Densities, Viscosities, and Excess Molar Enthalpies of Binary Mixtures Containing Essential Oils at (298.15 and 313.15) K. The (*S*)-(−)-Limonene + Cineole, (*S*)-(−)-Limonene + Linalool, and Cineole + Linalool Systems

Fabio Comelli

Centro di Studio per la Fisica delle Macromolecole del CNR, via Selmi 2, I-40126 Bologna, Italy

Romolo Francesconi* and Carlo Castellari

Dipartimento di Chimica "G. Ciamician", Università degli Studi, via Selmi 2, I-40126 Bologna, Italy

Densities, ρ, viscosities, η, and excess molar enthalpies, H_m^E, of binary mixtures containing (*S*)-(−)-limonene [(−)-1-methyl-4-(1-methylethenyl)cyclohexene] + 1,8-cineole (1,3,3-trimethyl-2-oxabicyclo[2,2,2]-octane), (*S*)-(−)-limonene + linalool (3,7-dimethyl-1,6-octadien-3-ol), and cineole + linalool were determined at (298.15 and 313.15) K and at atmospheric pressure using a digital density meter, a Schott measuring system, and a flow microcalorimeter, respectively. The excess molar volumes, V_m^E, the viscosity deviations, $\Delta\eta$, and the H_m^E's were calculated from experimental measurements. Results were fitted to the Redlich−Kister polynomial to obtain the adjustable parameters and standard deviations. Results were also qualitatively explained in terms of molecular interactions.

Introduction

Components of essential oils, such as (*S*)-(−)-limonene, cineole, and linalool, are used in several pharmaceuticals and in perfume industries.[1,2] (*S*)-(−)-Limonene is the principal compound of citrus oil and makes up ≈90 mass % of citrus oil but does not contribute much to the flavor or fragrance of citrus oil while cineole, whose presence is ≈1 mass %, is an important oxygenated compound which makes the characteristic flavor and fragrance of citrus oil. Cineole and tymol are the two main components of tyme oil. Essential oils are conventionally processed by distillation or solvent extraction, resulting in the thermal degradation of some valuable components. The use of supercritical fluids is an alternative to conventional distillation processes, and the literature reports some papers about them[3−6] but no study of the viscosity and excess properties of their binary mixtures is available. In this paper we report experimental data of kinematic viscosities, ν, densities, ρ, and excess molar enthalpies, H_m^E, of mixtures containing (*S*)-(−)-limonene + cineole, (*S*)-(−)-limonene + linalool, and cineole + linalool at (298.15 and 313.15) K with the purpose to provide new information about these mixtures, to correlate the experimental data, and to give a qualitative interpretation in terms of molecular interactions.

Experimental Section

Materials. (*S*)-(−)-Limonene (purity > 97%) was a Fluka product while cineole and linalool (purity 99% and 97%, respectively) were from Aldrich. All chemicals were purified following the procedure described elsewere,[7] and the purities of the distillate were checked by using a

Hewlett-Packard gas cromatograph (model 5890) supplied with a HP (cross-linked 5% ME siloxane) capillary column.

The impurity contents were <0.1 mass % for limonene and 0.7 mass % for cineole and linalool.

Prior to use, pure liquids were degassed by ultrasound (ultrasonic bath, Hellma, type 460, Milan, Italy), kept in dark bottles, and dried over molecular sieves (Union Carbide, type 4A, 1/16 in. pellets). The measured values of densities, ρ, dynamic viscosity, η, and refractive indices, n_D, were compared with literature data[2,7−9] and are presented in Table 1. Refractive indices, n_D, were determined by using an Abbe Refractometer (Officine Galileo, Florence, Italy) with an uncertainty of 0.0001 unit. The thermostat temperature was constant to ±0.01 K.

Values of densities and refractive indices are comparable with those of the literature while a disagreement is noted in the cases of viscosities of pure liquids. Authors remark that the viscosity value of (*S*)-(−)-limonene reported by Riddick et al.[8] refers to a paper of 1908,[10] while that of cineole[9] refers to the pure liquid not distilled. No literature data of viscosity are available for linalool.

