2004**, *219*, 149–155.
- Othmer, D. F.; Tobias, P. E. Liquid-Liquid Extraction Data-Toluene and Acetaldehyde Systems. *Ind. Eng. Chem.* **1942**, *34*, 690–692.

- (20) González-Tello, P.; Camacho, F.; Blázquez, G.; Alarcón, F. J. Molecular Interaction of Water Vapor and Air. *J. Chem. Eng. Data* **1996**, *41*, 1333–1336.
- (21) Maduro, R. M.; Aznar, M. Liquid-Liquid Equilibrium of Ternary Systems 1-Butyl-3-Methylimidazolium Hexafluorophosphate + Aromatic + Aliphatic. *Fluid Phase Equilib.* **2008**, *265*, 129–138.
- (22) Katayanagi, H.; Nishikawa, K.; Shimozaki, H.; Mike, K.; Weath, P.; Koga, Y. Mixing Schemes in Ionic Liquid-H₂O Systems: A Thermodynamic Study. *J. Phys. Chem. B* **2004**, *108*, 19451–19457.
- (23) Wells, H. A.; Atalla, R. H. An Investigation of the Vibrational Spectra of Glucose, Galactose and Mannose. *J. Mol. Struct.* **1990**, *224*, 385–242.
- (24) Mason, P. E.; Neilson, G. W.; Enderby, J. E.; Sabouni, M. L.; Brady, J. W. Structure of Aqueous Glucose Solutions as Determined by Neutron Diffraction with Isotopic Substitution Experiments and Molecular Dynamics Calculations. *J. Phys. Chem. B* **2005**, *109*, 13104–13111.

Received for review April 3, 2009. Accepted July 22, 2009.

JE900473U