Densities and Viscosities of Binary Mixtures of Vitamin K_3 with Benzene, Toluene, Ethylbenzene, *o*-Xylene, *m*-Xylene, and *p*-Xylene from (303.15 to 333.15) K

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The densities and viscosities for binary mixtures of vitamin K_3 + benzene, toluene, ethylbenzene, *o*-xylene, *m*-xylene, and *p*-xylene, respectively, have been determined experimentally under normal atmospheric pressure over the entire molality range from (303.15 to 333.15) K. The apparent molar volumes of vitamin K_3 were calculated from experimental measurements. Results were fit to obtain the appropriate parameters and standard deviations between the measured and fitted values.

Introduction

The density and viscosity are important basic data used in chemical engineering designs, solution theory, and molecular thermodynamics. Vitamin K_3 (2-methyl-1,4-naphthoquinone), which displays good antihemorrhagic activity, is an important compound in medical and dietary applications and a synthetic intermediate of vitamin K with wide uses and optimum application prospects.[1,2] In the synthesis and purification process of vitamin K_3, it is useful to know the physical properties of vitamin K_3 + organic solvents. However, a survey of the literature shows that very few measurements have been made on the physical properties of binary mixtures for vitamin K_3 + aromatic hydrocarbons. Song et al.[3,4] have reported the solubility data of vitamin K_3 in aromatic hydrocarbons and water + alcohols, respectively. Nevertheless, to our knowledge, no density and viscosity data on mixtures for vitamin K_3 + aromatic hydrocarbons were previously reported in the literature. In this work, densities and viscosities for vitamin K_3 + benzene, toluene, ethylbenzene, *o*-xylene, *m*-xylene, and *p*-xylene binary mixtures have been measured under normal atmospheric pressure over the entire molality range from (303.15 to 333.15) K. From measurements of densities, the apparent molar volumes of vitamin K_3 were calculated. Results were fit to obtain the appropriate parameters and standard deviations between the measured and fitted values.

Experimental Section

Materials. Analytical reagent vitamin K_3 obtained from Peking Biotech. Co. Ltd. was further purified by recrystallizations, and its purity was determined by UV spectrophotometry (type UV-2401PC, Shimadzu Co. Ltd.) to be 0.997 in mass fraction. Benzene, toluene, ethylbenzene, *o*-xylene, *m*-xylene, and *p*-xylene which were obtained from Shanghai Chemical Reagent Co. were purified by distillation. The mass fractions were determined by gas chromatography (type GC2010 Shimadzu Co. Ltd.) using a DB-1 capillary column with a FID detector, and they were 0.995, 0.995, 0.997, 0.997, 0.994, and 0.997, respectively. All the chemicals were stored over molecular sieve before use. Water used in experiments was double-distilled water, and the conductivity was less than $1 \cdot 10^{-4}$ $S \cdot m^{-1}$.

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Table 1. Comparison of Experimental and Literature Values of Density, ρ, and Viscosity, η, for Pure Compounds