Moreover, the discrepancy observed between our viscosity data and those of the literature may be due partially to the nature of the oil and to the purity of the compounds studied in this paper. In fact, the (*S*)-(−)-limonene samples by Fluka and by Aldrich, for instance, show different values of optical rotation $[\alpha]_D^{20}$, say −90 ± 5 and −94 ± 3, respectively, which compare with our value −97. Riddick[8] reports $[\alpha]_D^{20} = -122.1$.

Density Measurements. Solutions of different compositions were prepared by mass in a 25 cm³ flask using a digital balance (Mettler, model AE 160, Switzerland) accurate to within ±0.0001 g following the method described elsewhere.[11] Densities, ρ, of pure components and their binary mixtures were measured using a vibrating-tube densimeter (Anton Paar, model DM 60, Graz, Austria)

* Corresponding author. E-mail: romolo@ciam.unibo.it. Fax: +39 051 2094325.

Table 1. Comparison of Experimental Densities, ρ, Dynamic Viscosities, η, and Refractive Indices, n_D, of Pure Components with Literature Values

compound	T/K	ρ/g·cm^{-3}		η/mPa·s		n_D	
		this work	lit.	this work	lit.	this work	lit
(S)-(−)-limonene	298.15	0.839 44	0.8418[7]	0.846	1.806[8]	1.4707	1.4707[7]
	298.15		0.8348[8]				1.4701[8]
	313.15	0.827 88	0.8304[8]	0.702	n.a.	1.4641	1.4643[7]
cineole	298.15	0.920 13	0.9192[8]	2.559	2.303[9]	1.4556	1.4555[8]
	298.15		0.92029[9]				
	298.15		0.92009[9]				
	313.15	0.907 22	n.a.	1.886	n.a.	1.4491	n.a.
linalool	295.15					1.4610	1.4606[2]
	298.15	0.858 09	n.a.	4.464	n.a.	1.4603	n.a.
	313.15	0.845 43	n.a.	2.552	n.a.	1.4535	n.a.

Table 2. Excess Molar Volumes, V_m^E, for Binary Mixtures Containing Essential Oils

x_1	V_m^E/cm^3·mol^{-1}	x_1	V_m^E/cm^3·mol^{-1}
(S)-(−)-Limonene (1) + Cineole (2); T/K = 298.15			
0.0715	0.070	0.6401	0.209
0.1121	0.103	0.7336	0.172
0.2018	0.163	0.8226	0.124
0.3270	0.216	0.8648	0.100
0.4164	0.237	0.9499	0.037
0.5584	0.229		
T/K = 313.15			
0.0715	0.063	0.6401	0.198
0.1121	0.096	0.7336	0.162
0.2018	0.154	0.8226	0.117
0.3270	0.205	0.8648	0.091
0.4164	0.224	0.9499	0.029
0.5584	0.218		
(S)-(−)-Limonene (1) + Linalool (2); T/K = 298.15			
0.0422	0.035	0.5620	0.319
0.1332	0.104	0.6389	0.336
0.2273	0.167	0.7679	0.326
0.3523	0.237	0.8478	0.279
0.4816	0.295	0.9236	0.179
T/K = 313.15			
0.0422	0.037	0.5620	0.398
0.1332	0.125	0.6389	0.415
0.2273	0.209	0.7679	0.398
0.3523	0.301	0.8478	0.336
0.4816	0.373	0.9236	0.221
Cineole (1) + Linalool (2); T/K = 298.15			
0.0536	−0.058	0.5620	−0.319
0.1357	−0.139	0.6809	−0.287
0.2205	−0.207	0.8027	−0.212
0.3081	−0.260	0.8783	−0.144
0.4288	−0.306	0.9599	−0.049
0.6051	−0.310		
T/K = 313.15			
0.0536	−0.049	0.5620	−0.288
0.1357	−0.120	0.6809	−0.258
0.2205	−0.181	0.8027	−0.194
0.3081	−0.232	0.8783	−0.127
0.4288	−0.277	0.9599	−0.045
0.6051	−0.279		

