Expansivities of the Binary Mixtures Benzene + Pentan-1-ol and Benzene + Pentan-2-ol between 298.15 and 323.15 K

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Thermal expansion coefficients, α, are reported for binary mixtures of benzene with pentan-1-ol and with pentan-2-ol. The values, between 298.15 and 323.15 K, are determined from density measurements obtained in a vibrating-tube densimeter. Obtained as well are the values of V_m^E and $(\partial V_m^E/\partial t)$ for the systems indicated, correlated with appropriate equations. The data of α obtained are compared with those evaluated by using some equations of the specific refraction.

Introduction

In a previous paper (1) thermal expansion coefficients were determined for benzene with heptan-1-ol between 298.15 and 313.15. Continuing along the same line, the expansivities of benzene with pentan-1-ol and pentan-2-ol are reported in this paper, but now for a wider range of temperatures, namely between 298.15 and 323.15 K. To complete this study we have included in this paper a secondary alcohol in order to contrast its behavior to the primary alcohol. Just as in other papers (1, 2), the values of the average expansivities ($\bar{\alpha}$), in a range of temperature, are obtained for the pure compounds and their binary mixtures by using the empirical formulas reported in the mentioned papers. A comparison between the data obtained empirically and those estimated from the experimental densities is finally made.

Experimental Section

The benzene as well as the alcohols used were provided by Fluka. Their characteristics were benzene (99.5 nol %), pentan-1-ol (99 mol %), and pentan-2-ol (99 mol %). Prior to use, all products were degassed and dried with molecular sieves. The procedure and equipment used are the same as in the previous paper (1). There is, however, a difference in the calibration of the densitometer. In some papers (3, 4) water and air were used as pattern substances for calibration, while in others air was substituted by benzene (2), tetrachloromethane (5) or dry nitrogen (6). Of all these, water is the most frequently used substance; however, the densities of air and nitrogen are far too different from those of the organic products. Also, although the densities of C_6H_6 and CCl_4 have been determined sufficiently, they are fairly unstable compounds (high volatility, hygroscopic, etc.). In order to unify the results obtained, in this and future papers we have decided to use degassed and redistilled water, with density taken from ref 7, and nonane as references for calibration. The densities of nonane (Fluka, 74252, >99 mol %) were determined between 263.15 and 323.15 K at the Institute for Measuring Techniques of Dr Stabinger, Graz (Austria), and their values, at the temperatures used in this work, are the following: 713.85 at 298.15, 709.91 at 303.15, 705.96 at 308.15, 698.06 at 318.15, and 694.12 kg·m⁻³ at 323.15 K.

The densities of nonane and water offer a wide working range and, above all, one much closer to the majority of the densities of the organic products. Also, both compounds are quite stable and their characteristics are easily reproducible.

Results and Discussion

Experimental densities and refractive indices of the pure compounds are given in Table I along with those found in the literature, for each temperature in our experiments. The values of n_D for the pure liquids were correlated as a function of temperature (°C), using a linear relationship

$$n_D = a + bt \tag{1}$$

where the coefficients a and b were determined by the method

Table I. ρ and n_D at Various Temperatures and Comparison with Those Values Found in the Literature

	298.15 K		303.15 K		308.15 K		318.15 K		323.15 K	
					C_6H_6					
ρ, kg·m⁻³	873.47	873.70 (7)	868.14	868.5 (7)	862.74	862.96 (8)	852.01		846.58	
		873.50 (8)		868.33 (8)						
		873.78 (1)		868.40 (1)						
n_D	1.4979	1.4979 (7, 8)	1.4945	1.4948 (8)	1.4914	1.4908 (1)	1.4864		1.4837	
		1.4976 (1)		1.4943 (1)						
					$C_5H_{11}(OH)$					
ρ, kg·m⁻³	811.08	811.5 (7)	807.79	807.9 (9)	803.47	803.99* (9)	795.97	796.63 (9)	792.19	792.9 (9)
		811.2 (9)								
n_D	1.4079	1.4079 (7)	1.4057	1.4058 (9)	1.4040		1.4010		1.3993	
		1.4080 (9)								
					$C_6H_7OH(OH)CH_3$					
ρ, kg·m⁻³	805.16	805.4 (7)	800.97	801.2 (9)	796.79	797.06 (9)	788.26	788.51 (9)	783.75	784.1 (9)
		805.3 (9)								
n_D	1.4044	1.4044 (7, 9)	1.4021	1.4025 (9)	1.4000		1.3967		1.3944	

