Density, Viscosity, and Speed of Sound of Solutions of AOT Reverse Micelles in 2,2,4-Trimethylpentane

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The density, viscosity, and speed of sound for 2,2,4-trimethypentane + sodium bis(2-ethylhexyl) sulfosuccinate (AOT) have been measured. The effect of surfactant concentration upon these physical properties has been analyzed. Different equations employed in the literature have been employed to fit the experimental data.

Introduction

Alkenes are an important series of homologous, nonpolar, organic solvents, and their properties with other components are frequently studied as a function of chain length.[1] For this reason, a considerable amount of data on physicochemical properties has been reported in the last years.[2−5]

In the past decade, systems based on binary and ternary mixtures (i.e., emulsions and microemulsions) with an alkane as its major component have been used in several operations such as liquid/liquid extraction or reaction systems. The mixture considered in the present paper consists of 2,2,4-trimethylpentane + AOT (sodium bis(2-ethylhexyl) sullfosuccinate), which is the base of one of the microemulsions most employed in chemistry, used as an extraction media, as a selective reaction media, and for nanoparticle production.[6,7]

The influence of physicochemical properties upon the processes that involve mass transfer has been studied,[8] and this influence could be decisive upon the above operations. Specifically, the physical properties of these systems could explain the changes in the reaction kinetic mechanism[9] and mass transfer.[10] It is possible that physical properties could determine the presence of colloidal aggregates that could modify reaction mechanisms.[11] The present study includes the measurement of density, viscosity, and speed of sound as a function of surfactant concentration and temperature.

Experimental Section

Materials. 2,2,4-Trimethylpentane (CAS Registry No. 540-84-1) and AOT (CAS Registry No. 577-11-7) were supplied by Sigma with purities ≥ 99 % for 2,2,4-trimethylpentane, and 99 % for AOT. The final solutions were prepared by mass with deviations of less than ± 0.8 % from the desired concentration. All the mixtures were prepared by mass using an analytical balance (Kern 770) with a precision of ± 10^{-4} g. The uncertainty of the samples preparation was ± 0.001 mol·(kg of solution)$^{-1}$.

Methods. Density of pure liquid (2,2,4-trimethylpentane) and mixtures was measured with an Anton Paar DSA 5000 vibrating-tube densimeter and sound analyzer, with an accuracy of ± 10^{-6} g·cm^{-3} in relation to the density and ± 0.01 m·s^{-1} for the speed of sound. This apparatus allows temperature variation from 20 °C to 50 °C. The uncertainty in the density and speed of sound measurements was ± 3·10^{-5} g·cm^{-3} and ± 0.07 m·s^{-1}, respectively.

The kinematic viscosity (ν) was determined from the transit time of the liquid meniscus through a capillary viscosimeter supplied by Schott (Cap No. 0c, 0.46 ± 0.01 mm i.d., K = 0.003201 mm^2·s^{-2}) measured with an uncertainty of ± 0.0007 mm^2·s^{-1} using

$$\nu = K(t - \theta) \tag{1}$$

where t is the efflux time, K is the characteristic constant of the capillary viscosimeter, and θ is a correction value to prevent the final effects. An electronic stopwatch with an accuracy of ± 0.01 s was used for measuring efflux times. The capillary viscometer was immersed in a bath controlled to ± 0.1 °C. The viscometer was a Schott-Geräte AVS 350 Ubbelohde. Each measurement was repeated at least five times.

The dynamic viscosity (η) was obtained from the product of kinematic viscosity (ν) and the corresponding density (ρ) of the binary mixture, in terms of eq 2 for each temperature and mixture composition:

$$\eta = \rho\nu \tag{2}$$

These physical properties were determined for water and solvent and compared with literature to confirm that the experimental methods contribute suitable results.[12,13]

The adiabatic compressibility, κ_s, was calculated from the speed of sound and density values using the Laplace equation:

$$\kappa_s = \frac{1}{(u)^2 \cdot (\rho)} \tag{3}$$

where u is the speed of sound and ρ is the density of the solution.

Results and Discussion

Table 1 presents the experimental values for density, kinematics viscosity, and speed of sound of binary mixtures of AOT and 2,2,4-trimethylpentane and the calculated ones for isentropic compressibility.