Figure 1. Excess molar volumes, V_m^E, versus the mole fraction, x_1: upper part, (S)-(−)-limonene (1) + cineole (2) (●, ○) and (S)-(−)-limonene (1) + linalool (2) (■, □); closed points, at 298.15 K; open points, at 313.15 K; full lines, Redlich−Kister equation; lower part, cineole (1) + linalool (2) (●, ○); closed points, at 298.15 K; open point, at 313.15 K; full lines, Redlich−Kister equation.

equipped with a measuring cell (Anton Paar, type 602) and two digital thermometers (Anton Paar, DT-25 and DT-40). The apparatus was calibrated with deionized doubly distilled water[12] and dry air.[13] The temperature in the measuring cell was regulated to ±0.01 K, using an external bath circulator (Heto, type 01 DBT 623, Birkeröd, Denmark) accurate to within ±0.005 K.

The uncertainty of density measurements was ±1 × 10^{-5} g·cm^{-1}, and the excess molar volumes, V_m^E, were uncertain to ±0.003 cm^3·mol^{-1}. Corrections were made for buoyancy.

Before measurements, the apparatus was checked by determining V_m^E using the test mixture benzene + cyclohexane at 298.15 K, and our results agree with those of the literature[14] within 1%.
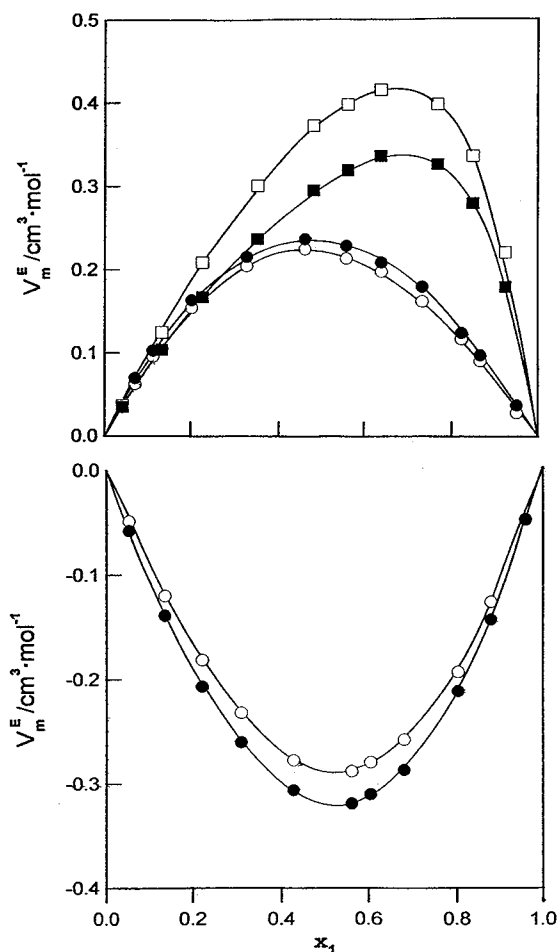
Viscosity Measurements. Kinematic viscosities, ν, of pure liquids and mixtures were determined at (298.15 and 313.15) K using a Schott-Geräte (Mains, Germany) AVS 310 unit equipped with an Ubbelohde viscosimeter (capillary No. 0a) having a cell constant $k = 0.004\ 971$ mm^2·s^{-2} and times varying from (180 to 1000) s. The experimental reproducibility between duplicate viscosity values of all samples was about ±0.3%. The viscometer was calibrated with double-distilled water, whose viscosity is well-known and reported in the literature.[8] The average of six flow times for each sample of liquid was taken for the purpose of the calculation of viscosity. A digital well-stirred water

Table 3. Experimental Densities, ρ, Dynamic Viscosities, η, and Deviations of Viscosities, $\Delta\eta$, of Binary Mixtures Containing Essential Oils