Table II. ρ, n_D, and V_m^E for the Mixture Benzene + Pentan-1-ol and Benzene + Pentan-2-ol at Various Temperatures

temp, K	x_1	ρ, g·cm⁻³	V_m^E, cm³·mol⁻¹	n_D	temp, K	x_1	ρ, g·cm⁻³	V_m^E, cm³·mol⁻¹	n_D
		C_6H_6 (1) + $C_5H_{11}(OH)$ (2)				0.68575	0.82920	0.3348	1.4531
298.15	0.04065	0.81302	0.0215	1.4109		0.72785	0.83181	0.3219	1.4571
	0.11985	0.81684	0.0685			0.80045	0.83656	0.2831	1.4643
	0.17119	0.81937	0.0995	1.4198		0.86707	0.84119	0.2311	1.4712
	0.21951	0.82176	0.1328	1.4235		0.90302	0.84385	0.1912	1.4751
	0.25667	0.82364	0.1568	1.4258	323.15	0.08178	0.79539	0.0707	1.4045
	0.31943	0.82692	0.1912	1.4927		0.11200	0.79664	0.0921	1.4065
	0.34998	0.82856	0.2061	1.4896		0.21292	0.80084	0.1728	1.4134
	0.38624	0.83053	0.2237	1.4312		0.31251	0.80519	0.2442	1.4203
	0.41963	0.83242	0.2360			0.39816	0.80907	0.3035	1.4266
	0.47240	0.83542	0.2535	1.4433		0.43295	0.81074	0.3199	1.4294
	0.49965	0.83701	0.2618	1.4458		0.48041	0.81308	0.3387	1.4331
	0.54675	0.83981	0.2746	1.4498		0.50802	0.81448	0.3471	1.4353
	0.61369	0.84396	0.2833	1.4562		0.56350	0.81740	0.3563	1.4398
	0.66737	0.84743	0.2833	1.4615		0.58426	0.81852	0.3582	1.4416
	0.73077	0.85175	0.2694	1.4675		0.69352	0.82472	0.3497	1.4514
	0.80228	0.85695	0.2329	1.4759		0.75644	0.82859	0.3238	1.4574
	0.80228	0.85695	0.2329	1.4759		0.84632	0.83448	0.2650	1.4665
	0.83893	0.85974	0.2074			0.91770	0.83963	0.1831	1.4740
	0.93441	0.86743	0.1188	1.4896					
	0.96449	0.87004	0.0785	1.4927			C_6H_6 (1) + $C_3H_7CH(OH)CH_3$ (2)		
303.15	0.04284	0.80976	0.0238	1.4086	298.15	0.04446	0.80714	0.0701	1.4073
	0.08597	0.81177	0.0481	1.4117		0.08452	0.80893	0.1359	1.4099
	0.11897	0.81331	0.0691	1.4140		0.13056	0.81106	0.2060	1.4131
	0.20225	0.81729	0.1204	1.4201		0.19911	0.81440	0.2967	1.4180
	0.26217	0.81021	0.1593	1.4241		0.22933	0.81588	0.3390	1.4200
	0.31414	0.82281	0.1910	1.4285		0.27644	0.81831	0.3934	1.4240
	0.36354	0.82534	0.2194	1.4322		0.34525	0.82200	0.4647	1.4293
	0.42770	0.82873	0.2521	1.4371		0.40590	0.82549	0.5080	
	0.48342	0.83179	0.2744	1.4410		0.43061	0.82697	0.5213	1.4366
	0.50063	0.83276	0.2798	1.4430		0.46623	0.82918	0.5342	1.4392
	0.53980	0.83501	0.2900	1.4468		0.51554	0.83235	0.5450	1.4439
	0.58548	0.83771	0.2980	1.4508		0.60062	0.83812	0.5460	1.4516
	0.60710	0.83903	0.2988	1.4531		0.62115	0.83960	0.5395	1.4538
	0.65555	0.84207	0.2960	1.4573		0.67523	0.84362	0.5156	1.4594
	0.69911	0.84491	0.2870	1.4613		0.70747	0.84615	0.4913	1.4625
