Densities and Excess Molar Volumes for Binary Glycerol + 1-Propanol, + 2-Propanol, + 1,2-Propanediol, and + 1,3-Propanediol Mixtures at Different Temperatures

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Liquid densities of the binary glycerol + 1-propanol, + 2-propanol, + 1,2-propanediol, and + 1,3-propanediol mixtures were measured at the temperatures in the range from (298.15 to 333.15) K in 5 K intervals. From these data, the excess molar volumes (V^E) and its standard deviations ($\sigma(V^E)$) were calculated. The experimental results have been correlated using the three parameters of the Redlich−Kister equation.

Introduction

Glycerol is important in the pharmaceutical, cosmetic, and food industries because it is nontoxic and possesses good solvent properties for many compounds, both organic and inorganic. It has useful solvent properties, similar to those of water and simple aliphatic alcohols, because it has three hydroxyl groups. It is, accordingly, completely miscible with 1-propanol, 2-propanol, 1,2-propanediol, and 1,3-propanediol. Widespread application of the glycerol mixtures has been found in the manufacturing of solvents. Knowledge of the elementary physicochemical properties such as density of these mixtures is essential in modeling and design of chemical processes. However, no experimental density and V^E measurements have been reported in the previous literature[1−3] for glycerol + 1-propanol, + 2-propanol, + 1,2-propanediol, and + 1,3-propanediol mixtures.

In this paper, liquid densities and V^E are reported for the binary mixtures glycerol + 1-propanol, + 2-propanol, + 1,2-propanediol, and + 1,3-propanediol between the temperatures of (298.15 to 333.15) K within the whole composition range. The extensive experimental data reported in this work have been correlated with the Redlich−Kister model. The parameters of the model and deviations between experimental and calculated data are given.

Experimental Sections

Materials. Chemical of high purity obtained from different suppliers were purified by simple vacuum fractionation. The purity was checked by gas chromatography (GC). In Table 1, the specifications of the experimental chemicals (mol wt, CASRN, purity) are summarized, and literature data (if available) for comparison are also presented.

Apparatus and Procedure. The densities of the pure components and binary mixtures were measured using a approximately 50 cm^3 Gay-Lussac pycnometer, which was calibrated by using pure water. The pycnometer containing the solutions was immersed in a constant-temperature bath. The temperature was controlled within ± 0.05 K of the desired temperature through a thermostat water bath. Once the solutions reached the desired temperature, they were weighed using an analytical balance (Sartorius CP124S, Germany) with an accuracy of ± 0.0001 g. Each reported value was the average of at least three measurements. The uncertainties of the density were about ± 0.0003 g·cm^{-3}.

Table 1. Pure Compound Specifications: Molecular Weight, CAS Registry Number (CASRN), Purity, Densities at Different Temperatures, and Comparison with Literature Data

					ρ/g·cm^{-3}	
compound	mol wt	CASRN	purity (% GC)	T/K	this work	literature
glycerol	92.09	56-81-5	> 99.9	298.15	1.2589	1.2581[4]
				303.15	1.2556	
				308.15	1.2527	
				313.15	1.2495	
				318.15	1.2462	
				323.15	1.2429	
				328.15	1.2396	
				333.15	1.2360	
1-propanol	60.10	71-23-8	> 99.5	298.15	0.7996	0.79978[9]
				303.15	0.7955	0.7956[7]
				308.15	0.7915	0.79138[9]
				313.15	0.7873	0.7875[7]
				318.15	0.7833	
				323.15	0.7790	0.77926[11]
				328.15	0.7749	
				333.15	0.7708	0.77065[11]
2-propanol	60.10	67-63-0	> 99.7	298.15	0.7806	0.78123[9]
				303.15	0.7766	0.7768[8]
				308.15	0.7723	0.77246[9]
				313.15	0.7679	0.7680[8]
				318.15	0.7633	
				323.15	0.7586	0.7589[8]
				328.15	0.7538	
				333.15	0.7489	
1,2-propanediol	76.10	57-55-6	> 99.6	298.15	1.0325	1.03277[10]
				303.15	1.0292	1.02894[5]
				308.15	1.0253	1.02519[5]
				313.15	1.0215	1.02140[5]
				318.15	1.0180	1.01740[5]
				323.15	1.0140	
				328.15	1.0102	1.00956[10]
				333.15	1.0062	
1,3-propanediol	76.10	504-63-2	> 99.4	298.15	1.0499	1.04972[6]
				303.15	1.0470	1.04672[6]
				308.15	1.0441	1.04356[6]
				313.15	1.0408	1.04028[6]
				318.15	1.0378	1.03752[6]
				323.15	1.0348	1.03415[6]
				328.15	1.0314	1.03097[10]
				333.15	1.0282	