x_1	ρ/g·cm^{-3}	η/mPa·s	$\Delta\eta$/mPa·s	x_1	ρ/g·cm^{-3}	η/mPa·s	$\Delta\eta$/mPa·s
			(S)-(−)-Limonene (1) + Cineole (2); T/K = 298.15				
0.0715	0.914 12	2.345	−0.092	0.6401	0.867 72	1.162	−0.300
0.1121	0.910 73	2.230	−0.137	0.7336	0.860 25	1.050	−0.252
0.2018	0.903 29	1.995	−0.219	0.8226	0.853 16	0.963	−0.187
0.3270	0.893 02	1.704	−0.295	0.8648	0.849 00	0.928	−0.149
0.4164	0.882 09	1.439	−0.330	0.9499	0.843 04	0.872	−0.060
0.5584	0.874 27	1.279	−0.324				
			T/K = 313.15				
0.0715	0.901 34	1.741	−0.060	0.6401	0.855 70	0.929	−0.199
0.1121	0.898 01	1.664	−0.090	0.7336	0.848 33	0.851	−0.167
0.2018	0.890 70	1.504	−0.143	0.8226	0.841 34	0.785	−0.127
0.3270	0.886 01	1.305	−0.194	0.8648	0.838 03	0.759	−0.103
0.4164	0.869 86	1.123	−0.217	0.9499	0.831 37	0.716	−0.046
0.5584	0.862 15	1.011	−0.214				
			(S)-(−)-Limonene (1) + Linalool (2); T/K = 298.15				
0.0422	0.857 21	4.062	−0.249	0.5620	0.846 49	1.429	−1.001
0.1332	0.855 32	3.237	−0.745	0.6389	0.844 94	1.282	−0.870
0.2273	0.853 37	2.695	−0.947	0.7679	0.842 47	1.011	−0.584
0.3523	0.850 79	2.072	−1.118	0.8478	0.841 11	1.013	−0.384
0.4816	0.848 12	1.626	−1.096	0.9236	0.840 09	0.933	−0.190
			T/K = 313.15				
0.0422	0.844 59	2.370	−0.104	0.5620	0.834 09	1.086	−0.427
0.1332	0.842 71	2.025	−0.281	0.6389	0.832 623	0.998	−0.372
0.2273	0.840 77	1.731	−0.401	0.7679	0.830 33	0.877	−0.255
0.3523	0.838 22	1.427	−0.473	0.8478	0.829 13	0.814	−0.170
0.4816	0.835 64	1.196	−0.465	0.9236	0.828 26	0.755	−0.088
			Cineole (1) + Linalool (2); T/K = 298.15				
0.0536	0.860 93	4.296	−0.066	0.6050	0.895 94	3.019	−0.293
0.1357	0.866 19	4.062	−0.144	0.6809	0.900 68	2.900	−0.267
0.2205	0.871 60	3.835	−0.209	0.8027	0.908 18	2.740	−0.195
0.3081	0.877 17	3.614	−0.263	0.8783	0.912 79	2.660	−0.131
0.4288	0.884 83	3.347	−0.301	0.9599	0.917 70	2.591	−0.045
0.5620	0.893 26	3.093	−0.301				
			T/K = 313.15				
0.0536	0.848 20	2.489	−0.027	0.6050	0.882 94	2.023	−0.126
0.1357	0.853 38	2.401	−0.061	0.6809	0.887 67	1.983	−0.115
0.2205	0.858 73	2.316	−0.089	0.8027	0.895 21	1.933	−0.085
0.3081	0.864 26	2.236	−0.111	0.8783	0.899 82	1.910	−0.573
0.4288	0.871 88	2.138	−0.128	0.9599	0.904 79	1.892	−0.021
0.5620	0.880 26	2.048	−0.130				

bath (Lauda, type E 200, Germany), whose temperature was controlled to ±0.005 K, was used for all measurements.

Calorimetric Measurements. A flow microcalorimeter (LKB Producer, model 2107, Bromma, Sweden), driven by two automatic burets (ABU, Radiometer, Copenhagen, Denmark) necessary to pump pure liquids into the mixing cell of the apparatus, was used to determine the excess molar enthalpies, H_m^E, at (298.15 and 313.15) K and at atmospheric pressure. The calibration and operating procedure of the instrument was detailed previously.[15,16] Mole fractions, x_1, of limonene or cineole (component 1) were determined from flow rates with a precision of 1×10^{-4}, which lead to an error in H_m^E of (0.5−1) J·mol^{-1}.

The performance of the calorimeter was checked by measuring H_m^E over the whole composition for the test mixture cyclohexane + hexane at 298.15 K, and the agreement with literature results[17] was <1%.