		ρ/g·cm^{-3}		η/mPa·s	
liquid	*T*/K	exptl	lit.	exptl	lit.
benzene	303.15	0.8680	0.8681[7]	0.5640	0.566[5]
			0.8683[8]		0.5627[7]
					0.5643[18]
	308.15	0.8622	0.86295[9]	0.5232	0.5218[7]
	313.15	0.8570		0.5001	0.503[19]
	318.15	0.8516		0.4714	
	323.15	0.8463	0.8468[8]	0.4397	0.4381[8]
					0.442[19]
	328.15	0.8407		0.4145	
	333.15	0.8354		0.3932	0.395[5]
					0.392[19]
toluene	303.15	0.8575	0.8576[7]	0.5253	0.523[5]
			0.8578[8]		0.5226[7]
	308.15	0.8529	0.85285[9]	0.4933	0.4920[7]
	313.15	0.8479	0.8482[7]	0.4717	0.4659[7]
					0.471[19]
	318.15	0.8435		0.4491	
	323.15	0.8387	0.8390[8]	0.4244	0.424[5]
			0.8387[10]		0.4216[8]
	328.15	0.8340		0.4082	
	333.15	0.8291		0.3835	0.3905[20]
ethylbenzene	303.15	0.8580	0.85780[11]	0.5986	0.5981[14]
			0.85810[12]		0.5976[20]
	>308.15	0.8535	0.85415[9]	0.5691	
			0.85343[13]		
	313.15	0.8495		0.5372	0.5369[20]
	318.15	0.8447		0.5060	
	323.15	0.8405	0.84227[14]	0.4805	0.482[5]
					0.4829[14]
	328.15	0.8359		0.4566	
	333.15	0.8316		0.4371	0.4410[20]
o-xylene	303.15	0.8721	0.87174[12]	0.7604	0.7602[14]
					0.7093[8]
	308.15	0.8677	0.86738[9]	0.6900	
	313.15	0.8640		0.6451	0.627[19]
	318.15	0.8597		0.6117	
	323.15	0.8555	0.85379[14]	0.5711	0.561[5]
					0.5554[14]
	328.15	0.8512		0.5433	
	333.15	0.8471		0.5105	
m-xylene	303.15	0.8556	0.85581[12]	0.5490	0.5494[8]
			0.85587[15]		0.5471[14]
	308.15	0.8511	0.85157[9]	0.5201	
			0.85140[16]		
	313.15	0.8469		0.4967	0.497[19]
	318.15	0.8424		0.4817	
	323.15	0.8383	0.83825[14]	0.4440	0.4444[8]
					0.445[5]
	328.15	0.8337		0.4350	
	333.15	0.8296		0.4130	
p-xylene	303.15	0.8520	0.85225[12]	0.5726	0.5714[14]
			0.85227[17]		0.567[17]
					0.5694[7]
	308.15	0.8477	0.84787[9]	0.5374	0.5355[7]
			0.8479[7]		
	313.15	0.8432		0.5178	0.513[19]
	318.15	0.8387		0.4882	
	323.15	0.8345	0.83490[14]	0.4595	0.4599[14]
					0.4580[21]
	328.15	0.8299		0.4439	
	333.15	0.8251		0.4189	

Apparatus and Procedure. The density was measured with five Ostwald−Sprengel-type pycnometers having a bulb volume

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Table 2. Density (ρ), Viscosity (η), and Apparent Molar Volumes ($V_{\Phi,2}$) for Benzene + Vitamin K_3 from (303.15 to 333.15) K

m / mol·kg^{-1}	ρ / g·cm^{-3}	$V_{\Phi,2}$ / cm^3·mol^{-1}	η / mPa·s	m / mol·kg^{-1}	ρ / g·cm^{-3}	$V_{\Phi,2}$ / cm^3·mol^{-1}	η / mPa·s
			$T = 303.15$ K				
0.0000	0.8680		0.5640	0.1778	0.8756	140.40	0.5927
0.0334	0.8694	142.50	0.5788	0.2215	0.8775	139.91	0.6006
0.0889	0.8718	141.01	0.5842	0.2681	0.8795	139.58	0.6063
0.1332	0.8737	140.64	0.5880				
			$T = 308.15$ K				
0.0000	0.8622		0.5232	0.1778	0.8698	140.96	0.5519
0.0334	0.8636	143.08	0.5408	0.2215	0.8717	140.46	0.5598
0.0889	0.8660	141.57	0.5443	0.2681	0.8737	140.13	0.5667
0.1332	0.8679	141.20	0.5484				
			$T = 313.15$ K				
0.0000	0.8570		0.5001	0.1778	0.8646	141.46	0.5189
0.0334	0.8584	143.60	0.5057	0.2215	0.8665	140.95	0.5242
0.0889	0.8608	142.08	0.5096	0.2681	0.8685	140.62	0.5309
0.1332	0.8627	141.70	0.5142				
			$T = 318.15$ K				
0.0000	0.8516		0.4714	0.1778	0.8592	141.98	0.4893
0.0334	0.8530	144.15	0.4782	0.2215	0.8611	141.45	0.4945
0.0889	0.8554	142.61	0.4811	0.2681	0.8631	141.13	0.5000
0.1332	0.8573	142.23	0.4847				
			$T = 323.15$ K				
0.0000	0.8463		0.4397	0.1778	0.8539	142.49	0.4566
0.0334	0.8477	144.69	0.4467	0.2215	0.8558	141.97	0.4610
0.0889	0.8501	143.13	0.4489	0.2681	0.8578	141.64	0.4647
0.1332	0.8520	142.74	0.4528				
			$T = 328.15$ K				
0.0000	0.8407		0.4145	0.1778	0.8483	143.03	0.4318
0.0334	0.8421	145.26	0.4206	0.2215	0.8502	142.51	0.4347
0.0889	0.8445	143.68	0.4235	0.2681	0.8522	142.17	0.4388
0.1332	0.8464	143.28	0.4266				
			$T = 333.15$ K				
0.0000	0.8354		0.3932	0.1778	0.8430	143.55	0.4069
0.0334	0.8368	145.80	0.3946	0.2215	0.8449	143.02	0.4084
0.0889	0.8392	144.20	0.3967	0.2681	0.8469	142.68	0.4121
0.1332	0.8411	143.81	0.4003				