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Table 2. Densities and Molar Excess Volumes (V^E) for the Glycerol (1) + 1-Propanol (2) Binary Mixture at Different Temperatures

x_1	ρ / $g \cdot cm^{-3}$	V^E / $cm^3 \cdot mol^{-1}$	x_1	ρ / $g \cdot cm^{-3}$	V^E / $cm^3 \cdot mol^{-1}$	x_1	ρ / $g \cdot cm^{-3}$	V^E / $cm^3 \cdot mol^{-1}$	x_1	ρ / $g \cdot cm^{-3}$	V^E / $cm^3 \cdot mol^{-1}$
T = 298.15 K											
0.0000	0.7996	0.000	0.2185	0.9035	−0.466	0.4946	1.0327	−0.647	0.8545	1.1987	−0.495
0.0676	0.8328	−0.264	0.3031	0.9429	−0.525	0.6036	1.0831	−0.630	1.0000	1.2589	0.000
0.1402	0.8673	−0.409	0.3949	0.9860	−0.604	0.7230	1.1388	−0.618			
T = 303.15 K											
0.0000	0.7955	0.000	0.2185	0.9000	−0.519	0.4946	1.0295	−0.704	0.8545	1.1956	−0.528
0.0676	0.8289	−0.284	0.3031	0.9393	−0.568	0.6036	1.0799	−0.680	1.0000	1.2556	0.000
0.1402	0.8632	−0.415	0.3949	0.9821	−0.618	0.7230	1.1357	−0.662			
T = 308.15 K											
0.0000	0.7915	0.000	0.2185	0.8960	−0.525	0.4946	1.0259	−0.727	0.8545	1.1927	−0.553
0.0676	0.8250	−0.295	0.3031	0.9356	−0.596	0.6036	1.0763	−0.692	1.0000	1.2527	0.000
0.1402	0.8594	−0.434	0.3949	0.9784	−0.636	0.7230	1.1324	−0.681			
T = 313.15 K											
0.0000	0.7873	0.000	0.2185	0.8921	−0.552	0.4946	1.0223	−0.758	0.8545	1.1895	−0.576
0.0676	0.8207	−0.287	0.3031	0.9315	−0.601	0.6036	1.0727	−0.714	1.0000	1.2495	0.000
0.1402	0.8554	−0.456	0.3949	0.9747	−0.673	0.7230	1.1288	−0.699			
T = 318.15 K											
0.0000	0.7833	0.000	0.2185	0.8883	−0.573	0.4946	1.0184	−0.774	0.8545	1.1861	−0.589
0.0676	0.8168	−0.304	0.3031	0.9277	−0.629	0.6036	1.0692	−0.746	1.0000	1.2462	0.000
0.1402	0.8513	−0.456	0.3949	0.9708	−0.690	0.7230	1.1255	−0.728			
T = 323.15 K											
0.0000	0.7790	0.000	0.2185	0.8841	−0.596	0.4946	1.0147	−0.811	0.8545	1.1827	−0.610
0.0676	0.8125	−0.314	0.3031	0.9236	−0.651	0.6036	1.0655	−0.777	1.0000	1.2429	0.000
0.1402	0.8472	−0.485	0.3949	0.9668	−0.716	0.7230	1.1220	−0.761			
T = 328.15 K											
0.0000	0.7749	0.000	0.2185	0.8803	−0.627	0.4946	1.0108	−0.825	0.8545	1.1792	−0.616
0.0676	0.8084	−0.316	0.3031	0.9197	−0.671	0.6036	1.0618	−0.799	1.0000	1.2396	0.000
0.1402	0.8431	−0.492	0.3949	0.9633	−0.760	0.7230	1.1183	−0.770			
T = 333.15 K											
0.0000	0.7708	0.000	0.2185	0.8763	−0.652	0.4946	1.0068	−0.840	0.8545	1.1758	−0.640
0.0676	0.8043	−0.331	0.3031	0.9157	−0.694	0.6036	1.0580	−0.819	1.0000	1.2360	0.000
0.1402	0.8392	−0.523	0.3949	0.9594	−0.794	0.7230	1.1143	−0.769			

