# Density and Viscosity for a Binary Mixture of *cis*-3-Hexenyl Formate, Butyl Acetate, *trans*-2-Hexenyl Acetate, and *cis*-3-Hexenyl Acetate with Ethanol at Several Temperatures

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The density and viscosity of binary mixtures *cis*-3-hexenyl formate (1) + ethanol (2), butyl acetate (1) + ethanol (2), *trans*-2-hexenyl acetate (1) + ethanol (2), and *cis*-3-hexenyl acetate (1) + ethanol (2) over the whole range of composition have been measured at three different temperatures (293.15 K, 303.15 K, and 313.15 K). The excess molar volume and viscosity deviation of these systems were also calculated, and the results were fitted to a well-known Redlich−Kister-type polynomial equation.

## Introduction

In the flavor and fragrance industries, aliphatic and acrylic esters are important materials in manufacturing processes.[1] Most of the esters used here are acetates, whereas ethanol is the most common alcohol component. In addition to straight-chain saturated compounds, branched-chain compounds and unsaturated esters are also important within these industries.

Studies of the thermodynamic behavior and physical properties of several esters in their binary mixtures have been performed, including ethyl valerate and hexyl acetate with 1-pentanol and 1-hexanol;[1] benzyl acetate, 2-ethylhexyl acetate, benzaldehyde, and pentyl acetate with 1-butanol and 1-pentanol;[2] methyl propanoate, methyl butanoate, ethyl propanoate, and ethyl butanoate with several hydrocarbon solvents;[3] ethyl acetate with several alcohols;[4] methyl butanoate with *n*-heptane, cyclooctane, *n*-octane, and 1-octanol;[5−7] ethyl acetate with aromatic hydrocarbons, alcohols, and water;[8−11] isopropyl acetate with an aromatic hydrocarbon;[12] acrylic esters with alcohols;[13,14] butyl acetate and ethyl propionate with methanol and water.[15] However, investigations of the physical properties of *cis*-3-hexenyl formate, butyl acetate, *trans*-2-hexenyl acetate, and *cis*-3-hexenyl acetate in a binary mixture with alcohol, especially ethanol, over a wide range of temperatures and compositions are still scarce and not available in the literature. Therefore, this study was undertaken to obtain reliable density and viscosity data for binary mixtures of these esters at 293.15 K, 303.15 K, and 313.15 K.

## Experimental Section

***Materials.*** High-purity and AR-grade samples of ethanol, *cis*-3-hexenyl formate, butyl acetate, *trans*-2-hexenyl acetate, and *cis*-3-hexenyl acetate were purchased from Sigma-Aldrich Singapore. The purity of these chemicals was analyzed by gas chromatography (Shimadzu, GC-17A) using a flame ionization detector with a DB-5 column. Helium (high purity) was used as the carrier gas. The purity of these esters is 97.4% for *cis*-3-hexenyl formate, 99.7% for butyl acetate, and 98.9% for *trans*-2-hexenyl acetate and *cis*-3-hexenyl acetate. These esters were used without any further purification.

**Table 1. Comparison of the Experimental Density and Viscosity of Pure Compounds with Literature Values at 293.15 K, 303.15 K, and 313.15 K**

| | | $\rho_l$/g·cm$^{-3}$ | | $\eta_l$/mPa·s | |
|---|---|---|---|---|---|
| compound | *T*/K | exptl | lit | exptl | lit |
| *cis*-3-hexenyl formate | 293.15 | 0.90915 | | 0.599 | |
| | 303.15 | 0.90660 | | 0.527 | |
| | 313.15 | 0.90317 | | 0.469 | |
| butyl acetate | 293.15 | 0.88104 | | 0.732 | |
| | 303.15 | 0.87130 | 0.87120[15] | 0.628 | 0.631[15] |
| | 313.15 | 0.86184 | | 0.546 | |
| *trans*-2-hexenyl acetate | 293.15 | 0.89784 | 0.89800[16] | 0.901 | |
| | 303.15 | 0.89178 | | 0.770 | |
| | 313.15 | 0.88435 | | 0.666 | |
| *cis*-3-hexenyl acetate | 293.15 | 0.90082 | | 0.893 | |
| | 303.15 | 0.89314 | | 0.763 | |
| | 313.15 | 0.88619 | | 0.660 | |
| ethanol | 293.15 | 0.78824 | | 1.160 | |
| | 303.15 | 0.78073 | 0.78080[17] | 0.968 | 0.995[17] |
| | | | 0.78068[18] | | 0.987[18] |
| | 313.15 | 0.77198 | 0.77213[18] | 0.810 | 0.814[18] |