The effect of mixture composition and temperature upon the value of density shows similar behavior than previously observed for different solutions.[14,15] An increment in the value of density is produced when the surfactant presence increases

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Table 1. Density ρ, Kinematic Viscosity ν, and Speed of Sound u of AOT (1) + 2,2,4-Trimethylpentane (2) Mixture from t = 20 °C to 50 °C

C_1 / mol·kg^{-1}	ρ / kg·m^{-3}	ν / mm^2·s^{-1}	u / m·s^{-1}	κ_s·10^{12} / Pa^{-1}
		t = 20 °C		
0.000	690.60	0.7328	1103.2	1190
0.141	704.23	0.8025	1103.5	1166
0.279	718.92	0.9049	1104.0	1141
0.410	736.65	1.038	1105.7	1110
0.535	754.54	1.214	1107.9	1080
0.676	775.50	1.516	1111.5	1044
0.764	794.10	1.828	1115.2	1013
0.867	812.69	2.282	1120.4	980.2
0.971	829.38	2.957	1126.2	950.6
1.07	847.23	4.070	1133.6	918.5
1.17	865.07	5.973	1142.4	885.8
		t = 25 °C		
0.000	686.30	0.6974	1082.2	1244
0.141	700.09	0.7581	1082.4	1219
0.279	714.76	0.8562	1083.1	1193
0.410	732.48	0.9870	1085.1	1160
0.535	750.77	1.144	1087.3	1127
0.676	771.20	1.419	1091.2	1089
0.764	789.80	1.670	1095.0	1056
0.867	808.51	2.103	1100.4	1021
0.971	825.19	2.759	1106.5	989.8
1.07	843.00	3.728	1113.8	956.2
1.17	860.81	5.272	1123.0	921.2
		t = 30 °C		
0.000	680.84	0.6635	1061.3	1304
0.141	695.93	0.7230	1061.6	1275
0.279	710.70	0.8132	1062.4	1247
0.410	728.39	0.9267	1064.5	1212
0.535	745.50	1.073	1066.9	1178
0.676	767.00	1.323	1071.1	1136
0.764	785.60	1.560	1075.0	1102
0.867	804.41	1.931	1080.5	1065
0.971	820.98	2.528	1086.5	1032
1.07	838.76	3.426	1094.1	996.0
1.17	856.54	4.765	1103.7	958.4
		t = 40 °C		
0.000	673.37	0.6022	1020.1	1427
0.141	687.78	0.6551	1020.3	1397
0.279	700.90	0.7342	1021.5	1367
0.410	718.50	0.8286	1024.0	1327
0.535	738.20	0.9534	1026.6	1285
0.676	756.10	1.170	1031.3	1244
0.764	776.50	1.350	1035.6	1201
0.867	795.70	1.666	1041.3	1159
0.971	812.51	2.117	1048.1	1120
1.07	830.24	2.793	1055.8	1081
1.17	847.98	3.885	1065.5	1039
		t = 50 °C		
0.000	664.65	0.5494	979.5	1568
0.141	680.26	0.5947	979.8	1531
0.279	694.20	0.6658	981.2	1496
0.410	712.00	0.7496	984.1	1450
0.535	729.70	0.8585	987.1	1406
0.676	747.00	1.043	992.3	1360
0.764	766.80	1.192	996.8	1313
0.867	786.90	1.467	1002.8	1264
0.971	804.04	1.830	1009.9	1219
1.07	821.70	2.349	1018.0	1174
1.17	839.35	3.090	1028.0	1127

too. As regards the effect of temperature upon this physical property, it is the typical one and produces a continuous decrease when temperature increases.

Similar behavior have been found in relation to the effect of the variables previously mentioned upon the absolute and kinematics viscosity, but in this case, no linear trends were observed. The presence of solutes produces an increase in the value of viscosity when AOT concentration increases in the organic solvent. The effect of AOT concentration upon the viscosity is bigger than the effect observed upon density, and at high concentration, it produces great changes in the viscosity value. An increase in temperature also produces a decrease in the viscosity. Figure 2 shows these behaviors.

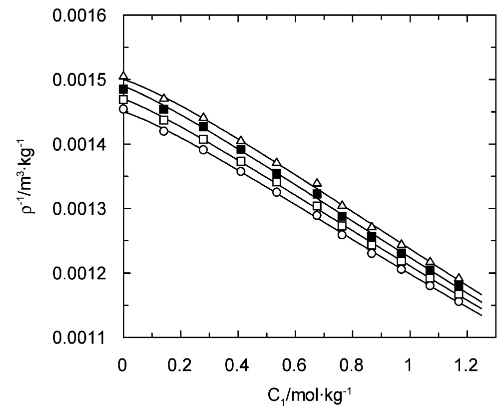

Figure 1. Effect of temperature t and mixture composition C_1 upon density ρ: ○, 20 °C; □, 30 °C; ■, 40 °C; △, 50 °C.

