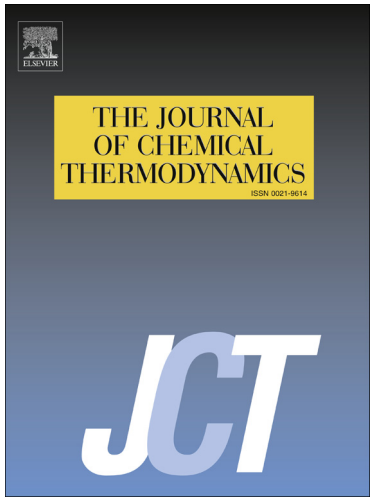

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Thermodynamics of Binary Mixtures 1-ethoxy-1,1,2,2,3,3,4,4,4-nonafluorobutane (HFE-7200) + 2-propanol: High Pressure Density, Speed of Sound and Derivative Properties.

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Abstract

Awareness about environmental impact of greenhouse gas emissions has lead to search for other alternatives which can cover the same utility range of wellknown CFCs, HCFCs and PFCs but without their undesirable effects on the planet. Since Hydrofluoroether fluids (HFEs) have emerged as a good alternative, it is necessary to characterize their thermophysical properties in order to bring reliable data to the industry. Density and speed of sound are two of the most important physical properties because of the amount of information that they provide in the design of the machinery involved in the utilization of these fluids as well as data for the parametrization of equations of state. This paper reports a set of new data concerning high pressure density, ρ, for the binary mixture x HFE-7200 + (1-x) 2-propanol in a broad range of pressures (0.1 – 140 MPa), and at several temperatures (from 293.15 to 393.15 K). Density values were correlated by employing a Tait-like equation in the same p, T ranges, and the derivative properties, that is, the isothermal compressibility κ_T, and the isobaric expansion α_P, were determined. Excess molar volumes V^E, which bring information about the change in volume observed in the mixture were also calculated for the eight mole fractions investigated. Speeds of sound, c, at 0.1 MPa were measured experimentally in the temperature range (293.15 – 333.15 K). By using the Laplace equation, isentropic compressibilities, κ_S, were calculated from density and sound velocity values.

Keywords

1-ethoxy-1,1,2,2,3,3,4,4,4-nonafluorobutane, 2-propanol, Density, Derivative Properties, Excess Volumes.

1. Introduction

Segregated hydrofluoroethers (HFEs) are a class of fluids which were introduced in 1996 as an environmentally acceptable alternative to commonly used CFCs and HCFCs [1]. Unlike these two kind of fluids, HFEs have no chlorine atoms in its molecule, which lead to a favorable environmental profile. In the same manner, the presence of fluorine atoms impart characteristics of stability and nonflammability [2], and the ether structure promotes an increase of reaction with –OH radicals in the lower atmosphere. HFEs exhibit a good balance between safety, performance, and environmental properties, due to its low toxicity, nonflammability, compatibility with other materials, stability, zero ODP, short atmospheric lifetimes (ALT), low global warming potentials (GWP), and low solubility in water among others [3] .

1-Ethoxy-1,1,2,2,3,3,4,4,4-nonafluorobutane, or HFE-7200, exhibits low viscosity, low surface tension, high density, no flash point and higher boiling point than most CFCs, HCFCs and HFCs, properties which make it useful as heat transfer fluid besides rinsing agent for vapor degreasing, aerosol cleaning, wipe cleaning, lubricant carrier, CFC, HCFC, HFC and PFC replacement agent. Particularly it is indicated to be a good substitute of HCFC-225 ca/cb, and HCFC-141b. Due to its dielectric nature, it can also be used for electronic cooling, and its mixture formulations are being considered for thermal management systems in the electronics industry [4].