Table 3. Densities and Molar Excess Volumes (V^E) for the Glycerol (1) + 2-Propanol (2) Binary Mixture at Different Temperatures

x_1	ρ / $g \cdot cm^{-3}$	V^E / $cm^3 \cdot mol^{-1}$	x_1	ρ / $g \cdot cm^{-3}$	V^E / $cm^3 \cdot mol^{-1}$	x_1	ρ / $g \cdot cm^{-3}$	V^E / $cm^3 \cdot mol^{-1}$	x_1	ρ / $g \cdot cm^{-3}$	V^E / $cm^3 \cdot mol^{-1}$
T = 298.15 K											
0.0000	0.7806	0.000	0.2185	0.8875	−0.556	0.4946	1.0238	−0.931	0.8545	1.1965	−0.631
0.0676	0.8135	−0.197	0.3031	0.9291	−0.703	0.6036	1.0770	−0.938	1.0000	1.2589	0.000
0.1402	0.8486	−0.346	0.3949	0.9743	−0.825	0.7230	1.1352	−0.894			
T = 303.15 K											
0.0000	0.7766	0.000	0.2185	0.8838	−0.593	0.4946	1.0200	−0.950	0.8545	1.1934	−0.661
0.0676	0.8095	−0.205	0.3031	0.9264	−0.821	0.6036	1.0734	−0.965	1.0000	1.2556	0.000
0.1402	0.8447	−0.365	0.3949	0.9706	−0.859	0.7230	1.1319	−0.933			
T = 308.15 K											
0.0000	0.7723	0.000	0.2185	0.8799	−0.633	0.4946	1.0162	−0.975	0.8545	1.1900	−0.664
0.0676	0.8055	−0.235	0.3031	0.9223	−0.838	0.6036	1.0704	−1.035	1.0000	1.2527	0.000
0.1402	0.8405	−0.373	0.3949	0.9673	−0.927	0.7230	1.1285	−0.956			
T = 313.15 K											
0.0000	0.7679	0.000	0.2185	0.8759	−0.670	0.4946	1.0126	−1.028	0.8545	1.1868	−0.686
0.0676	0.8014	−0.267	0.3031	0.9184	−0.887	0.6036	1.0670	−1.084	1.0000	1.2495	0.000
0.1402	0.8361	−0.377	0.3949	0.9634	−0.968	0.7230	1.1250	−0.985			
T = 318.15 K											
0.0000	0.7633	0.000	0.2185	0.8717	−0.712	0.4946	1.0087	−1.070	0.8545	1.1832	−0.706
0.0676	0.7968	−0.271	0.3031	0.9145	−0.945	0.6036	1.0631	−1.118	1.0000	1.2462	0.000
0.1402	0.8319	−0.420	0.3949	0.9592	−0.999	0.7230	1.1213	−1.010			
T = 323.15 K											
0.0000	0.7586	0.000	0.2185	0.8674	−0.750	0.4946	1.0048	−1.125	0.8545	1.1803	−0.759
0.0676	0.7922	−0.277	0.3031	0.9102	−0.986	0.6036	1.0596	−1.187	1.0000	1.2429	0.000
0.1402	0.8276	−0.458	0.3949	0.9553	−1.064	0.7230	1.1176	−1.045			
T = 328.15 K											
0.0000	0.7538	0.000	0.2185	0.8633	−0.823	0.4946	1.0009	−1.181	0.8545	1.1766	−0.776
0.0676	0.7875	−0.293	0.3031	0.9062	−1.059	0.6036	1.0557	−1.226	1.0000	1.2396	0.000
0.1402	0.8233	−0.515	0.3949	0.9513	−1.127	0.7230	1.1141	−1.091			
T = 333.15 K											
0.0000	0.7489	0.000	0.2185	0.8588	−0.872	0.4946	0.9972	−1.263	0.8545	1.1731	−0.801
0.0676	0.7829	−0.329	0.3031	0.9016	−1.090	0.6036	1.0519	−1.290	1.0000	1.2360	0.000
0.1402	0.8184	−0.526	0.3949	0.9475	−1.217	0.7230	1.1105	−1.142			