	0.72536	0.84666	0.2799	1.4642		0.74121	0.84884	0.4654	1.4640
	0.76700	0.84954	0.2614	1.4684		0.79149	0.85300	0.4183	1.4714
	0.82263	0.85354	0.2286	1.4743		0.82989	0.85634	0.3715	1.4760
	0.89049	0.85868	0.1745	1.4816		0.87637	0.86057	0.3033	1.4812
	0.97148	0.86540	0.0696	1.4911		0.96781	0.86969	0.1147	1.4928
308.15	0.06452	0.80640	0.0352	1.4083	303.15	0.06359	0.80382	0.0920	1.4063
	0.10502	0.80827	0.0577	1.4109		0.08446	0.80467	0.1355	1.4077
	0.15658	0.81061	0.0967	1.4146		0.12394	0.80642	0.2010	1.4103
	0.18674	0.81204	0.1140	1.4167		0.20330	0.81006	0.3262	1.4160
	0.26466	0.81571	0.1710	1.4224		0.26411	0.81310	0.3985	1.4204
	0.27932	0.81643	0.1794	1.4235		0.31954	0.81598	0.4580	1.4246
	0.32082	0.81848	0.2043	1.4265		0.36323	0.81830	0.5038	1.4281
	0.38670	0.82184	0.2384	1.4316		0.44193	0.82285	0.5523	1.4347
	0.45187	0.82529	0.2666	1.4368		0.48651	0.82557	0.5698	1.4385
	0.47944	0.82678	0.2779	1.4391		0.51741	0.82752	0.5775	1.4413
	0.52807	0.82950	0.2912	1.4432		0.57245	0.83116	0.5784	1.4466
	0.55978	0.83130	0.3000	1.4460		0.59608	0.83280	0.5726	1.4488
	0.63252	0.83561	0.3087	1.4526		0.65046	0.83667	0.5553	1.4542
	0.67215	0.83810	0.3030	1.4565		0.68430	0.83922	0.5333	1.4575
	0.72033	0.84123	0.2904	1.4609		0.74015	0.84356	0.4913	1.4633
	0.75298	0.84344	0.2757	1.4641		0.79016	0.84768	0.4377	1.4689
	0.79777	0.84650	0.2579	1.4687		0.82305	0.85048	0.3981	1.4724
	0.85282	0.85051	0.2172	1.4746		0.84634	0.85250	0.3688	1.4751
	0.90621	0.85459	0.1670	1.4804		0.90566	0.85801	0.2653	1.4822
	0.96644	0.85975	0.0633	1.4875		0.96768	0.86428	0.1213	1.4902
318.15	0.03913	0.79758	0.0300		308.15	0.04380	0.79859	0.0801	1.4027
	0.09035	0.79973	0.0679	1.4068		0.10198	0.80102	0.1868	1.4062
	0.13889	0.80178	0.1067	1.4101		0.15453	0.80330	0.2773	1.4102
	0.18005	0.80358	0.1349	1.4127		0.20818	0.80579	0.3537	1.4140
	0.23602	0.80605	0.1758	1.4170		0.25379	0.80795	0.4180	1.4171
	0.25213	0.80678	0.1862	1.4177		0.34087	0.81249	0.4997	1.4239
	0.32144	0.80995	0.2333	1.4230		0.37870	0.81454	0.5311	1.4270
	0.37129	0.81230	0.2644	1.4267		0.45271	0.81878	0.5746	1.4331
	0.45517	0.81641	0.3091	1.4334		0.48994	0.82099	0.5925	1.4363
	0.47549	0.81744	0.3180	1.4351		0.52647	0.82328	0.5991	1.4396
	0.53490	0.82057	0.3348	1.4399		0.56411	0.82574	0.5979	1.4431
	0.60972	0.82474	0.3406	1.4464		0.60961	0.82870	0.6028	1.4474
	0.63215	0.82603	0.3403	1.4484		0.64577	0.83134	0.5797	1.4509