Of utmost interest is its mixture with 2-propanol because at a mass composition of 87% of HFE-7200 an azeotrope is formed with a minimun boiling point at 338.15 K. This binary azeotrope is viable to replace HCFC-225ca/cb for solvent cleaning operations [5]. The cleaning processes that use azeotropes require a stronger solvent mixture, and the mechanism of cleaning with an azeotrope system is almost exclussively via dissolving the soil [6], being able to clean many oils, waxes and greases. Though isopropanol is a flammable agent, the addition of the HFE leads the mixture to be nonflammable, and the equipment in which this azeotrope can be used does not differ from the conventionally used with other azeotropes.

Due to the applications of the binary mixture x HFE-7200 + (1-x) 2-propanol, its thermophysical properties characterization is of interest. Density provides information about the change in volume that takes place when changes in pressure, p, and in temperature, T, occur in the mixture, and from its knowledge, derivative properties such as isobaric expansion α_P, and isothermal compressibility κ_T, which are also of importance, can be determined. Obtaining high pressure and high temperature density data will provide the industry valuable information concerning this mixture. This paper reports 1264 points of density at several pressures (from 0.1 to 140 MPa) and at different temperatures (from 293.15 to 393.15 K) for eight mole fractions of the binary system x HFE-7200 + (1-x) 2-propanol. Isothermal compressibilities κ_T, and isobaric expansion values α_P, were also determinded as well as the excess volumes in the temperature and pressure ranges considered. Speeds of sound at atmospheric pressure and in the temperature range (293.15 – 333.15 K) were determined and isentropic compressibilities were calculated from these data.

2. Experimental

2.1 Materials

Hydrofluoroether fluid 1-ethoxy-1,1,2,2,3,3,4,4,4-nonafluorobutane, also known as HFE-7200 (CAS 163702-06-5 / 163702-05-4) which consists of a mixture of two inseparable isomers with identical properties, was supplied by the 3M Company with a mass fraction purity greater than 99.0%. The compositions of the binary isomers of HFE-7200 were determined both by using F-NMR and H-NMR analysis, with a Varian Unity Inova 400 MHz apparatus. The obtained results showed that the mole fraction of the isomer with CAS number 163702-06-5 was 61.7%, whereas the mole composition of the isomer with CAS 163702-05-4 was 38.3%, with an expanded uncertainty $U(x)$ = 0.05. The observed peaks for both spectroscopies are gathered in Figures S1 and S2.

2-propanol (CAS 67-63-0) was obtained from Sigma-Aldrich with mole fraction purity greater than 99.8%. This fluid was stored over molecular sieves type 0.4 to prevent any moisture. Both the two fluids were degassed prior any measurement in order to avoid air bubbles in the sample. None of the fluids was subject to further purtification method. The data list concerning the properties of the pure compounds can be seen in Table 1.

2.2. Measurement technique. High pressure density

Various techniques are available to determine density data: piezometers, pycnometers, isochoric methods, densitometers based on vibrating elements, *etc*. One of the most widely used methods corresponds to vibrating tube densitometers (VTD), which used has increased due to its main advantages: simple operation, high accuracy and small sample requirement among others [7].

In our case, we used an Anton Paar vibrating tube densitometer model DMA HPM to measure high pressure density values. The description and operation of this densitometer was addressed in a previous paper [8]. The ranges in which the measurements were carried out are (0.1 – 140 MPa) for the pressure and (293.15 – 393.15 K) for the temperature. The pressure inside the measuring cell is generated by a step by step engine, while the Anton Paar mPDS 2000V3 evaluation unit controls the oscillation period from the measuring cell which is filled with the sample. The estimated expanded uncertainty of the measured pressure was ±0.04 MPa (pressure transducer WIKA CPH 6000). The temperature inside the densitometer is ensured by means of a silicone oil circulating fluid which is heated or cooled in a thermosthatic bath Julabo F25 HE. A Pt 100 probe directly inserted in the measuring cell measures the temperature of the sample with an expanded uncertainty of ±0.03 K. Both temperature and pressure probes were periodically calibrated before and after the measurement campaign.