Table 4. Densities and Molar Excess Volumes (V^E) for the Glycerol (1) + 1,2-Propanediol (2) Binary Mixture at Different Temperatures

x_1	ρ / $g \cdot cm^{-3}$	V^E / $cm^3 \cdot mol^{-1}$	x_1	ρ / $g \cdot cm^{-3}$	V^E / $cm^3 \cdot mol^{-1}$	x_1	ρ / $g \cdot cm^{-3}$	V^E / $cm^3 \cdot mol^{-1}$	x_1	ρ / $g \cdot cm^{-3}$	V^E / $cm^3 \cdot mol^{-1}$
T = 298.15 K											
0.0000	1.0325	0.000	0.2615	1.0941	−0.183	0.5534	1.1610	−0.224	0.8815	1.2333	−0.081
0.0841	1.0526	−0.081	0.3552	1.1158	−0.215	0.6585	1.1844	−0.193	1.0000	1.2589	0.000
0.1712	1.0727	−0.115	0.4524	1.1383	−0.240	0.7677	1.2078	−0.106			
T = 303.15 K											
0.0000	1.0292	0.000	0.2615	1.0905	−0.165	0.5534	1.1575	−0.215	0.8815	1.2301	−0.088
0.0841	1.0492	−0.076	0.3552	1.1126	−0.221	0.6585	1.1812	−0.204	1.0000	1.2556	0.000
0.1712	1.0696	−0.130	0.4524	1.1348	−0.229	0.7677	1.2050	−0.139			
T = 308.15 K											
0.0000	1.0253	0.000	0.2615	1.0871	−0.182	0.5534	1.1542	−0.228	0.8815	1.2274	−0.111
0.0841	1.0457	−0.097	0.3552	1.1093	−0.244	0.6585	1.1780	−0.217	1.0000	1.2527	0.000
0.1712	1.0661	−0.149	0.4524	1.1314	−0.240	0.7677	1.2022	−0.162			
T = 313.15 K											
0.0000	1.0215	0.000	0.2615	1.0838	−0.211	0.5534	1.1512	−0.263	0.8815	1.2244	−0.126
0.0841	1.0420	−0.108	0.3552	1.1056	−0.247	0.6585	1.1751	−0.249	1.0000	1.2495	0.000
0.1712	1.0624	−0.155	0.4524	1.1282	−0.271	0.7677	1.1992	−0.186			
T = 318.15 K											
0.0000	1.0180	0.000	0.2615	1.0802	−0.209	0.5534	1.1479	−0.276	0.8815	1.2210	−0.132
0.0841	1.0385	−0.110	0.3552	1.1023	−0.259	0.6585	1.1715	−0.242	1.0000	1.2462	0.000
0.1712	1.0586	−0.138	0.4524	1.1248	−0.282	0.7677	1.1956	−0.181			
T = 323.15 K											
0.0000	1.0140	0.000	0.2615	1.0763	−0.209	0.5534	1.1441	−0.268	0.8815	1.2180	−0.153
0.0841	1.0347	−0.121	0.3552	1.0983	−0.252	0.6585	1.1681	−0.255	1.0000	1.2429	0.000
0.1712	1.0550	−0.158	0.4524	1.1212	−0.290	0.7677	1.1925	−0.203			
T = 328.15 K											
0.0000	1.0102	0.000	0.2615	1.0727	−0.220	0.5534	1.1405	−0.267	0.8815	1.2147	−0.161
0.0841	1.0310	−0.127	0.3552	1.0947	−0.257	0.6585	1.1646	−0.256	1.0000	1.2396	0.000
0.1712	1.0514	−0.172	0.4524	1.1175	−0.290	0.7677	1.1890	−0.200			
T = 333.15 K											
0.0000	1.0062	0.000	0.2615	1.0692	−0.246	0.5534	1.1373	−0.308	0.8815	1.2113	−0.170
0.0841	1.0272	−0.142	0.3552	1.0912	−0.282	0.6585	1.1613	−0.287	1.0000	1.2360	0.000
0.1712	1.0476	−0.179	0.4524	1.1143	−0.333	0.7677	1.1858	−0.234			