Results and Discussion

Tables 2 and 3 give the experimental results of the excess molar volumes, V_m^E, and dynamic viscosities, η, at (298.15 and 313.15) K while excess molar enthalpies, H_m^E, versus the mole fraction, x_1, are reported in Table 4.

The plots of the V_m^E, deviation of viscosities, $\Delta\eta$, and H_m^E, versus the mole fraction, x_1, are given in Figures 1−3.

The experimental density values, ρ, were used to calculate the excess molar volume, V_m^E, using the following equation

$$V_m^E = (x_1 M_1 + x_2 M_2)/\rho - x_1 M_1/\rho_1 - x_2 M_2/\rho_2 \quad (1)$$

where ρ is the density of the mixture and M_1, M_2, x_1, x_2, ρ_1, and ρ_2 are the molar weight, the mole fractions, and the densities of the pure compounds 1 and 2, respectively.

The deviations of viscosity, $\Delta\eta$, are obtained by the following equation

$$\Delta\eta = \eta - x_1\eta_1 - x_2\eta_2 \quad (2)$$

where η is the dynamic viscosity of the mixture and x_1, x_2, η_1, and η_2 are the mole fractions and dynamic viscosities of components 1 and 2, respectively.

To each set of experimental values, a Redlich−Kister polynomial of the type

$$Q_m^E = x_1 x_2 \sum_{k\geq 0} a_k (x_1 - x_2)^k \quad (3)$$

has been fitted by an unweighted least-squares method, where $Q_m^E = V_m^E$/cm^3·mol^{-1}, $\Delta\eta$/mPa·s, or H_m^E/J·mol^{-1}, x_1, and x_2 are the molar fractions of components 1 and 2,

Table 4. Excess Molar Enthalpies, H_m^E, for Binary Mixtures Containing Essential Oils

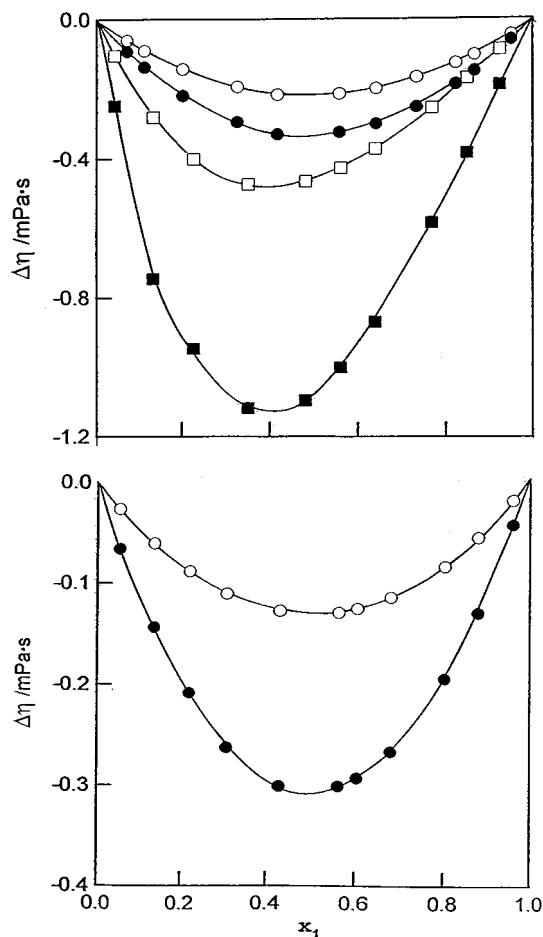| x_1	$H_m^E/\text{J·mol}^{-1}$	x_1	$H_m^E/\text{J·mol}^{-1}$
(S)-(−)-Limonene (1) + Cineole (2); $T/\text{K} = 298.15$
0.0413	21	0.6739	59
0.0792	37	0.7561	27
0.1144	49	0.8052	8
0.1469	59	0.8611	−9
0.2053	77	0.8921	−15
0.2561	87	0.9254	−18
0.3406	101	0.9612	−14
0.4077	106	0.9697	−12
0.5081	100	0.9800	−9
0.6079	79		
$T/\text{K} = 313.15$
0.0413	5	0.6079	22
0.0792	12	0.6739	1
0.1144	19	0.756	−26
0.1469	26	0.8052	−39
0.2053	38	0.8611	−47
0.2561	48	0.8921	−46
0.3406	57	0.9254	−40
0.4077	59	0.9612	−26
0.5081	46	0.9800	−15
(S)-(−)-Limonene (1) + Linalool (2); $T/\text{K} = 298.15$
0.0441	82	0.6245	1049
0.0846	170	0.6891	1055
0.1217	261	0.7688	1021
0.1559	335	0.8160	944
0.2170	474	0.8693	799
0.2698	590	0.8987	691
0.3566	746	0.9301	536
0.4249	847	0.9638	306
0.5257	982		
$T/\text{K} = 313.15$
0.441	100	0.6245	1111
0.846	192	0.6891	1101
0.1217	289	0.7688	1016
0.1559	388	0.8160	902
0.2170	537	0.8693	743
0.2698	660	0.8987	629
0.3566	837	0.9301	477
0.4249	950	0.9638	267
0.5257	1063		
Cineole (1) + Linalool (2); $T/\text{K} = 298.15$
0.0428	6	0.6169	116
0.0821	15	0.6821	108
0.1183	23	0.7630	89
0.1517	35	0.8110	74
0.2115	53	0.8656	54
0.2634	70	0.8957	42
0.3492	94	0.9279	29
0.4169	108	0.9626	15
0.5176	119		
$T/\text{K} = 313.15$
0.0428	6	0.6169	122
0.0821	14	0.6821	108
0.1183	24	0.7630	85
0.1517	36	0.8110	67
0.2115	54	0.8656	46
0.2634	70	0.8957	31
0.3492	99	0.9279	21
0.4169	114	0.9626	10
0.5176	127		