Densitometer calibrations were performed according to the procedure described by Comuñas *et al.* [9] which is a modification of the procedure previously proposed by Lagourette *et al.* [10]. Taking this into account, two reference fluids were used, vacuum and water. The density values of water were taken from the equation of state (EoS) reported by Wagner and Pruss [11]. Because of the boiling points of the pure components (T_b = 349.15 K for HFE-7200, reference [12], and T_b = 355.39 K for 2-propanol, reference [13]), no measurements were carried out at temperatures 353.15 K and higher at 0.1 MPa for all the compositions in order to ensure liquid state.

Concerning the uncertainty, taking into account the accuracy of the temperature, the pressure, the period of oscillation measurement for water, vacuum, and the studied systems, and the water density accuracy, the estimated expanded density uncertainty (k = 2) is ±0.7 kg·m^{-3} (*i.e*, around ±0.07 % for density close to water density), following the EA-4/02 document [14].

To prevent any bubble formation inside the sample, a degasification procedure was carried out before introducing the sample in the densitometer. An ultrasonic bath PSelecta, model Ultrasons-H was employed for this purpose. The mixtures were prepared by weighing amounts of the pure components with a Mettler Toledo model MS 204S with resolution of 10^{-4} g, and uncertainty ±0.0001 g. The estimated expanded uncertainty in the composition of the mixture is $\pm 5 \cdot 10^{-4}$ in mole fraction. Then the expanded uncertainty for the excess volumes is stated to be ±0.004 cm^3·mol^{-1}.

2.3. Measurement technique. Speed of sound

Speed of sound at 0.1 MPa was measured by using an Anton Paar DSA 5000 density and sound velocity meter in the temperature ranges (293.15 – 333.15 K). The temperatures differ from those considered for high pressure density measurements due to the limit in temperature given by the manufacturer of the apparatus. Speed of sound in a fluid is obtained by measuring the travelling time, t that a wave needs to pass across the fluid at a fixed distance. In the case of this benchtop apparatus, two transducers (emitter and receiver), working in a frequency of approximately 3 MHz, are responsible for the determination of the speed of sound. This property provides information on transport coefficients, thermodynamic properties as well as relaxation processes [7]. The sound velocity analyzer employed allows us also to calculate the density of the sample; a vibrating tube made of glass located inside the apparatus is filled with the sample, being the operating principle the one of a vibrating tube densitometer. Then the two properties, speed of sound and density can be determined simultaneously with the same sample. The density and sound velocity analyzer is provided with a built-in thermostat, with a stability in temperature ±0.01 K. The uncertainty for the experimental pressure, measured by using a Lambrecht model 604 barometer is determined to be $U(p_{0.1})$ = 10^{-3} MPa. The expanded uncertainty in speed of sound is estimated to be ±1 m·s^{-1} while the expanded uncertainty in density is $\pm 9 \cdot 10^{-4}$ g·cm^{-3}. The instrument is calibrated once a week following

the instructions of the manufacturer with two fluids: ambient air and Millipore quality water or *n*-decane. Concerning the sound velocity, as there are no certified liquid standards for speed of sound available, the calibration method involves the comparison with a reference value, and it is only possible to do this procedure for the density. In our case, during the calibration procedure, three measurements with each fluid were made in order to calculate an average of the period of vibration for the sample. With these data it is possible to determine the two constants, *a* and *b* of the following calibration equation:

$$\rho = a + \tau^2 \cdot b \tag{1}$$

Where τ corresponds to the period of oscillation of the vibrating tube with the sample. The results of the calibrations were compared with those of [11] in the case of water, and with reference [15] in the cases of air and *n*-decane. The choice of *n*-decane was subject to the bubbles formation inside the glass tube at high temperatures (323.15 K and 333.15 K), which lead to bad values of density in the case of water. In those cases, calibration was made with ambient air and *n*-decane. The mixtures were prepared by weighing amounts of each compound by using a Mettler Toledo balance model MS 204S with resolution of 10^{-4} g, and uncertainty ±0.0001 g. The expanded uncertainty in the composition is determined to be $5 \cdot 10^{-4}$ in mole fraction. The components were placed in stoppered bottles of 14 cm^3 and degassed during at least 15 minutes prior to any measurement with an ultrasonic bath PSelecta, model Ultrasons-H. The standard uncertainty for the experimental pressure, determined by using a Lambrecht model 604 barometer, is determined to be $U(P_{0.1}) = 10^{-4}$ MPa.