of 25 cm^3 and an internal capillary diameter of about 1 mm. The internal volumes of the pycnometers were calibrated with pure water at each of the measured temperatures, and the densities of water were taken from the literature.[5] The thoroughly cleaned and perfectly dried pycnometers were first weighed on an electronic balance (type AW120, Shimadzu Co.) accurate to within ± 0.0001 g and then filled with experimental liquid and immersed in a thermostat (type 501, Shanghai Laboratory Instrument Works Co. Ltd.) controlled to within ± 0.01 K. After thermal equilibrium had been achieved at the required temperature, the pycnometers were removed from the thermostat and properly cleaned, dried, and weighed. The density was then determined from the mass of the sample and the volume of the pycnometers. The readings from five pycnometers were averaged to determine the density. Uncertainties in density measurements were estimated to be within ± 0.0002 g·cm^{-3}.

The viscosity was measured using a commercial Ubbelohde capillary viscometer (type 1836-A, Shanghai Glass Instruments Factory, China) of 0.55 mm diameter, calibrated with double-distilled water at temperatures of (303.15, 308.15, 313.15, 318.15, 323.15, 328.15, and 333.15) K. A thoroughly cleaned and perfectly dried viscometer, filled with experimental liquid, was placed vertically in an insulated jacket, wherein constant temperature (± 0.01 K) was maintained by circulating water from a thermostatically controlled water bath at the required temperature. After thermal stability was attained, the flow times of the liquids were recorded with an electronic digital stopwatch correct to ± 0.01 s. At least five repetitions of each datum point obtained were reproducible to ± 0.05 s, and the results were averaged. Since all flow times were greater than 200 s and the capillary diameter (0.55 mm) was far less than its length (100 mm), the kinetic energy and end corrections, respectively, were found to be negligible. The viscosity η was then calculated from the relationship[6]

$$\frac{\eta}{\eta_w} = \frac{\rho t}{\rho_w t_w} \tag{1}$$

where η, ρ, and t and η_w, ρ_w, and t_w are the viscosities, densities, and flow time of the mixture and water, respectively. The values of the viscosity and density of pure water come from the literature.[5] The overall uncertainty of the viscosity measurements is dependent on the equilibrium stability of the viscometer, the time of flow, and the change of density, and viscosity values are uncertain to within the range ± 0.0030 mPa·s.

Results and Discussion

The measured densities and viscosities of benzene, toluene, ethylbenzene, *o*-xylene, *m*-xylene, and *p*-xylene together with literature values are included in Table 1, and it is clear from Table 1 that the experimental results show good agreement with the literature data. The experimental densities and viscosities at different temperatures are listed in Tables 2 to 7. In terms of the data shown in Tables 2 to 7, which showed the dependencies of density and viscosity on temperature and concentration, were plotted, respectively. It can be found that the density and viscosity increase with increasing concentration of vitamin K_3 at constant temperature and decrease with increasing temperature at a fixed concentration of vitamin K_3. The dependence of density and viscosity on temperature and concentration has been calculated by means of the Vogel–Tamman–Fulcher (VTF) equation[22]

Table 3. Density (ρ), Viscosity (η), and Apparent Molar Volumes ($V_{\Phi,2}$) for Toluene + Vitamin K_3 from (303.15 to 333.15) K