Table 5. Densities and Molar Excess Volumes (V^E) for the Glycerol (1) + 1,3-Propanediol (2) Binary Mixture at Different Temperatures

x_1	ρ / $g \cdot cm^{-3}$	V^E / $cm^3 \cdot mol^{-1}$	x_1	ρ / $g \cdot cm^{-3}$	V^E / $cm^3 \cdot mol^{-1}$	x_1	ρ / $g \cdot cm^{-3}$	V^E / $cm^3 \cdot mol^{-1}$	x_1	ρ / $g \cdot cm^{-3}$	V^E / $cm^3 \cdot mol^{-1}$
T = 298.15 K											
0.0000	1.0499	0.000	0.2615	1.1057	−0.048	0.5534	1.1676	−0.095	0.8815	1.2352	−0.050
0.0841	1.0678	−0.012	0.3552	1.1256	−0.063	0.6585	1.1893	−0.082	1.0000	1.2589	0.000
0.1712	1.0864	−0.028	0.4524	1.1464	−0.088	0.7677	1.2126	−0.077			
T = 303.15 K											
0.0000	1.0470	0.000	0.2615	1.1030	−0.068	0.5534	1.1646	−0.099	0.8815	1.2321	−0.057
0.0841	1.0650	−0.015	0.3552	1.1228	−0.078	0.6585	1.1864	−0.093	1.0000	1.2556	0.000
0.1712	1.0835	−0.032	0.4524	1.1434	−0.092	0.7677	1.2090	−0.089			
T = 308.15 K											
0.0000	1.0441	0.000	0.2615	1.1000	−0.065	0.5534	1.1618	−0.113	0.8815	1.2293	−0.067
0.0841	1.0620	−0.015	0.3552	1.1198	−0.080	0.6585	1.1835	−0.101	1.0000	1.2527	0.000
0.1712	1.0806	−0.035	0.4524	1.1406	−0.104	0.7677	1.2061	−0.096			
T = 313.15 K											
0.0000	1.0408	0.000	0.2615	1.0969	−0.072	0.5534	1.1587	−0.119	0.8815	1.2261	−0.064
0.0841	1.0588	−0.016	0.3552	1.1168	−0.091	0.6585	1.1804	−0.106	1.0000	1.2495	0.000
0.1712	1.0775	−0.043	0.4524	1.1373	−0.103	0.7677	1.2030	−0.100			
T = 318.15 K											
0.0000	1.0378	0.000	0.2615	1.0939	−0.085	0.5534	1.1556	−0.129	0.8815	1.2228	−0.071
0.0841	1.0557	−0.018	0.3552	1.1137	−0.099	0.6585	1.1772	−0.115	1.0000	1.2462	0.000
0.1712	1.0745	−0.049	0.4524	1.1343	−0.114	0.7677	1.1997	−0.102			
T = 323.15 K											
0.0000	1.0348	0.000	0.2615	1.0909	−0.093	0.5534	1.1525	−0.134	0.8815	1.2198	−0.086
0.0841	1.0527	−0.016	0.3552	1.1107	−0.108	0.6585	1.1741	−0.123	1.0000	1.2429	0.000
0.1712	1.0714	−0.053	0.4524	1.1312	−0.119	0.7677	1.1966	−0.110			
T = 328.15 K											
0.0000	1.0314	0.000	0.2615	1.0876	−0.102	0.5534	1.1492	−0.143	0.8815	1.2166	−0.094
0.0841	1.0493	−0.017	0.3552	1.1075	−0.118	0.6585	1.1708	−0.124	1.0000	1.2396	0.000
0.1712	1.0681	−0.058	0.4524	1.1278	−0.122	0.7677	1.1934	−0.117			
T = 333.15 K											
0.0000	1.0282	0.000	0.2615	1.0844	−0.107	0.5534	1.1459	−0.148	0.8815	1.2133	−0.105
0.0841	1.0461	−0.022	0.3552	1.1041	−0.119	0.6585	1.1675	−0.133	1.0000	1.2360	0.000
0.1712	1.0649	−0.064	0.4524	1.1246	−0.129	0.7677	1.1900	−0.123			