3. 3. Results and Discussion

3.1. Density

For the purpose of bringing an adequate representation of density along the different compositions in the mixture, eight mole fractions were studied (x = 0.0000, x = 0.1520, x = 0.3275, x = 0.5019, x = 0.6053, x = 0.6777, x = 0.8526 and x = 1.0000). Since an azeotrope is described to appear at a mass composition of 87% [5], the corresponding mole fraction, x = 0.6053 was added in order to characterize the density at this point. Density of every mole fraction was determined along 23 isobars from 0.1 MPa to 140 MPa at every 5 MPa (from 0.1 to 65 MPa), and at every 10 MPa (from 70 to 140 MPa), and along seven isotherms (293.15 K, 298.15 K, 313.15 K, 333.15 K, 353.15 K, 373.15 K and 393.15 K). All the density values at each *p*, *T* sets are gathered in Table 2. As mentioned in the previous section, no measurements were carried out at 0.1 MPa and at temperatures 353.15 K and over due to the boiling point of the pure compounds is lower or close to 353.15 K.

3.2. Tait representation

Correlation equations are necessary to be employed with experimental data due to with its utilization density points which have not been measured at a determined *P* or *T* can be obtained. In our case we have used a Tait-like equation to correlate the high pressure density values measured experimentally. The Tait equation, which was firstly used to fit the results on the compressibility of fresh water and seawater at different pressures, has demonstrated to bring a great accuracy in reproducing high pressure density data for liquids [16]. This equation was used in some of our previous works [17 - 20], and is as follows:

$$\rho(T,p) = \frac{\rho_0(T)}{1 - C\ln\left(\frac{B(T)+p}{B(T)+0.1\,\mathrm{MPa}}\right)} \tag{2}$$

where:

$$\rho_0(T) = A_0 + A_1T + A_2T^2 + A_3T^3 \tag{3}$$

$$B(T) = B_0 + B_1T + B_2T^2 \tag{4}$$

The A_i, B_i and C parameters are obtained by correlating simultaneously all the experimental densities values versus pressure and temperature. Table 3 shows the eight parameters obtained for the eight mole fractions along with its deviations: AAD% (Average Absolute Deviation), MD% (Maximum Deviation), Bias% (Average Deviation), σ (Standard Deviation), and RMSD (Root Mean Square Deviation). It can be seen that for all the mole fractions the AAD% and the Bias% are lower than the experimental uncertainty. Evaluating the MD%, mole fractions x = 0.5019, x = 0.6053, x = 0.6777, x = 0.8526 and x = 1.0000 slightly exceed this value, with a maximum MD% = 0.10 for the compositions x = 0.8526 and x = 1.0000.

Figure 1 reports some representations of experimental densities with the correlation given by the Tait equation vs. the temperature *T*, in cases (a) and (b), and vs. the pressure for graphs (c) and (d). Graphs (a) and (b) show data at each mole composition at 1 MPa (a) and at 140 MPa (b). Regardless of pressure, a decrease in the value of density is observed when the temperature increases. Considering the different pressures, the density values are higher at 140 MPa than at 1 MPa when comparing the same composition at the same temperature, with a maximum value of density = 1.6428 g·cm^{-3} at a mole fraction x = 1.000. Graphs (c) and (d) report density data at 293.15 K and at 393.15 K

respectively. In both two graphs the shape of the curves is concave, which is related to the negative second order derivative, being this appearance compatible with the logarithmic relationship used in the Tait-like equation. Following this trend of the curves, it can be stated that when the pressure increases, the density also increases in a logarithmic form regardless of the temperature. The highest values of density are found at 293.15 K (graph 1 (c)), due to at lower temperatures the molecules in the fluid have less energy than at high temperature, resulting in an approximation of them and hence in lower values of density.