Table II (Continued)

temp, K	x_1	ρ, g·cm⁻³	V_m^E, cm³·mol⁻¹	n_D	temp, K	x_1	ρ, g·cm⁻³	V_m^E, cm³·mol⁻¹	n_D
	0.704 67	0.835 72	0.5408	1.4568		0.716 93	0.826 44	0.5743	1.4533
	0.749 04	0.839 17	0.5027	1.4614		0.760 29	0.829 79	0.5317	1.4577
	0.780 70	0.841 70	0.4724	1.4648		0.805 82	0.833 33	0.4851	1.4629
	0.833 45	0.846 12	0.4080	1.4705		0.867 45	0.838 60	0.3857	1.4698
	0.861 98	0.848 61	0.3671	1.4737		0.938 73	0.845 24	0.2315	1.4783
	0.911 82	0.853 22	0.2759	1.4798	323.15	0.067 53	0.786 34	0.1318	1.3987
	0.969 01	0.859 08	0.1252	1.4871		0.108 27	0.787 89	0.2170	1.4013
318.15	0.068 01	0.790 90	0.1342			0.148 04	0.789 43	0.2993	1.4039
	0.124 20	0.793 13	0.2445	1.4044		0.218 07	0.792 33	0.4251	1.4086
	0.140 39	0.793 77	0.2777	1.4055		0.272 09	0.794 79	0.4984	1.4126
	0.216 96	0.797 10	0.4001	1.4110		0.356 12	0.798 90	0.5874	1.4189
	0.263 60	0.799 21	0.4695	1.4142		0.455 94	0.804 25	0.6540	1.4270
	0.324 82	0.802 19	0.5398	1.4187		0.501 37	0.806 91	0.6641	1.4308
	0.356 52	0.803 85	0.5642	1.4212		0.548 51	0.809 77	0.6683	1.4349
	0.418 83	0.418 83	0.6098	1.4261		0.598 90	0.812 99	0.6600	1.4395
	0.471 25	0.810 21	0.6291	1.4306		0.693 74	0.819 45	0.6178	1.4485
	0.535 83	0.814 12	0.6399	1.4361		0.762 01	0.824 54	0.5544	1.4555
	0.579 51	0.816 88	0.6389	1.4400		0.824 99	0.829 58	0.4715	1.4622
	0.637 86	0.820 79	0.6221	1.4454		0.917 39	0.837 70	0.2979	1.4727
	0.682 99	0.823 98	0.5962	1.4498					

of least squares. The values of $b = dn_D/dt$ were -6×10^{-4} °C⁻¹ for benzene and -4×10^{-4} °C⁻¹ for pentan-1-ol and pentan-2-ol. Likewise, the densities of all pure products were correlated through an exponential equation

$$\rho = Ae^{Bt} \qquad (2)$$

where the parameter $B = -\alpha$ is the thermal expansion coefficient, with a minus sign, of the substance considered. The values obtained for this parameter by using an appropriate fitting method were 0.00125, 0.00095, and 0.00108 °C⁻¹ for benzene, pentan-1-ol, and pentan-2-ol, respectively. In a previous paper (*1*) the value found for benzene was 0.00124; however, we must indicate that, in this work, the range of temperatures has been increased by 10 °C; therefore, the minimum differences observed are considered acceptable. The estimated figures for dn_D/dt and α are average values in the temperature range of 298.15–323.15 K; average thermal expansion coefficients are indicated by $\bar\alpha$.

The application of the empirical formulas already used in previous papers (*1*, *2*) gave the following results for the average thermal expansion coefficients: $\bar\alpha_{G-D} = 0.00114$, $\bar\alpha_{L-L} = 0.00097$, and $\bar\alpha_E = 0.00107$ °C⁻¹ for benzene $\bar\alpha_{G-D} = 0.00084$, $\bar\alpha_{L-L} = 0.00074$, and $\bar\alpha_E = 0.00079$ °C⁻¹ for pentan-1-ol; $\bar\alpha_{G-D} = 0.00098$, $\bar\alpha_{L-L} = 0.00086$, and $\bar\alpha_E = 0.00092$ °C⁻¹ for pentan-2-ol. The $\bar\alpha$ values, evaluated here empirically, are noted to be quite smaller than those estimated previously for benzene by the author using the same relationships (*1*). This is due to $\bar\alpha$ being directly proportional to the slope (dn_D/dt), and in this work, the experimental measurements of $n_D = n_D(t)$ gave a somewhat smaller slope value.