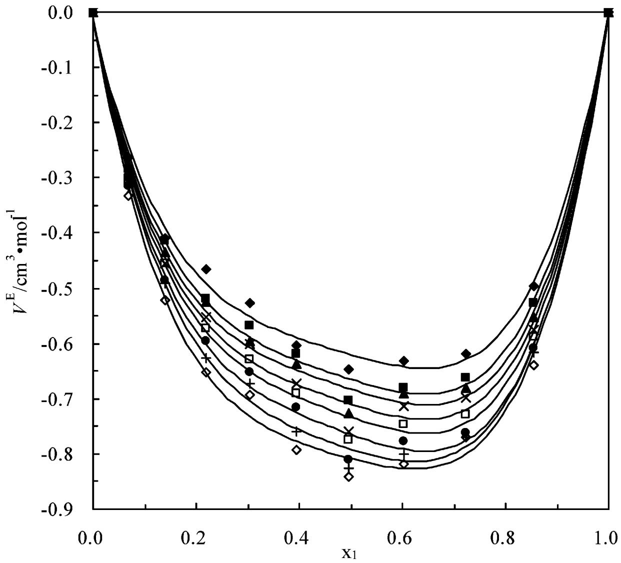

Figure 1. Excess molar volumes (V^E) for the glycerol (1) + 1-propanol (2) mixture at different temperatures: ◆, 298.15 K; ■, 303.15 K; ▲, 308.15 K; ×, 313.15 K; □, 318.15 K; ●, 323.15 K; +, 328.15 K; ◇, 333.15 K.

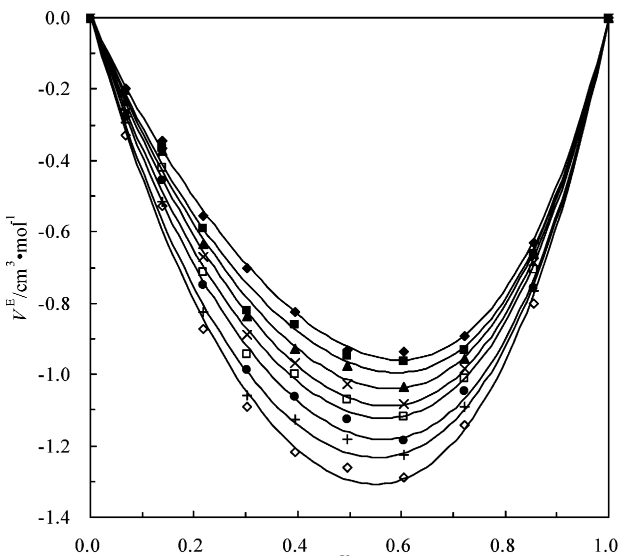

Figure 2. Excess molar volumes (V^E) for the glycerol (1) + 2-propanol (2) mixture at different temperatures: ◆, 298.15 K; ■, 303.15 K; ▲, 308.15 K; ×, 313.15 K; □, 318.15 K; ●, 323.15 K; +, 328.15 K; ◇, 333.15 K.