The binary mixture samples were prepared by mass in airtight-stoppered glass bottles using a Mettler Toledo AE 240 balance with an uncertainty of $\pm 10^{-5}$ g. The uncertainty of the mole fraction for each binary mixture is less than 0.0001.

***Density Measurements.*** Measurements of the densities of the pure components and the binary mixtures were carried out using a Mettler Toledo density meter type DE50 with an uncertainty of about $10^{-5}$ g·cm$^{-3}$. Prior to measurement, the instrument was calibrated with double-distilled water at 293.15 K, 303.15 K, and 313.15 K. The temperature of the measuring cell was maintained at 293.15 K, 303.15 K, and 313.15 K using a Julabo refrigerated and heating circulator (model F12-MD with an uncertainty of 0.1 K).

***Viscosity Measurements.*** For the viscosity measurement, an Anton Paar type AMV$_n$ automatic microviscosimeter equipped with an automatic timer (±0.01 s), was used. This instrument uses the rolling ball principle

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**Table 2. Experimental Density and Viscosity and Excess Molar Volume for Binary Mixtures of *cis*-3-Hexenyl Formate (1) + Ethanol (2) at 293.15 K, 303.15 K, and 323.15 K**

| $x_1$ | $\rho_L$/g·cm$^{-3}$ | $\eta_L$/mPa·s | $V^E$/cm$^3$·mol$^{-1}$ | $x_1$ | $\rho_L$/g·cm$^{-3}$ | $\eta_L$/mPa·s | $V^E$/cm$^3$·mol$^{-1}$ |
|---|---|---|---|---|---|---|---|
| | | | 293.15 K | | | | |
| 0.0000 | 0.78824 | 1.160 | 0.000 | 0.6058 | 0.86100 | 0.777 | 2.829 |
| 0.1054 | 0.80153 | 1.082 | 1.128 | 0.7254 | 0.87536 | 0.718 | 2.350 |
| 0.2078 | 0.81241 | 1.011 | 2.111 | 0.8007 | 0.88120 | 0.683 | 2.352 |
| 0.2987 | 0.82436 | 0.952 | 2.535 | 0.9154 | 0.89612 | 0.633 | 1.281 |
| 0.4015 | 0.83245 | 0.889 | 3.357 | 1.0000 | 0.90915 | 0.599 | 0.000 |
| 0.5143 | 0.84925 | 0.825 | 3.075 | | | | |
| | | | 303.15 K | | | | |
| 0.0000 | 0.78073 | 0.968 | 0.000 | 0.5980 | 0.85600 | 0.672 | 2.912 |
| 0.1036 | 0.79124 | 0.908 | 1.433 | 0.7058 | 0.87019 | 0.630 | 2.390 |
| 0.2154 | 0.80253 | 0.849 | 2.691 | 0.8205 | 0.88401 | 0.587 | 1.727 |
| 0.3087 | 0.82054 | 0.802 | 2.598 | 0.9014 | 0.89628 | 0.559 | 0.717 |
| 0.4221 | 0.83345 | 0.748 | 3.080 | 1.0000 | 0.90660 | 0.527 | 0.000 |
| 0.5231 | 0.84614 | 0.704 | 3.109 | | | | |
| | | | 313.15 K | | | | |
| 0.0000 | 0.77198 | 0.810 | 0.000 | 0.6078 | 0.85009 | 0.581 | 3.235 |
| 0.0984 | 0.78051 | 0.767 | 1.606 | 0.7145 | 0.86572 | 0.548 | 2.541 |
| 0.1895 | 0.80042 | 0.730 | 1.734 | 0.8154 | 0.87804 | 0.518 | 1.981 |
| 0.3122 | 0.81294 | 0.682 | 2.849 | 0.9089 | 0.89122 | 0.492 | 1.002 |
| 0.4087 | 0.82543 | 0.647 | 3.177 | 1.0000 | 0.90317 | 0.469 | 0.000 |
| 0.5041 | 0.83922 | 0.614 | 3.080 | | | | |