As indicated in the preceding work, the isobaric thermal expansion coefficients of a binary mixture can be obtained, at a specified concentration, either from the densities as a function of the temperature, or by adding the contributions of the expansivities of each component in the mixture. The application of this second method requires using the expression

$$\alpha = \frac{1}{V_m}\left| \sum \frac{M_i x_i}{\rho_i} \alpha_i + \left(\frac{\partial V_m^E}{\partial T}\right)_{p,x} \right| \qquad (3)$$

where V_m is the average value of the molar volume of the mixture at each concentration, and ρ_i, α_i, M_i, and x_i are respectively the average value of density and expansivity, the molecular mass and the concentration of component *i*. The average values for the magnitudes indicated are understood to be within the range of temperature used in this work. The
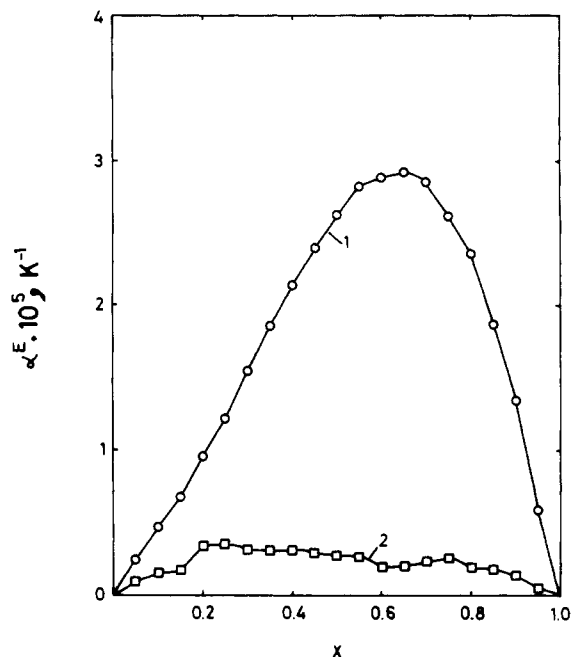
Figure 1. Average excess expansivities evaluated for xC_6H_6 + (1 − x)C₅H₁₁(OH) (1) and + (1 − x)C₇H₁₅(OH) (derived from ref *1*) (2), at every 0.05 units.
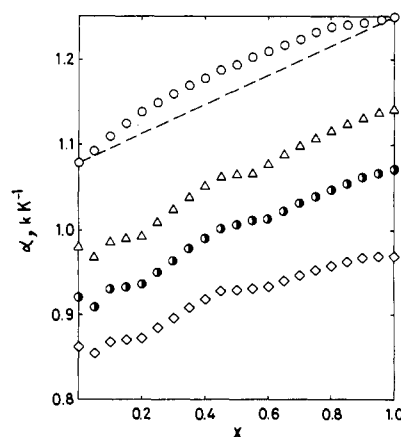
Figure 2. $\bar\alpha$-Values for xC_6H_6 + (1 − x)C₅H₁₁(OH): (O) average experimental values evaluated from densities; (△), $\bar\alpha_{G-D}$; (◐), $\bar\alpha_E$; (◇), $\bar\alpha_{L-L}$.

Table III. Parameters of Eq 4–6 and Standard Deviations for the Fit of V_m^E by Eq 6 at Various Temperatures