Figure 2. Deviation of viscosity, $\Delta\eta$, versus the mole fraction, x_1: upper part, (S)-(−)-limonene (1) + cineole (2) (●, ○) and (S)-(−)-limonene (1) + linalool (2) (■, □); closed points, at 298.15 K; open points, at 313.15 K; full lines, Redlich−Kister equation; lower part, cineole (1) + linalool (2) (●, ○); closed points, at 298.15 K; open points, at 313.15 K; full line, Redlich−Kister equation.

respectively, and a_k's are the adjustable parameters. The a_k values are given in Table 5 together with the standard deviation $\sigma(Q_m^E)$, defined as

$$\sigma(Q_m^E) = |\phi_{min}/(N − n)|^{0.5} \tag{4}$$

In eq 4, N and n are the number of experimental points and of parameters, respectively, whereas ϕ_{min} is the minimum value of the objective function ϕ, defined as

$$\phi = \sum_{k=1}^{N} \omega_k^2 \tag{5}$$

where $\omega_k = Q_{m,calcd}^E − Q_m^E$; Q_m^E is the experimental value, and $Q_{m,calcd}^E$ is evaluated through eq 3.

Values of H_m^E are positive for the mixtures containing linalool whereas the mixture limonene + cineole shows an inversion of H_m^E as a function of mole fraction. Maxima of H_m^E range between (60 and 1100) J·mol^{-1}, the lowest value being for limonene + cineole.

The temperature dependence of H_m^E is a small entity and shows no regular trend.