**Table 3. Experimental Density and Viscosity and Excess Molar Volume for Binary Mixtures of Butyl Acetate (1) + Ethanol (2) at 293.15 K, 303.15 K, and 323.15 K**

| $x_1$ | $\rho_L$/g·cm$^{-3}$ | $\eta_L$/mPa·s | $V^E$/cm$^3$·mol$^{-1}$ | $x_1$ | $\rho_L$/g·cm$^{-3}$ | $\eta_L$/mPa·s | $V^E$/cm$^3$·mol$^{-1}$ |
|---|---|---|---|---|---|---|---|
| | | | 293.15 K | | | | |
| 0.0000 | 0.78824 | 1.160 | 0.000 | 0.6123 | 0.84601 | 0.875 | 1.795 |
| 0.1135 | 0.79954 | 1.100 | 0.793 | 0.7008 | 0.85217 | 0.840 | 1.818 |
| 0.2054 | 0.80563 | 1.055 | 1.532 | 0.8054 | 0.86304 | 0.800 | 1.229 |
| 0.3078 | 0.81547 | 1.006 | 1.912 | 0.9127 | 0.87294 | 0.762 | 0.622 |
| 0.4122 | 0.82914 | 0.959 | 1.707 | 1.0000 | 0.88104 | 0.732 | 0.000 |
| 0.5191 | 0.83641 | 0.913 | 2.033 | | | | |
| | | | 303.15 K | | | | |
| 0.0000 | 0.78073 | 0.968 | 0.000 | 0.6015 | 0.83468 | 0.746 | 1.998 |
| 0.1082 | 0.79150 | 0.923 | 0.738 | 0.7028 | 0.84462 | 0.714 | 1.633 |
| 0.2006 | 0.79954 | 0.887 | 1.291 | 0.8043 | 0.85358 | 0.683 | 1.240 |
| 0.3121 | 0.80754 | 0.845 | 1.938 | 0.9074 | 0.86291 | 0.653 | 0.656 |
| 0.4018 | 0.81714 | 0.806 | 1.989 | 1.0000 | 0.87130 | 0.628 | 0.000 |
| 0.5213 | 0.82793 | 0.779 | 2.091 | | | | |
| | | | 313.15 K | | | | |
| 0.0000 | 0.77198 | 0.810 | 0.000 | 0.6091 | 0.82934 | 0.637 | 1.604 |
| 0.1051 | 0.78051 | 0.777 | 0.892 | 0.7053 | 0.83536 | 0.613 | 1.679 |
| 0.1988 | 0.78751 | 0.748 | 1.586 | 0.8144 | 0.84516 | 0.587 | 1.207 |
| 0.3047 | 0.79906 | 0.718 | 1.820 | 0.9058 | 0.85773 | 0.566 | 0.023 |
| 0.4038 | 0.80827 | 0.690 | 2.010 | 1.0000 | 0.86184 | 0.546 | 0.000 |
| 0.5088 | 0.81770 | 0.662 | 2.063 | | | | |

according to DIN 53015 and ISO/DIS 12058, where gold-covered steel balls roll down inside an inclined, sample-filled glass capillary. The uncertainty of time in the range of (0 to 250) s is less than 0.02 s with a resolution of ±0.01 s. The temperature range of this viscosimeter is from (283.15 to 343.15) K with an uncertainty of less than 0.05 K. The calibration of the instrument was performed periodically with double-distilled water. The uncertainty in the viscosity measurement was estimated to be better than 0.004 mPa·s. The measuring temperature was kept at 293.15 K, 303.15 K, and 313.15 K by placing the sample-filled glass capillary in a block controlled by a Julabo refrigerated and heating circulator.

All measurements described above were performed at least three times, and the results were averaged to give the final values.