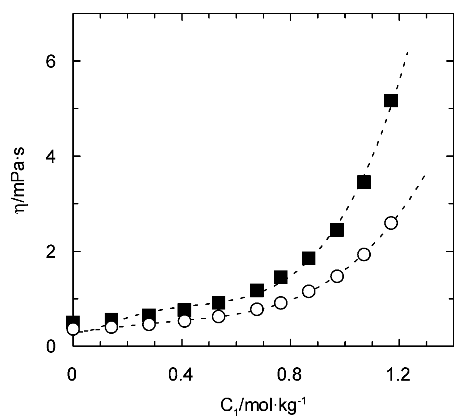

Figure 2. Effect of concentration C_1 and temperature t upon the absolute viscosity η of binary mixtures: ■, 20 °C; ○, 50 °C. —, eq 5.

The last physical property analyzed has been the speed of sound, and the effect of temperature and composition was the same as previously observed for density and viscosity. The speed of sound shows similar trends to density, with a linear trend in relation to the effect of temperature.

The density of AOT in 2,2,4-trimethylpentane solutions was expressed as a function of the surfactant concentration by an empirical equation of the form:[16]

$$\frac{1}{\rho} = \frac{1}{\rho_s} + \sum_{i=2}^{4} A_i \cdot C^{i/2} \quad (4)$$

where ρ is density of solution, ρ_s is the density of the 2,2,4-trimethylpentane at different temperatures, C is the surfactant concentration (mol of surfactant per kg of solution), and A_i is the adjustable coefficients whose values are listed in Table 2. This equation has been employed with good results for different authors.[17,18] This equation allows the calculation with low deviations of the density values for the systems employed in the present paper (see Figure 1).

The dynamic viscosity's behavior in the system studied with the AOT concentration was expressed through an extended Jones−Dole equation:[19]

$$\eta = \eta_s + a \cdot C^{0.5} + b \cdot C + c \cdot C^2 + d \cdot C^{3.5} \quad (5)$$

Table 2. Fit Parameters Corresponding to Equation 4 for Density Data

t/°C	$A_2 \cdot 10^{-4}$/$m^3 \cdot mol^{-1}$	$A_3 \cdot 10^{-4}$/$m^3 \cdot kg^{0.5} \cdot mol^{-1.5}$	$A_4 \cdot 10^{-4}$/$m^3 \cdot kg \cdot mol^{-2}$	σ/$kg \cdot m^{-3}$
20	−1.0	−2.7	1.2	1.4
25	−2.4	−0.3	0.1	1.5
30	−1.4	−2.2	1.0	1.4
40	−1.5	−2.1	0.9	1.8
50	−1.1	−2.6	1.1	1.9

Table 3. Fit Parameters Corresponding to Equation 5 for Viscosity Data

	t/°C				
	20	25	30	40	50
$a \cdot 10^{-3}$/$kg^{1.5} \cdot mol^{-0.5} \cdot m^{-1} \cdot s^{-1}$	−2.45	−1.82	−1.53	−1.23	−0.64
$b \cdot 10^{-3}$/$kg^{2} \cdot mol^{-1} \cdot m^{-1} \cdot s^{-1}$	7.63	5.77	4.92	3.94	2.19
$c \cdot 10^{-3}$/$kg^{3} \cdot mol^{-2} \cdot m^{-1} \cdot s^{-1}$	−8.89	−6.71	−5.73	−4.47	−2.36
$d \cdot 10^{-3}$/$kg^{4.5} \cdot mol^{-3.5} \cdot m^{-1} \cdot s^{-1}$	6.03	4.84	4.22	3.27	2.06
σ/mPa·s	0.08	0.02	0.03	0.03	0.01

where η is the viscosity of the solution, η_s is the viscosity in the absence of AOT (2,2,4-trimethylpentane), and C is the surfactant (AOT) concentration. The values of the fitted parameters are listed in Table 3. The experimental and calculated viscosities at different temperatures are compared in Figure 2. Equation 5 shows good agreement in relation to the experimental and calculated values.

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