	T, K	c_0	c_1	c_2	c_3	d_0	d_1	d_2	d_3	R	A_0	A_1	A_2	A_3	A_4	$\sigma(V_m^E)$, cm³·mol⁻¹
C$_6$H$_6$ + C$_5$H$_{11}$(OH)	298.15	0.81103	0.04827	0.00074	0.01307	0.0003	-0.0259	0.0207	0.0040	4.3110	0.5348	3.9181	-6.6709	5.1870		0.0035
	303.15	0.80752	0.04536	0.00274	0.01228	-0.0001	-0.0196	0.0052	0.0144	3.7000	0.5231	4.0046	-6.7640	5.2841		0.0006
	308.15	0.80341	0.04631	-0.00254	0.01542	-0.0001	-0.0211	0.0091	0.0121	0.9236	0.4421	1.9889	-2.2616	1.9496		0.0034
	318.15	0.79588	0.04297	-0.00249	0.01544	-0.0003	-0.0200	0.0083	0.0116	1.5450	0.7789	0.6954	4.2101	-9.1806	6.4708	0.0013
	323.15	0.79206	0.04142	-0.00282	0.01571	-0.0001	-0.0206	0.0074	0.0131	1.1086	0.9660	-1.1209	10.2625	-17.9482	10.9434	0.0018
C$_6$H$_6$ + C$_7$H$_{\cdot}$CH(CH)CH$_3$	298.15	0.80512	0.04448	0.00772	0.01592	-0.0002	-0.0277	0.0154	0.0115	2.7835	1.6279	3.5492	-6.9794	6.0624		0.0024
	303.15	0.80097	0.04298	0.00758	0.01627	0.0001	-0.0288	0.0182	0.0103	2.2420	1.5359	4.8704	-10.0401	8.0462		0.0056
	308.15	0.79668	0.04197	0.00732	0.01640	-0.0002	-0.0280	0.0187	0.0086	3.4600	1.9506	2.7349	-4.7104	4.9095		0.0044
	318.15	0.78816	0.03890	0.00890	0.01571	-0.0005	-0.0244	0.0087	0.0161	1.7200	2.0385	3.1311	-7.0865	6.7142		0.0038
	323.15	0.78387	0.03495	0.01689	0.00969	0.0001	-0.0289	0.0196	0.0080	1.2475	1.8984	4.7370	-10.6789	8.7925		0.0054
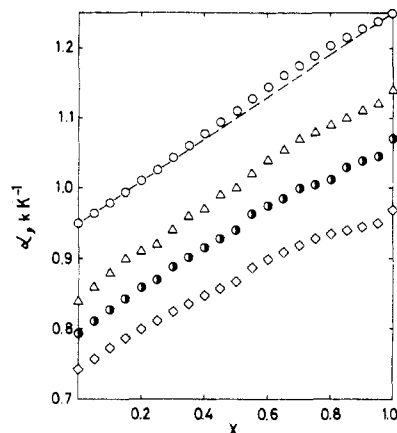
Figure 3. $\bar{\alpha}$-Values for $xC_6H_6 + (1 - x)C_3H_7CH(OH)CH_3$: (O) average experimental values evaluated from densities; (△), $\bar{\alpha}_{G-D}$; (◉), $\bar{\alpha}_E$; (◇), $\bar{\alpha}_{L-L}$.

application of eq 3 demands that, at a particular concentration, we have the numerical values for the parameters shown in it. For this reason, it was necessary to obtain adequate relations for $\rho = \rho(x)$, $n_D = n_D(x)$ and $V_m^E = V_m^E(x)$. Table II shows the ρ, n_D, and V_m^E for the mixtures as a function of the composition of benzene between 298.15 and 323.15 K. Densities and refractive indices were correlated, at each temperature, as a function of the concentration of benzene, x, using the following polynomial equations:

$$\rho = \sum c_i x^i \tag{4}$$

$$n_D = n_{D_1} x + n_{D_2}(1 - x) + \sum d_i x^i \tag{5}$$

As the excess molar volumes present a nonsymmetrical distribution, a polynomial form of the equation of Z (1–3) was used to correlate the V_m^E values. Now, this equation is presented as

$$V_m^E = x(1 - x)\sum A_i Z^i \tag{6}$$

where

$$Z = x/[x + R(1 - x)] \tag{7}$$

The parameters of all these equations appear in Table III at each temperature. Once the parameters of eq 4–6 were defined, the values of ρ, n_D, and V_m^E, at every 0.05 units of the molar fraction of benzene, x, were estimated for each temperature. Then, with x constant, the relationships of $\rho = \rho(t)$, $n_D = n_D(t)$, and $V_m^E = V_m^E(t)$ were obtained through expressions similar to (1) and (2). Knowing these equations and $(\partial V_m^E/\partial t)$, we can evaluate the $\bar{\alpha}$ values of our binary mixtures using eq 3. In order to analyze the behavior of benzene + alcohol mixtures and compare the results obtained, all these equations applied to benzene + pentan-1-ol and benzene + heptan-1-ol (derived from ref 1) were processed on a minicomputer, and represented in Figure 1 are the $\bar{\alpha}^E$'s calculated at every 0.05 units between $x = 0$ and $x = 1$. The distribution of $\bar{\alpha}^E$ is seen even better if the points evaluated are joined by means of the broke line, such as appears in Figure 1. $\bar{\alpha}^E$'s were calculated from $\bar{\alpha}^E = \bar{\alpha} - \sum \Phi_i \bar{\alpha}_i$, where Φ_i is the corresponding fraction in volume of component i, given by $\Phi_i = x_i V_{m,i}/V_m$.