## Results and Discussion

Table 1 summarizes the experimental results of the density and viscosity of the pure liquid and compares these results to those from the literatures. The experimental values are generally in agreement with those available in the literature.[15−18] The density and viscosity of binary mixtures of *cis*-3-hexenyl formate (1) + ethanol (2), butyl acetate (1) + ethanol (2), *trans*-2-hexenyl acetate (1) + ethanol (2), and *cis*-3-hexenyl acetate (1) + ethanol (2) obtained in this study at three different temperatures are given in Tables 3−6.

The excess molar volume, $V^E$, and viscosity deviation, $\Delta\eta$, were calculated from density and viscosity measurements according to the following equations[1−4]

$$V^E = \frac{x_1M_1 + x_2M_2}{\rho_L} - (x_1V_1 + x_2V_2) \tag{1}$$

and

$$\Delta\eta = \eta_L - x_1\eta_{p1} - x_2\eta_{p2} \tag{2}$$

Here, $\rho_L$ is the density of the mixture, and $x_1$, $V_1$, $M_1$, $x_2$, $V_2$, and $M_2$ are the mole fraction, molar volume, and molecular weight of pure components 1 and 2, respectively.

**Table 4. Experimental Density and Viscosity and Excess Molar Volume for Binary Mixtures of *trans*-2-Hexenyl Acetate (1) + Ethanol (2) at 293.15 K, 303.15 K, and 323.15 K**

| $x_1$ | $\rho_L$/g·cm$^{-3}$ | $\eta_L$/mPa·s | $V^E$/cm$^3$·mol$^{-1}$ | $x_1$ | $\rho_L$/g·cm$^{-3}$ | $\eta_L$/mPa·s | $V^E$/cm$^3$·mol$^{-1}$ |
|---|---|---|---|---|---|---|---|
| | | | 293.15 K | | | | |
| 0.0000 | 0.78824 | 1.160 | 0.000 | 0.5906 | 0.85297 | 0.999 | 3.105 |
| 0.1022 | 0.79752 | 1.130 | 1.426 | 0.7123 | 0.86791 | 0.968 | 2.347 |
| 0.2074 | 0.81097 | 1.100 | 2.220 | 0.8146 | 0.87752 | 0.944 | 1.885 |
| 0.3158 | 0.82430 | 1.071 | 2.713 | 0.9057 | 0.88516 | 0.922 | 1.451 |
| 0.4125 | 0.83345 | 1.045 | 3.185 | 1.0000 | 0.89784 | 0.901 | 0.000 |
| 0.4987 | 0.84290 | 1.022 | 3.248 | | | | |
| | | | 303.15 K | | | | |
| 0.0000 | 0.78073 | 0.968 | 0.000 | 0.6006 | 0.84743 | 0.843 | 3.157 |
| 0.1046 | 0.79235 | 0.945 | 1.318 | 0.7028 | 0.85878 | 0.824 | 2.712 |
| 0.2158 | 0.80469 | 0.921 | 2.346 | 0.8069 | 0.87034 | 0.804 | 1.996 |
| 0.3047 | 0.81457 | 0.902 | 2.901 | 0.9123 | 0.88204 | 0.785 | 1.012 |
| 0.4061 | 0.82583 | 0.882 | 3.257 | 1.0000 | 0.89178 | 0.770 | 0.000 |
| 0.5087 | 0.83722 | 0.861 | 3.330 | | | | |
| | | | 313.15 K | | | | |
| 0.0000 | 0.77198 | 0.810 | 0.000 | 0.6052 | 0.83999 | 0.719 | 3.232 |
| 0.1014 | 0.78025 | 0.794 | 1.607 | 0.7142 | 0.85223 | 0.704 | 2.722 |
| 0.2083 | 0.79614 | 0.777 | 2.277 | 0.8059 | 0.86049 | 0.691 | 2.402 |
| 0.3056 | 0.80632 | 0.762 | 2.990 | 0.9041 | 0.87259 | 0.678 | 1.299 |
| 0.4009 | 0.81493 | 0.748 | 3.607 | 1.0000 | 0.88435 | 0.666 | 0.000 |
| 0.5017 | 0.82936 | 0.734 | 3.291 | | | | |