The systems containing linalool show a large increase of H_m^E in passing from cineole to limonene. This may be qualitatively explained by considering the approximated expression $H_m^E \approx E_{11} + E_{22} − 2E_{12}$, with E_{ij} the interaction energy between molecules i and j. The breakage of hydrogen bonds between the OH groups of linalool during mixing gives a large contribution to E_{22}, which is contrasted by the interaction energy E_{12} between the double bonds of linalool and the ethereal oxygen of cineole, which is absent in the mixture with limonene.
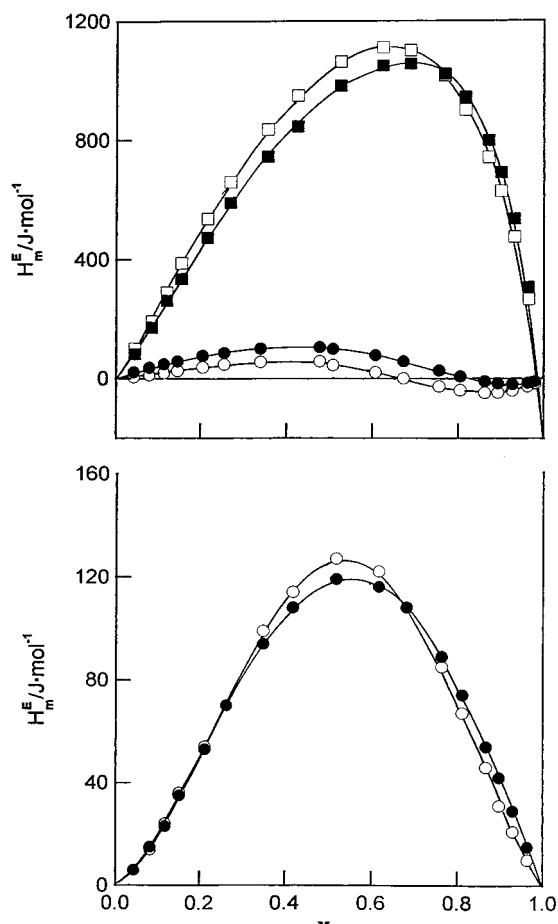
Figure 3. Excess molar enthalpies, H_m^E, versus the mole fraction, x_1: upper part, (*S*)-(−)-limonene (1) + cineole (2) (●, ○) and (*S*)-(−)-limonene (1) + linalool (2) (■, □); closed points, at 298.15 K; open points, at 313.15 K; full line, Redlich−Kister equation; lower part, cineole (1) + linalool (2) (●, ○); closed points, at 298.15 K; open points, at 313.15 K; full line, Redlich−Kister equation.

Table 5. Least-Squares Parameters, a_k, Eq 3, and Standard Deviations, $\sigma(Q_m^E)$, Eq 4, of Binary Mixtures Containing Essential Oils

function	a_0	a_1	a_2	a_3	$\sigma(Q_m^E)$
(S)-(−)-Limonene (1) + Cineole (2); T/K = 298.15					
V_m^E/cm^3·mol^{-1}	0.9438	−0.1173	−0.0229	−0.0348	0.0003
$\Delta\eta$/mPa·s	−1.3217	0.0646			0.0003
H_m^E/J·mol^{-1}	404.8	−228.3	−387.5	−305.0	0.6
T/K = 313.15					
V_m^E/cm^3·mol^{-1}	0.9000	−0.1022	−0.0702	−0.0640	0.0023
$\Delta\eta$/mPa·s	−0.8680	0.0178	−0.0394		0.0017
H_m^E/J·mol^{-1}	196.7	−343.5	−553.3	−129.2	0.5
(S)-(−)-Limonene (1) + Linalool (2); T/K = 298.15					
V_m^E/cm^3·mol^{-1}	1.1997	0.7028	0.6870	0.3965	0.0015
$\Delta\eta$/mPa·s	−4.3213	1.9612	0.0020		0.0020
H_m^E/J·mol^{-1}	3797.0	2141.3	1754.4	1831.9	5.5
T/K = 313.15					
V_m^E/cm^3·mol^{-1}	1.5118	0.7813	0.7209	0.6470	0.0021
$\Delta\eta$/mPa·s	−1.8315	0.7811	−0.0681		0.0013
H_m^E/J·mol^{-1}	4170.4	1999.0	938.8	1049.3	5.1
Cineole (1) + Linalool (2); T/K = 298.15					
V_m^E/cm^3·mol^{-1}	−1.2699	−0.1197			0.0018
$\Delta\eta$/mPa·s	−1.2280	0.0006			0.0017
H_m^E/J·mol^{-1}	474.4	143.3	−222.2		0.7
T/K = 313.15					
V_m^E/cm^3·mol^{-1}	−1.1519	−0.1309	0.0752		0.0016
$\Delta\eta$/mPa·s	−0.5257	−0.0110			0.0005
H_m^E/J·mol^{-1}	501.8	144.8	−344.4	−97.1	0.8

In fact, authors[18] report the structure of an inclusion compound between limonene and a diol molecule, showing no specific interaction between the components.