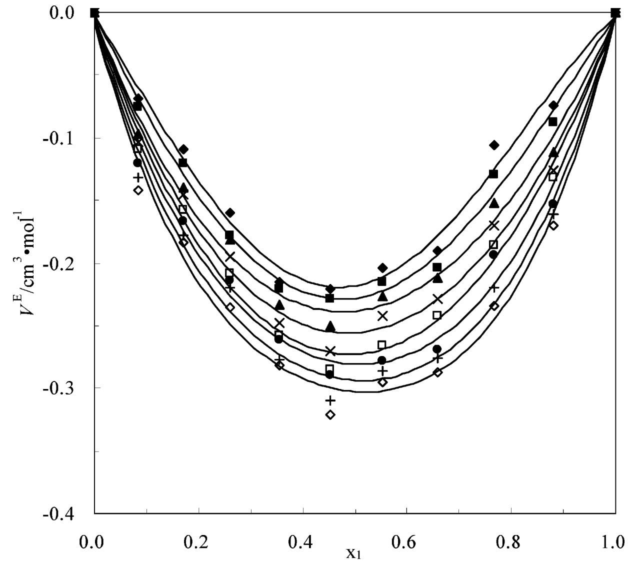

Figure 3. Excess molar volumes (V^E) for the glycerol (1) + 1,2-propanediol (2) mixture at different temperatures: ◆, 298.15 K; ■, 303.15 K; ▲, 308.15 K; ×, 313.15 K; □, 318.15 K; ●, 323.15 K; +, 328.15 K; ◇, 333.15 K.

Values of V^E were calculated from the density of the mixture (ρ) and the density (ρ_i), molar fraction (x_i), and molar masses (M_i) of the pure components (i) using the relation

$$V^E = \frac{(x_1M_1 + x_2M_2)}{\rho} - (x_1M_1/\rho_1 + x_2M_2/\rho_2) \tag{1}$$

Results and Discussion

The densities and excess molar volumes at temperatures between (298.15 and 333.15) K for the glycerol + 1-propanol, 2-propanol, 1,2-propanediol, and 1,3-propanediol binary mixtures are presented in Tables 2 to 5, respectively. The experimental excess molar volumes have been correlated by means of Redlich−Kister expansion in the form

$$V^E = x_1x_2\sum_{j=0}^{2} a_j(x_2 - x_1)^j \tag{2}$$

The regression was performed by means of the maximum likelihood method using a program with possibility to select the number adjustable parameters and to input estimated standard deviations for the measured properties. The conclusion

Table 6. Redlich−Kister Parameters, a_i, and Standard Deviations of Molar Excess Volumes, $\sigma(V^E)$, for the Investigated Systems at Different Temperatures