**Table 5. Experimental Density and Viscosity and Excess Molar Volume for Binary Mixtures of *cis*-3-Hexenyl Acetate (1) + Ethanol (2) at 293.15 K, 303.15 K, and 323.15 K**

| $x_1$ | $\rho_L$/g·cm$^{-3}$ | $\eta_L$/mPa·s | $V^E$/cm$^3$·mol$^{-1}$ | $x_1$ | $\rho_L$/g·cm$^{-3}$ | $\eta_L$/mPa·s | $V^E$/cm$^3$·mol$^{-1}$ |
|---|---|---|---|---|---|---|---|
| | | | 293.15 K | | | | |
| 0.0000 | 0.78824 | 1.160 | 0.000 | 0.6047 | 0.85140 | 0.990 | 3.827 |
| 0.0987 | 0.79726 | 1.130 | 1.428 | 0.7063 | 0.86776 | 0.964 | 2.675 |
| 0.1788 | 0.80934 | 1.106 | 1.939 | 0.8159 | 0.88293 | 0.937 | 1.456 |
| 0.3041 | 0.82451 | 1.071 | 2.654 | 0.9178 | 0.89045 | 0.912 | 1.136 |
| 0.4058 | 0.83159 | 1.043 | 3.522 | 1.0000 | 0.90082 | 0.893 | 0.000 |
| 0.5071 | 0.84752 | 1.015 | 3.019 | | | | |
| | | | 303.15 K | | | | |
| 0.0000 | 0.78073 | 0.968 | 0.000 | 0.6074 | 0.84901 | 0.837 | 3.163 |
| 0.1043 | 0.79245 | 0.944 | 1.328 | 0.7159 | 0.86120 | 0.816 | 2.661 |
| 0.2381 | 0.80749 | 0.914 | 2.531 | 0.8064 | 0.87138 | 0.798 | 2.018 |
| 0.3048 | 0.81499 | 0.900 | 2.929 | 0.9088 | 0.88289 | 0.779 | 1.057 |
| 0.3981 | 0.82548 | 0.880 | 3.270 | 1.0000 | 0.89314 | 0.763 | 0.000 |
| 0.4995 | 0.83688 | 0.859 | 3.365 | | | | |
| | | | 313.15 K | | | | |
| 0.0000 | 0.77198 | 0.810 | 0.000 | 0.6188 | 0.84059 | 0.713 | 3.530 |
| 0.0988 | 0.78056 | 0.793 | 1.554 | 0.7059 | 0.85439 | 0.700 | 2.523 |
| 0.2047 | 0.79851 | 0.776 | 2.030 | 0.8064 | 0.86140 | 0.686 | 2.525 |
| 0.3058 | 0.80720 | 0.760 | 2.994 | 0.9056 | 0.87541 | 0.672 | 1.124 |
| 0.4085 | 0.81936 | 0.745 | 3.305 | 1.0000 | 0.88619 | 0.660 | 0.000 |
| 0.5096 | 0.83256 | 0.729 | 3.138 | | | | |

The terms $\eta_L$, $\eta_{p1}$, and $\eta_{p2}$ in eq 2 are the viscosity of the binary mixture viscosity of pure components 1 and 2, respectively.

The calculated excess molar volumes for the given binary systems are also summarized in Tables 2−5. From these Tables, it can be seen that the excess molar volumes for all mixtures are positive. The positive $V^E$ values are due to several factors such as the declustering of ethanol in the presence of ester[1,4] and repulsive forces due to the electronic charges of both components and more domination of steric hindrance in the ester molecules. The results of the excess molar volume, $V^E$, as a function of the mole fraction of component 1, $x_1$, of the ester + ethanol systems at 303.15 are depicted in Figure 1. In this Figure, the calculated excess molar volumes, $V^E$, for various systems are represented by symbols, whereas the solid lines represent the well-known Redlich−Kister polynomial equation for excess molar volume, $V^E$, which has the form

$$V^E = x_1 x_2 \sum_{i=0}^{n} A_i (x_1 - x_2)^i \tag{3}$$

where $A_i$ represents the parameters of the Redlich−Kister polynomial equation and those obtained from the least-squares method. The parameters of the Redlich−Kister polynomial equation for excess molar volume $V^E$ are given in Table 6.