Volumetric and viscometric determinations for mixtures containing linalool show the same trend as that for H_m^E. In fact, V_m^E is lower and $\Delta\eta$ is less negative for the mixture cineole + linalool, where the interaction energy E_{12} is relatively larger, since increasing interactions between different molecules are expected to show an increase in volume contraction and in the viscosity of the mixture.

Finally, $\Delta\eta$ is more temperature dependent than H_m^E and V_m^E; thus, the viscosity of the mixture shows a decrease with increased temperature larger than that for the pure components.

Acknowledgment

Literature Cited

(1) Martindale, W. *The Extra Pharmacopoeia;* Pharmaceutical Press: London, 1989.

(2) *The Merck Index*, 12th ed.; Merck & Co., Inc.: Whitehouse Station, NJ, 1996.

(3) Karla, H.; Chung, S. Y.; Chen, G. J. Phase Equilibrium Data for Supercritical Extraction of Lemon Flavors and Palm Oils with Carbon Dioxide. *Fluid Phase Equilib.* **1987**, *36*, 263−278.

(4) Gomes, A.; Serrano, L.; Ferrero, R. Solid−Liquid Equilibria in 1,8-Cineole/Terpenic Hydrocarbon Systems. *J. Chem. Eng. Data* **1988**, *33*, 194−196.

(5) Rodrigues, M. F.; Bernardo-Gil, M. G. Vapor-Liquid Equilibrium Data of α-Pinene + β-Pinene + Limonene at 80 kPa and 101 kPa. *J. Chem. Eng. Data* **1996**, *41*, 581−585.

(6) Iwai, Y.; Hosotani, N.; Morotomi, T.; Koga, Y.; Arai, Y. High-Pressure Vapor−Liquid Equilibria for Carbon Dioxide + Linalool. *J. Chem. Eng. Data* **1994**, *39*, 900−902.

(7) Ribeiro, A.; Bernardo-Gil, G. Densities and Refractive Indices of Components of Pine Resins. *J. Chem. Eng. Data* **1990**, *35*, 204−206.

(8) Riddick, J. A.; Bunger, W. B.; Sakano, T. K. *Organic Solvents*, 4th ed.; Wiley-Interscience: New York, 1986.

(9) Barata, P. A.; Serrano, M. L. Densities and Viscosities of Tymol + 1,8-Cineole. *J. Chem. Eng. Data* **1994**, *39*, 298−301.

(10) Dunstan, A. E.; Thole, f. B. The Relation Between Viscosity and Chemical Constitution. Part II. The Existence of Racemic Compounds in the Liquid State. *Am. Chem. Soc.* **1908**, 1815−1921.

(11) Fermeglia, M.; Lapasin, J. Excess Volumes and Viscosities of Binary Mixtures of Organics. *J. Chem. Eng. Data* **1988**, *33*, 415−417.

(12) Wagenbreth, H.; Blanke, W. Die Dichte des Wassers im Internationalen Einheitensystem und in die Internationalen Practishen Temperaturskala von 1968. PTB−Mitteilungen 6/71, 412.

(13) Kohlrausch, F. Density of Air. *Prakt. Phys.* **1968**, *3*, 40.

(14) Wilhelm, E. *Int. DATA Ser., Sel. Data Mixtures, Ser. A* **1985**, 164.

(15) Monk, P.; Wadsö, I. A Flow Micro Reaction Calorimeter. *Acta Chem. Scand.* **1968**, *22*, 1842−1852.

(16) Francesconi, R.; Comelli, F. Liquid-Phase Enthalpy of Mixing for the System 1,3-Dioxolane-Chlorobenzene in the Range 288.15−313.15 K. *J. Chem. Eng. Data* **1986**, *31*, 250−253.

(17) Gmehling, I. Excess Enthalpies for 1,1,1-Trichloroethane with Alkanes, Ketones, and Esters. *J. Chem. Eng. Data* **1993**, *38*, 143−146.

(18) Toda, F.; Tanaka, K.; Stein, Z.; Goldberg, I. Structure and Inclusion Characteristics of (*R, R*)-(−)-2,3-Dimethoxy-1,1,4,4-tetraphenyl-1,4-diol. *J. Chem. Soc., Perkin Trans. 2* **1993**, 2359−2361.