T/K	a_0	a_1	a_2	$\sigma(V^E)$/cm^3•mol^{-1}	T/K	a_0	a_1	a_2	$\sigma(V^E)$/cm^3•mol^{-1}
Glycerol (1) + 1-Propanol (2)									
298.15	−2.4762	0.5050	−2.2063	0.023	318.15	−2.9264	0.6052	−2.6241	0.023
303.15	−2.6148	0.5283	−2.3343	0.024	323.15	−3.0538	0.6424	−2.6748	0.025
308.15	−2.7184	0.5756	−2.4249	0.025	328.15	−3.1694	0.5967	−2.7216	0.023
313.15	−2.8303	0.5821	−2.5361	0.026	333.15	−3.2711	0.5943	−2.8273	0.028
Glycerol (1) + 2-Propanol (2)									
298.15	−3.7197	1.3626	−0.6360	0.015	318.15	−4.4478	1.1115	−0.8492	0.040
303.15	−3.9059	1.2781	−0.7221	0.037	323.15	−4.6640	1.0370	−0.8691	0.037
308.15	−4.0685	1.2480	−0.7520	0.033	328.15	−4.8736	0.9581	−0.8818	0.038
313.15	−4.2642	1.1182	−0.8123	0.040	333.15	−5.1964	0.9063	−0.9063	0.035
Glycerol (1) + 1,2-Propanediol (2)									
298.15	−0.8722	−0.1453	0.3224	0.018	318.15	−1.0906	−0.0436	−0.1381	0.015
303.15	−0.9117	−0.1107	0.1546	0.009	323.15	−1.1227	0.0205	−0.2890	0.015
308.15	−0.9534	−0.0844	−0.0735	0.011	328.15	−1.1725	0.0404	−0.3908	0.021
313.15	−1.0223	−0.0453	−0.1225	0.014	333.15	−1.2090	0.0498	−0.4898	0.017
Glycerol (1) + 1,3-Propanediol (2)									
298.15	−0.3490	0.1939	0.0867	0.004	318.15	−0.4854	0.2306	−0.0069	0.007
303.15	−0.3819	0.2063	0.0603	0.007	323.15	−0.5190	0.2343	−0.0280	0.009
308.15	−0.4189	0.2187	0.0439	0.005	328.15	−0.5348	0.2375	−0.1152	0.011
313.15	−0.4511	0.2245	0.0123	0.005	333.15	−0.5525	0.2414	−0.1986	0.011

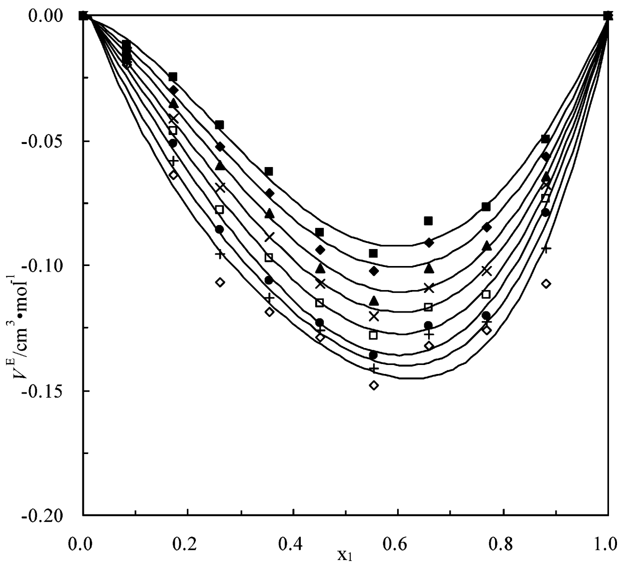

Figure 4. Excess molar volumes (V^E) for the glycerol (1) + 1,3-propanediol (2) mixture at different temperatures: ◆, 298.15 K; ■, 303.15 K; ▲, 308.15 K; ×, 313.15 K; □, 318.15 K; ●, 323.15 K; +, 328.15 K; ◇, 333.15 K.

was to use just three parameters for the Redlich−Kister equation and to find the source of possibly errors. Therefore, the input estimated standard deviation for the composition determinations (in more fractions) was set to 0.001 for all mixtures under investigation.

The Redlich−Kister parameters obtained from the correlation of V^E−composition data are summarized in Table 6 together with the resulting standard deviations in excess molar volume $\sigma(V^E)$. The standard deviation was calculated by

$$\sigma(V^E) = \left[\frac{\sum (V^E_{expt} - V^E_{cal})^2}{D - N}\right]^{0.5} \quad (3)$$

where D and N are the numbers of data points and parameters, respectively.[5] It was shown that the experimental data provided previously was reliable. From the inspection of Table 1, one may conclude that the pure compound densities at different temperatures are in good agreement with the available literature values.

The graphical presentation of the excess molar volumes (V^E) is shown in Figures 1 to 4. The observed values of V^E are negative over the entire range of composition in the investigated systems.

Conclusions

The densities of binary mixtures of glycerol + C_3-alkanol have been measured at different temperatures under atmospheric pressure over the whole concentration range. The values of excess molar volumes are calculated by the densities and have been correlated well using the Redlich−Kister polynomial equation.

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