The experimental values of viscosity listed in Tables 2−5 were used to calculate viscosity deviations using eq 2. The viscosity deviations of *cis*-3-hexenyl formate (1) + ethanol (2), butyl acetate (1) + ethanol (2), *trans*-2-hexenyl acetate (1) + ethanol (2), and *cis*-3-hexenyl acetate (1) + ethanol (2) at 293.15 are presented in Figure 2 with the minimum point located near $x_1 \approx 0.55$. In this Figure, the viscosity deviations, $\Delta\eta$, for various systems are represented by symbols, and the solid lines represent the well-known Redlich−Kister polynomial equation for the viscosity deviation, which has the following form:

$$\Delta\eta = x_1 x_2 \sum_{i=0}^{n} A_i (x_1 - x_2)^i \tag{4}$$

The parameters $A_i$ of eq 4 obtained by the least-squares

**Table 6. Parameter and Standard Deviations of the Redlich−Kister Polynomial Equation for Selected Ester + Ethanol Systems**

| | $T$/K | $A_o$ | $A_1$ | $A_2$ | $A_3$ | $\sigma$ |
|---|---|---|---|---|---|---|
| | *cis*-3-Hexenyl Formate (1) + Ethanol (2) | | | | | |
| $V^E$/cm$^3$· mol$^{-1}$ | 293.15 | 12.414 | −2.696 | 2.150 | 9.645 | 0.007 |
| | 303.15 | 12.322 | −0.706 | 1.373 | −6.384 | 0.006 |
| | 313.15 | 12.823 | 1.248 | 0.971 | −4.872 | 0.010 |
| $\Delta\eta$/mPa·s | 293.15 | −0.186 | 0.0223 | 0.000 | −0.009 | 0.001 |
| | 303.15 | −0.135 | 0.012 | 0.006 | −0.003 | 0.000 |
| | 313.15 | −0.095 | 0.015 | −0.006 | −0.018 | 0.000 |
| | Butyl Acetate (1) + Ethanol (2) | | | | | |
| $V^E$/cm$^3$·mol$^{-1}$ | 293.15 | 7.884 | −0.284 | 1.514 | −0.680 | 0.013 |
| | 303.15 | 8.388 | −1.263 | −0.962 | 2.374 | 0.003 |
| | 313.15 | 8.133 | −0.378 | −0.887 | −6.025 | 0.024 |
| $\Delta\eta$/mPa·s | 293.15 | −0.099 | 0.009 | −0.006 | 0.002 | 0.000 |
| | 303.15 | −0.074 | 0.008 | −0.010 | −0.004 | 0.000 |
| | 313.15 | −0.054 | 0.008 | −0.004 | −0.012 | 0.001 |
| | *trans*-2-Hexenyl Acetate (1) + Ethanol (2) | | | | | |
| $V^E$/cm$^3$·mol$^{-1}$ | 293.15 | 12.531 | −1.870 | 2.529 | 3.286 | 0.008 |
| | 303.15 | 13.337 | −0.892 | 0.055 | 0.008 | 0.000 |
| | 313.15 | 13.596 | −1.019 | 3.222 | 1.316 | 0.006 |
| $\Delta\eta$/mPa·s | 293.15 | −0.034 | −0.001 | −0.007 | 0.005 | 0.004 |
| | 303.15 | −0.025 | 0.002 | −0.004 | −0.008 | 0.005 |
| | 313.15 | −0.016 | 0.006 | −0.005 | −0.015 | 0.004 |
| | *cis*-3-Hexenyl Acetate (1) + Ethanol (2) | | | | | |
| $V^E$/cm$^3$·mol$^{-1}$ | 293.15 | 13.741 | 1.219 | −2.056 | −5.878 | 0.026 |
| | 303.15 | 13.459 | −0.906 | 0.062 | −0.005 | 0.000 |
| | 313.15 | 13.330 | 1.118 | 2.603 | −2.806 | 0.016 |
| $\Delta\eta$/mPa·s | 293.15 | −0.036 | 0.002 | −0.004 | 0.004 | 0.003 |
| | 303.15 | −0.026 | 0.009 | −0.006 | −0.005 | 0.002 |
| | 313.15 | −0.017 | −0.002 | −0.011 | 0.004 | 0.009 |

