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Experimental Study of the Dynamic Viscosity Deviations in the Binary Systems: Hexane + Ethylbenzene, + *o*-Xylene, + *m*-Xylene, + *p*-Xylene at 298.15 K

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Abstract In this study experimental measurements of the thermophysical properties of binary mixtures containing hexane + aromatic hydrocarbon are continued. Here experimental data of the dynamic viscosity, η, at 298.15 K and atmospheric pressure, over the complete composition range are presented. As noted, the second compound of all mixtures belong to the same aromatic family, with a benzene ring having one ethyl chain or two methyl chains placed at different sites of the benzene ring. So, the molar mass for all four second compounds is exactly the same. Thus, these measurements will provide information about the influence of the methyl chain positions on the viscosity when it is mixed with hexane. From the measured values of the dynamic viscosity, dynamic viscosity deviations of the binary mixtures are determined and the viscosity deviations are compared with other deviation results for similar mixtures, and among the different binary mixtures.

Keywords Density · Dynamic viscosity · Ethyl benzene · Hexane · Xylene

1 Introduction

In previous studies we published measurements of different thermophysical properties for mixtures of hexane plus an aromatic hydrocarbon. Thus, in Ref. [1] we presented densities, surface tensions, and refractive indexes of hexane + ethylbenzene; excess molar enthalpies of hexane + ethylbenzene, + *o*-xylene, + *m*-xylene, and +*p*-xylene appeared in Ref. [2], and we published the densities, surface tensions and refractive indexes of the hexane + *p*-xylene binary system in Ref. [3]. On the other hand, this work continues our studies of the dynamic viscosity, η, in binary and ternary mixtures

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of nonelectrolyte organic compounds [4]. Here, we present the dynamic viscosity of binary mixtures of hexane + ethyl benzene, + *o*-xylene, + *m*-xylene, and + *p*-xylene at 298.15 K and atmospheric pressure. To measure η, we need to know the density, ρ, of the same mixtures over all ranges of concentrations. Thus, the density was also measured, and we also present here the density results for the four binary mixtures. Although the data for the hexane + ethylbenzene mixture were published in Ref. [1] and that for hexane + *m*-xylene in Ref. [3], new data are presented here for hexane + *o*-xylene and hexane + *p*-xylene mixtures.

A knowledge of the viscosity for these mixtures is useful from both applied and theoretical points of view. A knowledge of the viscosity of the presented mixtures allows optimization of chemical engineering processes, due to the fact that xylene is used in the manufacture of chemical products (as foams and light plastics) for medicine, transport, communications, clothes, and sport materials. From a theoretical point of view, the viscosity data will help to develop and test different models to explain the transport properties of these compounds from a molecular viewpoint, and the influence of the alkyl chain position.

2 Experimental Procedures and Results

The chemicals employed were supplied by Fluka. Their mass purities were as follows: hexane (Fluka, ≥99.5 %), ethyl benzene (Fluka, ≥99 %), *o*-xylene (Fluka, ≥99 %), *m*-xylene (Fluka, ≥99 %), and *p*-xylene (Fluka, ≥99 %). The substances were degassed by ultrasound and dried over molecular sieves (Sigma type, 0.4 nm), and otherwise they were used as supplied.

All the mixtures were prepared by mass using a Mettler AT 201 balance, which has a precision of 1×10^{-5}, and so the uncertainty of the mole fraction, x, is estimated to be about 1×10^{-8}. The experimental data of the kinematic viscosity were measured with an automatic Schott-Geräte viscosimeter, thermostated to (25.00 ± 0.01) °C. The uncertainties of the viscosities are about $5 \times 10^{-4}\ \text{mm}^2 \times \text{s}^{-1}$. To calculate the dynamic viscosity, we multiply the value of the kinematic viscosity with the density of the mixture, which has been measured with an Anton Paar DMA 60/602 densimeter thermostated with a Schott Geräte CT 1450 circulating-water bath, with a precision in the temperature control of 0.01 K. The uncertainties of the densities are about $2 \times 10^{-6}\ \text{g} \cdot \text{cm}^{-3}$. Calibration is performed daily with Milli-Q water and heptane (Sigma, >99 %). More details of the experimental procedure were published previously [5].