We continue to be interested in contrasting these results with those obtained from the empirical relationships derived by differentiation of the Gladstone–Dale, Lorentz–Lorenz, and Eykman equations (ref 2). To achieve this, it is necessary to have a great deal of experimental data for pure products and mixtures in order to obtain a better comparison between the empirical and experimental results. Figures 2 and 3 show the graphic comparison of the data for the two systems in this work

using on the one hand eq 3, and on the other, the empirical relationships previously mentioned and derived from ref 1 and 2. The data represented have been evaluated at every 0.05 units of the molar fraction of benzene, x.

The analysis of the figures permits us to establish the following: while for benzene + heptan-1-ol, the distribution of the $\bar{\alpha}$ values presented a negative deviation in relation to the straight line $\bar{\alpha}_1 x + \bar{\alpha}_2(1-x)$, now, for benzene + pentan-1-ol and benzene + pentan-2-ol, the deviation is positive. Likewise, it is interesting to observe the shift that has taken place in the distribution of the points empirically and in a direction totally contrary to that of the $\bar{\alpha}$-values. The shifting of $\bar{\alpha}_{G-D}$, $\bar{\alpha}_{L-L}$, and $\bar{\alpha}_E$ has the same order in both systems as those of the benzene + heptan-1-ol mixture (see ref 1), giving the impression of having moved $\bar{\alpha}$-axis. While for the system $C_6H_6 + C_7H_{15}(OH)$ the empirical equation that produced the least deviation from experimental data was that derived from Lorentz–Lorenz, in this work that equation was that which caused the greatest differences due to the translation of the $\bar{\alpha}$-axis previously mentioned. These differences are due to the particular behavior of each mixture. The mean errors obtained from the empirical equa-

tions in relation to the experimental ones are respectively for benzene + pentan-1-ol and benzene + pentan-2-ol 9.73% and 12.21% with $\bar{\alpha}_{G-D}$; 15.05% and 16.41% with $\bar{\alpha}_E$; 21.46% and 22.59% with $\bar{\alpha}_{L-L}$.

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Densities, Viscosities, and Refractive Indexes for the Methyl Isobutyl Ketone + Pentanols Systems. Measurements and Correlations

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In order to facilitate interpolation of the data, empirical single equations for density, viscosity, and refractive index as functions of composition and temperature were obtained by using the experimental results for the methyl isobutyl ketone + 1-pentanol, + 2-pentanol, + isoamyl alcohol, and + *tert*-amyl alcohol binary systems at 25, 30, 35, and 40 °C. The properties calculated through the empirical relations are in fairly good agreement with the experimental data.

Many industrial chemical processes or laboratory works need experimental data of density, viscosity, and refractive index at any given temperature and composition for binary liquid mixtures. Keeping in mind this problem, we are developing equations in which temperature and composition are incorporated to facilitate the interpolation data for these properties of the methyl isobutyl ketone (MIK) + 1-pentanol (P₁), + 2-pentanol (P₂), + isoamyl alcohol (IA), and + *tert*-amyl alcohol (TA) systems.

Experimental Section

Materials. The components were supplied by Merck-Darmstadt (A.R. grade). All species were dried with anhydrous K_2CO_3 and fractionally distilled. The middle fraction was collected in each case and kept out from humidity with 3 Å molecular sieves for the pentanols and 4 Å for the methyl isobutyl ketone. The samples were maintained over molecular sieves to prevent water absorption. The physical properties of chem-

icals used here are compared with those reported in the literature in Table I.

Procedure. Mixtures were prepared by mixing accurately weighed quantities of pure liquids. Caution was taken to prevent evaporation. The Anton Paar DMA 46 calculating density meter with a built-in thermostat, a Cannon-Fenske viscosimeter, and a Jena dipping refractometer were used to obtain the density, viscosity, and refractive index, respectively. The accuracy of the measurements of these properties reported here is reproducible to within ±0.0001 g cm^{-3}, $\pm0.5\%$, and ±0.00002, respectively. In all cases, a thermostatically controlled bath to ±0.01 °C was used.

Results and Discussion

The experimental results of densities, viscosities, and refractive indexes at several temperatures and compositions for the systems (MIK + P₁), (MIK + P₂), (MIK + IA), and (MIK + TA) are summarized in Tables II, III, IV, and V, respectively.

The following functional relationships of density, viscosity, and refractive index of the mixtures with the temperature were assumed (4–6).

$$\rho = A_1 e^{B_1 t} \tag{1}$$

$$\eta = A_2 e^{B_2/T} \tag{2}$$

$$n_D = A_3 e^{B_3 t} \tag{3}$$