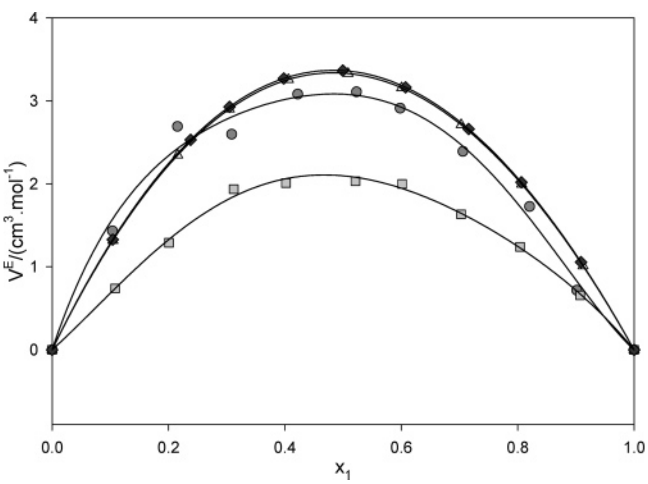


**Figure 1.** Excess molar volume $V^E$ of the binary mixtures studied at 303.15 K for ●, *cis*-3-hexenyl formate (1) + ethanol (2); ■, butyl acetate (1) + ethanol (2); ▲, *trans*-2-hexenyl acetate (1) + ethanol (2); and ♦, *cis*-3-hexenyl acetate (1) + ethanol (2).

method are given in Table 6. From Table 6, that is clear that the Redlich−Kister polynomial equation can represent the excess molar volume and viscosity deviation very well, which is indicated by low standard deviations.

## Conclusions

New experimental values of the density and viscosity for mixtures of *cis*-3-hexenyl formate (1) + ethanol (2), butyl acetate (1) + ethanol (2), *trans*-2-hexenyl acetate (1) + ethanol (2), and *cis*-3-hexenyl acetate (1) + ethanol (2) were obtained at 293.15 K, 303.15 K, and 313.15 K. From these experimental values, the excess molar volume, $V^E$, and viscosity deviation, $\Delta\eta$, were also determined. The excess molar volumes for all mixtures are positive. The excess

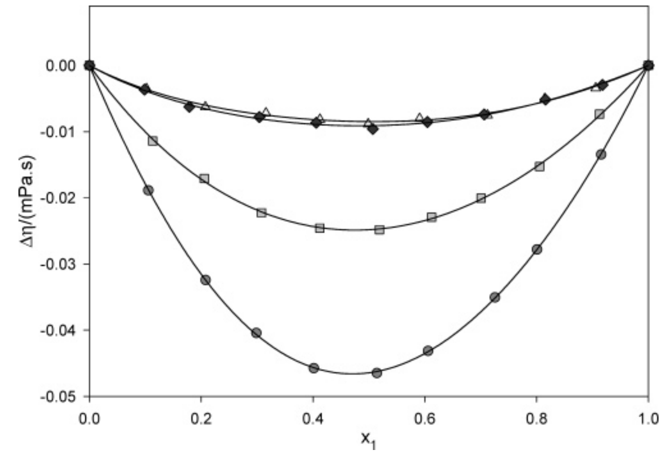


**Figure 2.** Viscosity deviation $\Delta\eta$ of the binary mixtures studied at 293.15 K for ●, *cis*-3-hexenyl formate (1) + ethanol (2); ■, butyl acetate (1) + ethanol (2); ▲, *trans*-2-hexenyl acetate (1) + ethanol (2); and ♦, *cis*-3-hexenyl acetate (1) + ethanol (2).

molar volume and viscosity deviation were correlated by the Redlich−Kister polynomial equation, and correlation parameters were obtained.

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