The dynamic viscosities of the pure compounds, η, are listed in Table 1 together with literature values. The agreement between our data and that published is very good, with deviations less than 0.5 % for the five compounds. It indicates the purity of the chemicals employed and the reliability of our equipment.

In Table 2 we present the measured data for the viscosity, η, of the four mixtures at different mole fractions of hexane, covering the complete range of concentrations. The values obtained for the mixtures follows the same tendency as the viscosity of the pure compounds; thus, for all concentrations, the data for the mixtures with *m*-xylene and *p*-xylene are very similar, and they are higher for ethyl benzene, and even much higher for the mixture with *o*-xylene.

Table 1 Density and dynamic viscosity of the pure liquids at 298.15 K

Component	$\rho_{\text{exp.}}$ (g · cm^{-3})	$\rho_{\text{literature}}$ (g · cm^{-3})	$\eta_{\text{exp.}}$ (mPa · s)	$\eta_{\text{literature}}$ (mPa · s)
Hexane	0.65470	0.65471 [6]	0.2973	0.2968 [6]
Ethylbenzene	0.86237	0.86253 [7]	0.6369	0.6373 [7]
o-Xylene	0.87489	0.8759 [6]	0.7506	0.754 [6]
m-Xylene	0.85978	0.8600 [6]	0.5830	0.581 [7]
p-Xylene	0.85651	0.85661 [7]	0.5999	0.603 [6]

Table 2 Density, dynamic viscosity, and dynamic viscosity deviations for the binary systems at 298.15 K

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)
x_1 Hexane + x_2 ethyl benzene (density data from Ref. [1])							
0.0437	0.85288	0.6071	−0.015	0.5429	0.74718	0.3761	−0.076
0.0884	0.84321	0.5751	−0.032	0.5916	0.73714	0.3654	−0.071
0.1830	0.82288	0.5169	−0.058	0.6534	0.72445	0.3527	−0.062
0.2262	0.81366	0.4791	−0.069	0.7050	0.71392	0.3426	−0.055
0.2774	0.80277	0.4672	−0.076	0.7644	0.70186	0.3326	−0.045
0.3283	0.79201	0.4450	−0.081	0.8090	0.69285	0.3250	−0.037
0.3784	0.78146	0.4234	−0.085	0.8882	0.67694	0.3130	−0.022
0.4359	0.76942	0.4047	−0.084	0.9478	0.66505	0.3046	−0.010
0.4880	0.75856	0.3902	−0.081				
x_1 Hexane + x_2 *o*-xylene							
0.0520	0.86309	0.678	−0.0397	0.5100	0.76035	0.4031	−0.1147
0.1413	0.84286	0.5944	−0.0924	0.5856	0.74371	0.3816	−0.1014
0.2482	0.81874	0.5239	−0.1145	0.6351	0.73288	0.3711	−0.0918
0.2901	0.80933	0.4930	−0.1264	0.6753	0.72412	0.3632	−0.0814
0.3550	0.79479	0.4620	−0.1279	0.7858	0.70023	0.3344	−0.0600
0.4004	0.78466	0.4425	−0.1269	0.8317	0.69038	0.3264	−0.0473
0.4815	0.76665	0.4126	−0.1193	0.9014	0.67552	0.3140	−0.0280
x_1 Hexane + x_2 *m*-xylene (density data from Ref. [3])							
0.1329	0.83170	0.4984	−0.0839	0.6430	0.72617	0.3513	−0.0633
0.1519	0.82771	0.4896	−0.0865	0.6663	0.72145	0.3473	−0.0597
0.2717	0.80264	0.4418	−0.0949	0.7190	0.71078	0.3389	−0.0507
0.3390	0.78864	0.4221	−0.0925	0.8049	0.69350	0.3238	−0.0371
0.4303	0.76973	0.3978	−0.0868	0.8730	0.67989	0.3175	−0.0213
0.4480	0.76608	0.3935	−0.0852	0.9278	0.66899	0.3115	−0.0096
0.5734	0.74035	0.3652	−0.0730				
x_1 Hexane + x_2 *p*-xylene							
0.0423	0.84780	0.5660	−0.0212	0.5620	0.74169	0.3654	−0.0645
0.1073	0.83445	0.5235	−0.0440	0.6427	0.72547	0.3502	−0.0553
0.2137	0.81260	0.4702	−0.0651	0.7455	0.70495	0.3324	−0.0419
0.2956	0.79581	0.4378	−0.0727	0.7909	0.69594	0.3256	−0.0349