m / mol·kg^{-1}	ρ / g·cm^{-3}	$V_{\Phi,2}$ / cm^3·mol^{-1}	η / mPa·s	m / mol·kg^{-1}	ρ / g·cm^{-3}	$V_{\Phi,2}$ / cm^3·mol^{-1}	η / mPa·s
			$T = 303.15$ K				
0.0000	0.8575		0.5253	0.1817	0.8659	136.58	0.5572
0.0454	0.8596	137.55	0.5365	0.2270	0.8680	136.22	0.5612
0.0909	0.8617	137.28	0.5440	0.2728	0.8701	135.98	0.5683
0.1365	0.8638	137.02	0.5487				
			$T = 308.15$ K				
0.0000	0.8529		0.4933	0.1817	0.8613	136.98	0.5246
0.0454	0.8550	137.95	0.5088	0.2270	0.8634	136.61	0.5277
0.0909	0.8571	137.68	0.5160	0.2728	0.8655	136.37	0.5346
0.1365	0.8592	137.41	0.5185				
			$T = 313.15$ K				
0.0000	0.8479		0.4717	0.1817	0.8563	137.40	0.4955
0.0454	0.8500	138.38	0.4814	0.2270	0.8584	137.03	0.4987
0.0909	0.8521	138.11	0.4880	0.2728	0.8605	136.79	0.5051
0.1365	0.8542	137.84	0.4902				
			$T = 318.15$ K				
0.0000	0.8435		0.4491	0.1817	0.8519	137.78	0.4677
0.0454	0.8456	138.77	0.4535	0.2270	0.8540	137.40	0.4753
0.0909	0.8477	138.50	0.4582	0.2728	0.8561	137.16	0.4775
0.1365	0.8498	138.22	0.4630				
			$T = 323.15$ K				
0.0000	0.8387		0.4244	0.1817	0.8471	138.19	0.4430
0.0454	0.8408	139.19	0.4321	0.2270	0.8492	137.81	0.4459
0.0909	0.8429	138.91	0.4362	0.2728	0.8513	137.57	0.4515
0.1365	0.8450	138.64	0.4390				
			$T = 328.15$ K				
0.0000	0.8340		0.4082	0.1817	0.8424	138.59	0.4208
0.0454	0.8361	139.60	0.4130	0.2270	0.8445	138.21	0.4242
0.0909	0.8382	139.32	0.4147	0.2728	0.8466	137.96	0.4303
0.1365	0.8403	139.05	0.4176				
			$T = 333.15$ K				
0.0000	0.8291		0.3835	0.1817	0.8375	139.01	0.3980
0.0454	0.8312	140.03	0.3872	0.2270	0.8396	138.63	0.4065
0.0909	0.8333	139.75	0.3909	0.2728	0.8417	138.38	0.4137
0.1365	0.8354	139.47	0.3927				

Table 4. Density (ρ), Viscosity (η), and Apparent Molar Volumes ($V_{\Phi,2}$) for Ethylbenzene + Vitamin K_3 from (303.15 to 333.15) K

m / mol·kg^{-1}	ρ / g·cm^{-3}	$V_{\Phi,2}$ / cm^3·mol^{-1}	η / mPa·s	m / mol·kg^{-1}	ρ / g·cm^{-3}	$V_{\Phi,2}$ / cm^3·mol^{-1}	η / mPa·s
			$T = 303.15$ K				
0.0000	0.8580		0.5986	0.1805	0.8656	142.22	0.6317
0.0451	0.8599	143.13	0.6083	0.2256	0.8675	141.90	0.6333
0.0903	0.8618	142.88	0.6164	0.2710	0.8694	141.65	0.6361
0.1354	0.8637	142.54	0.6218				
			$T = 308.15$ K				
0.0000	0.8535		0.5691	0.1805	0.8611	142.66	0.5893
0.0451	0.8554	143.58	0.5735	0.2256	0.8630	142.34	0.5948
0.0903	0.8573	143.33	0.5794	0.2710	0.8649	142.08	0.5991
0.1354	0.8592	142.99	0.5853				
			$T = 313.15$ K				
0.0000	0.8495		0.5372	0.1805	0.8571	143.06	0.5570
0.0451	0.8514	143.98	0.5439	0.2256	0.8590	142.73	0.5611
0.0903	0.8533	143.73	0.5484	0.2710	0.8609	142.48	0.5673
0.1354	0.8552	143.38	0.5543				
			$T = 318.15$ K				
0.0000	0.8447		0.5060	0.1805	0.8523	143.53	0.5241
0.0451	0.8466	144.47	0.5104	0.2256	0.8542	143.21	0.5283
0.0903	0.8485	144.21	0.5148	0.2710	0.8561	142.95	0.5330
0.1354	0.8504	143.87	0.5192				
			$T = 323.15$ K				
0.0000	0.8405		0.4805	0.1805	0.8481	143.95	0.4969
0.0451	0.8424	144.89	0.4832	0.2256	0.8500	143.62	0.5015
0.0903	0.8443	144.63	0.4881	0.2710	0.8519	143.36	0.5054
0.1354	0.8462	144.28	0.4937				
			$T = 328.15$ K				
0.0000	0.8359		0.4566	0.1805	0.8435	144.40	0.4740
0.0451	0.8378	145.36	0.4615	0.2256	0.8454	144.08	0.4758
0.0903	0.8397	145.10	0.4648	0.2710	0.8473	143.81	0.4806
0.1354	0.8416	144.75	0.4715				
			$T = 333.15$ K				
0.0000	0.8316		0.4371	0.1805	0.8392	144.84	0.4510
0.0451	0.8335	145.80	0.4405	0.2256	0.8411	144.50	0.4546
0.0903	0.8354	145.53	0.4440	0.2710	0.8430	144.24	0.4581
0.1354	0.8373	145.18	0.4475				

Table 5. Density (ρ), Viscosity (η), and Apparent Molar Volumes ($V_{\Phi,2}$) for *o*-Xylene + Vitamin K_3 from (303.15 to 333.15) K

m / mol·kg^{-1}	ρ / g·cm^{-3}	$V_{\Phi,2}$ / cm^3·mol^{-1}	#x03B7; / mPa·s	m / mol·kg^{-1}	ρ / g·cm^{-3}	$V_{\Phi,2}$ / cm^3·mol^{-1}	η / mPa·s
			T = 303.15 K				
0.0000	0.8721		0.7404	0.1767	0.8796	140.42	0.7658
0.0436	0.8739	142.85	0.7432	0.2215	0.8816	139.52	0.7765
0.0884	0.8758	141.80	0.7496	0.2656	0.8835	139.17	0.7833
0.1326	0.8777	141.00	0.7581				
			T = 308.15 K				
0.0000	0.8677		0.6900	0.1767	0.8752	140.84	0.7159
0.0436	0.8695	143.30	0.6988	0.2215	0.8772	139.93	0.7260
0.0884	0.8714	142.23	0.7021	0.2656	0.8791	139.59	0.7348
0.1326	0.8733	141.43	0.7081				
0.0000	0.8640		0.6451	0.1767	0.8715	141.20	0.6742
0.0436	0.8658	143.68	0.6532	0.2215	0.8735	140.29	0.6810
0.0884	0.8677	142.60	0.6592	0.2656	0.8754	139.94	0.6888
0.1326	0.8696	141.79	0.6687				
			T = 318.15 K				
0.0000	0.8597		0.6117	0.1767	0.8672	141.61	0.6407
0.0436	0.8615	144.12	0.6212	0.2215	0.8692	140.69	0.6473
0.0884	0.8634	143.03	0.6256	0.2656	0.8711	140.34	0.6525
0.1326	0.8653	142.21	0.6319				
			T = 323.15 K				
0.0000	0.8555		0.5711	0.1767	0.8630	142.02	0.5967
0.0436	0.8573	144.55	0.5792	0.2215	0.8650	141.09	0.6011
0.0884	0.8592	143.45	0.5832	0.2656	0.8669	140.74	0.6087
0.1326	0.8611	142.63	0.5905				
			T = 328.15 K				
0.0000	0.8512		0.5433	0.1767	0.8587	142.44	0.5665
0.0436	0.8530	144.99	0.5498	0.2215	0.8607	141.50	0.5706
0.0884	0.8549	143.89	0.5531	0.2656	0.8626	141.15	0.5773
0.1326	0.8568	143.05	0.5601				
			T = 333.15 K				
0.0000	0.8471		0.5105	0.1767	0.8546	142.84	0.5309
0.0436	0.8489	145.42	0.5177	0.2215	0.8566	141.90	0.5358
0.0884	0.8508	144.30	0.5202	0.2656	0.8585	141.54	0.5412
0.1326	0.8527	143.46	0.5277				