Table 2 continued

x_1	$\rho(\mathrm{g \cdot cm^{-3}})$	$\eta(\mathrm{mPa \cdot s})$	$\Delta\eta(\mathrm{mPa \cdot s})$	x_1	$\rho(\mathrm{g \cdot cm^{-3}})$	$\eta(\mathrm{mPa \cdot s})$	$\Delta\eta(\mathrm{mPa \cdot s})$
0.3769	0.77921	0.4119	−0.0740	0.8792	0.67848	0.3130	−0.0208
0.4201	0.77042	0.3998	−0.0730	0.9599	0.66262	0.3024	−0.0070
0.5355	0.74703	0.3717	−0.0662				

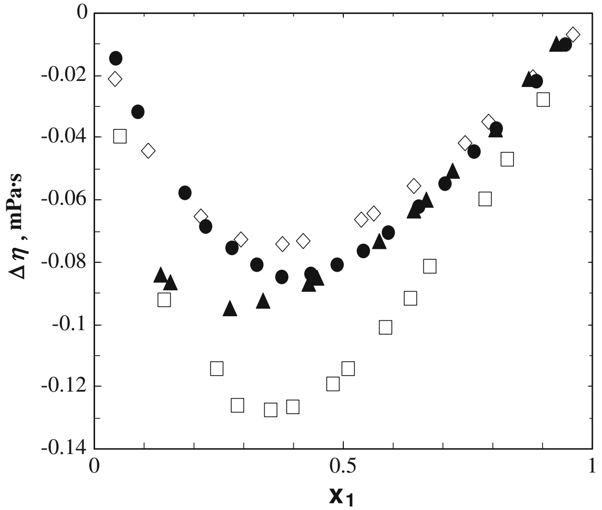

Fig. 1 Dynamic viscosity deviations versus the mole fraction of (●) hexane + ethylbenzene, (□) hexane + *o*-xylene, (▲) hexane + *m*-xylene, and (◇) hexane + *p*-xylene

From the dynamic viscosity of the pure components and the mixtures, we calculate the dynamic viscosity deviations, $\Delta\eta$, using the usual expression,

$$\Delta\eta = \eta - x_1\eta_1 - x_2\eta_2 \tag{1}$$

where η is the dynamic viscosity of the mixture, η_1 and η_2, and x_1 and x_2 are, respectively, the dynamic viscosity and the mole fraction of components 1 (hexane) and 2 (aromatic hydrocarbon). The precision of the calculated $\Delta\eta$ values is 1×10^{-3}mPa·s. In Table 2, we include the calculated values of $\Delta\eta$ for the four binary systems studied in this work, while in Fig. 1, they are plotted. We observe that all data are negative, and the resulting curves are skewed to mixtures lean in hexane. For $x_1 > 0.5\Delta\eta$ is equal for the two mixtures with ethyl benzene and *m*-xylene, while the most negative $\Delta\eta$ value is for *o*-xylene, and the less negative for *p*-xylene, at least, at the equimolar composition.

If we compare our results with those for excess molar enthalpies, H^{E}, for the same mixtures [2], we observe that the sign differs because H^{E} is positive for the four mixtures. This last result indicates that in the mixture process, some energy has been liberated, and so the resulting intermolecular interactions for the mixture are weaker.

This agrees with our data, because a negative $\Delta\eta$ indicates that the movement of a molecule among others is easier when mixed.

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