Table 6. Density (ρ), Viscosity (η), and Apparent Molar Volumes ($V_{\Phi,2}$) for *m*-Xylene + Vitamin K_3 from (303.15 to 333.15) K

m / mol·kg^{-1}	ρ / g·cm^{-3}	$V_{\Phi,2}$ / cm^3·mol^{-1}	η / mPa·s	m / mol·kg^{-1}	ρ / g·cm^{-3}	$V_{\Phi,2}$ / cm^3·mol^{-1}	η / mPa·s
			T = 303.15 K				
0.0000	0.8556		0.5490	0.1802	0.8636	139.29	0.5844
0.0452	0.8576	140.47	0.5673	0.2254	0.8656	139.01	0.5902
0.0902	0.8596	140.01	0.5771	0.2720	0.8677	138.51	0.6031
0.1352	0.8616	139.64	0.5802				
			T = 308.15 K				
0.0000	0.8511		0.5201	0.1802	0.8591	139.70	0.5523
0.0452	0.8531	140.89	0.5351	0.2254	0.8611	139.42	0.5566
0.0902	0.8551	140.42	0.5422	0.2720	0.8632	138.92	0.5654
0.1352	0.8571	140.05	0.5467				
			T = 313.15 K				
0.0000	0.8469		0.4967	0.1802	0.8549	140.09	0.5237
0.0452	0.8489	141.28	0.5098	0.2254	0.8569	139.80	0.5284
0.0902	0.8509	140.81	0.5144	0.2720	0.8590	139.29	0.5352
0.1352	0.8529	140.44	0.5188				
			T = 318.15 K				
0.0000	0.8424		0.4817	0.1802	0.8504	140.50	0.5013
0.0452	0.8444	141.70	0.4864	0.2254	0.8524	140.21	0.5050
0.0902	0.8464	141.23	0.4931	0.2720	0.8545	139.70	0.5117
0.1352	0.8484	140.85	0.4977				
			T = 323.15 K				
0.0000	0.8383		0.4440	0.1802	0.8463	140.87	0.4711
0.0452	0.8403	142.09	0.4593	0.2254	0.8483	140.58	0.4753
0.0902	0.8423	141.61	0.4642	0.2720	0.8504	140.07	0.4817
0.1352	0.8443	141.23	0.4669				
			T = 328.15 K				
0.0000	0.8337		0.4350	0.1802	0.8417	141.30	0.4497
0.0452	0.8357	142.52	0.4381	0.2254	0.8437	141.00	0.4539
0.0902	0.8377	142.04	0.4432	0.2720	0.8458	140.48	0.4630
0.1352	0.8397	141.66	0.4456				
			T = 333.15 K				
0.0000	0.8296		0.4130	0.1802	0.8376	141.67	0.4269
0.0452	0.8316	142.91	0.4148	0.2254	0.8396	141.38	0.4290
0.0902	0.8336	142.43	0.4198	0.2720	0.8417	140.85	0.4342
0.1352	0.8356	142.04	0.4242				

Table 7. Density (ρ), Viscosity (η), and Apparent Molar Volumes ($V_{\Phi,2}$) for *p*-Xylene + Vitamin K_3 from (303.15 to 333.15) K

m / mol·kg^{-1}	ρ / g·cm^{-3}	$V_{\Phi,2}$ / cm^3·mol^{-1}	η / mPa·s	m / mol·kg^{-1}	ρ / g·cm^{-3}	$V_{\Phi,2}$ / cm^3·mol^{-1}	η / mPa·s
			$T = 303.15$ K				
0.0000	0.8520		0.5726	0.1815	0.8601	139.29	0.6048
0.0454	0.8540	141.07	0.5859	0.2267	0.8621	139.07	0.6092
0.0902	0.8560	140.34	0.5904	0.2724	0.8641	138.92	0.6161
0.1361	0.8581	139.35	0.5958				
			$T = 308.15$ K				
0.0000	0.8477		0.5374	0.1815	0.8558	139.68	0.5716
0.0454	0.8497	141.48	0.5528	0.2267	0.8578	139.45	0.5748
0.0902	0.8517	140.74	0.5581	0.2724	0.8598	139.31	0.5820
0.1361	0.8538	139.74	0.5631				
			$T = 313.15$ K				
0.0000	0.8432		0.5178	0.1815	0.8513	140.08	0.5396
0.0454	0.8452	141.90	0.5222	0.2267	0.8533	139.86	0.5430
0.0902	0.8472	141.16	0.5274	0.2724	0.8553	139.72	0.5477
0.1361	0.8493	140.15	0.5349				
			$T = 318.15$ K				
0.0000	0.8387		0.4882	0.1815	0.8468	140.49	0.5152
0.0454	0.8407	142.33	0.4999	0.2267	0.8488	140.26	0.5183
0.0902	0.8427	141.58	0.5047	0.2724	0.8508	140.12	0.5242
0.1361	0.8448	140.55	0.5097				
			$T = 323.15$ K				
0.0000	0.8345		0.4595	0.1815	0.8426	140.87	0.4824
0.0454	0.8365	142.73	0.4686	0.2267	0.8446	140.65	0.4864
0.0902	0.8385	141.97	0.4737	0.2724	0.8466	140.50	0.4907
0.1361	0.8406	140.94	0.4770				
			$T = 328.15$ K				
0.0000	0.8299		0.4439	0.1815	0.8380	141.29	0.4615
0.0454	0.8319	143.16	0.4467	0.2267	0.8400	141.07	0.4633
0.0902	0.8339	142.40	0.4509	0.2724	0.8420	140.92	0.4698
0.1361	0.8360	141.36	0.4560				
			$T = 333.15$ K				
0.0000	0.8256		0.4189	0.1815	0.8337	141.69	0.4364
0.0454	0.8276	143.57	0.4225	0.2267	0.8357	141.46	0.4384
0.0902	0.8296	142.80	0.4258	0.2724	0.8377	141.31	0.4429
0.1361	0.8317	141.75	0.4309				

Table 8. Coefficient of Equation 2 and Standard Deviation, σ, for ρ and η for Different Systems

systems		P_1	P_2	P_3	P_4	$10^2 \cdot \sigma$
benzene + vitamin K_3	ρ/g·cm^{-3}	0.5542	148.6659	17.2963	−28.2062	0.037
	η/mPa·s	49.0000	1686.1000	−79.0000	681.4000	0.37
toluene + vitamin K_3	ρ/g·cm^{-3}	1.1962	107.8169	−16.6108	627.0509	0.025
	η/mPa·s	0.0432	517.1752	53.3071	97.0893	0.26
ethylbenzene + vitamin K_3	ρ/g·cm^{-3}	0.4492	389.3177	30.4710	−298.4230	0.027
	η/mPa·s	0.0683	373.1751	35.9872	131.9381	0.18
o-xylene + vitamin K_3	ρ/g·cm^{-3}	0.6169	116.8163	17.4809	−34.3732	0.036
	η/mPa·s	0.0421	600.5687	51.0830	93.3713	0.32
m-xylene + vitamin K_3	ρ/g·cm^{-3}	0.6281	86.6281	15.4146	22.8961	0.034
	η/mPa·s	0.0472	529.5420	56.2024	88.9173	0.38
p-xylene + vitamin K_3	ρ/g·cm^{-3}	1.1683	102.9023	−16.3655	629.0201	0.026
	η/mPa·s	0.0392	604.0916	55.5911	78.6688	0.30

$$F = P_1 \exp\left(\frac{P_2 + P_3 m}{T - P_4}\right) \tag{2}$$

where $F = (\rho \text{ or } \eta)$; ρ and η are the density and viscosity of solution, respectively; m is the molality of vitamin K_3; T is the absolute temperature; and P_1, P_2, P_3, and P_4 are the curve-fit coefficients. The values are listed in Table 8 along with standard deviations. The standard deviation is defined by

$$\sigma = \left[\sum_{i=1}^{p} \left((Y_i^{\text{exptl}} - Y_i^{\text{calcd}})^2 \Big/ (p - n)\right)\right]^{\frac{1}{2}} \tag{3}$$

where p is the number of experimental points and n is the number of parameters. Y_i^{calcd} and Y_i^{exptl} refer to the calculated values from the equation and to the experimental value. From Table 8, it can be found that the standard deviations for densities and viscosities of binary mixtures for vitamin K_3 + aromatic hydrocarbons is less than $3.7 \cdot 10^{-4}$ g·cm^{-3} and $3.8 \cdot 10^{-3}$ mPa·s, respectively. We conclude that eq 2 can be successfully used for the correlation of the investigated physical properties.

The apparent molar volume of vitamin K_3, $V_{\Phi,2}$, is given by the following equation

$$V_{\Phi,2} = \frac{M}{\rho} - \frac{10^3(\rho - \rho_0)}{m\rho\rho_0} \tag{4}$$

where M is the molar mass of vitamin K_3; ρ is the density of the solution; and ρ_0 is the density of pure solvent. The values of the apparent molar volume of vitamin K_3 in pure solvent have also been given in Tables 2 to 7. The apparent molar volume increases as temperature increases at fixed concentration of vitamin K_3 and decreases with concentration at the same temperature. These values are important because they form the basis for understanding molecular interactions.

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