3.3. Comparison with literature data

It was possible to compare our density values for the two pure compounds with the literature data available, but concerning the mixture, no data was found to compare with. Due to some of the published data are not in the same *p*, *T*, sets than ours, we used equations (2) to (4) to establish a correlation that would allow to compare our data with those from the literature. Three references [4], [21 and 22] at atmospheric pressure were found for pure HFE-7200, while references [23 and 24] report 126 points at high pressure in the interval (0.1 – 100 MPa), and reference [25] provides 80 points between the temperature ranges (298.15 – 323.15) and in the pressure interval (0.1 – 40) MPa. Only reference [21] reports deviations lower than the expanded uncertainty, with a MD% = 0.06, an AAD% = 0.04 and a Bias% = -0.04. For the references at high pressure, the MD% reported by references [23 and 24] is = 0.38 while the AAD% and the Bias% return data slightly higher than the uncertainty, 0.13 and -0.13 respectively. Reference [25] brings better results than references [23 and 24], with a MD% = 0.12, an AAD% = 0.03 and a Bias% = -0.02. The worst datum is given by reference [22], with a MD% = AAD% = 0.75 and a Bias% = -0.75. Table 4 gathers all the information concerning the comparisons done for pure HFE-7200. A graphical comparison is also given in Figure 2.

Several references were found for 2-propanol; in this work we have considered those which contain data at high pressure. Figure 3 shows graphically the deviations obtained when comparing with the 11 references found [17], [26 - 35].

Most of the references report density data at pressures lower than 70 MPa, being references [27], [33], [35] and [17] the ones which have measured up to 140 MPa (up to 138.9 in the case of reference [27]. According to the temperature intervals, no reference overlaps our lower limit (293.15 K), since the lowest temperature value measured is 293.15 K for reference [33]. The upper limit in temperature (393.15 K) is overtaken by references [27] and [35], with 400.00 and 403.15 K respectively. For the deviations between the literature values and those obtained by our correlation, the best values are those found in the comparison with our previous paper [17], with a MD% = 0.04, and AAD% = 0.01 and a Bias% = $-8.30 \cdot 10^{-6}$. References [27], [28], [33 and 34], report maximum deviations MD close to

the experimental uncertainty, with values of 0.09%, 0.09%, 0.12% and 0.06% respectively. The worst value correspond to the comparison with reference [31], which reports 156 points with an AAD% = 0.18, a MD% = 0.27 and a Bias% = 0.18.

3.4. Excess Molar Volumes

The excess volume V^E, can be defined as the difference between the real change in volume on the mixture and the ideal change of volume on mixing. Excess volumes provide reliable information so its determination from experimental high pressure density data is reported in this section. From the aforementioned definition one can determine the equation of calculation for excess volume:

$$V^E = \sum_{i=1}^{n} x_i M_i \left[\left(1/\rho \right) - \left(1/\rho_i \right) \right] \tag{5}$$

Where n is the number of components, x_i is the mole fraction of component i in the mixture, M_i is the molar mass of component i, ρ and ρ_i are the measured densities of the mixture and pure component i, respectively.

Figure 4 shows representations of excess volumes V^E, vs. the composition x, at different pressures and at (a) 293.15 K and (b) at 393.15 K and at different temperatures, where (c) shows excess volumes at 1 MPa, and (d) at 140 MPa. In all cases excess volumes show a positive trend and relatively high values, which is a result of the low packing effect between the molecules of HFE-7200 and 2-propanol. When comparing graph (a) with (b) a big difference in the values of excess volumes is observed. At higher temperatures, as is the case of (b), the packing effect is less effective than at lower temperatures, being the V^E values much higher at 393.15 K (b) than at 293.15 K (a). At 293.15 K the highest value of excess volume is found at the lowest pressure (1 MPa) and at a mole composition of x = 0.5019 being this trend the same for the rest of the pressures. In the case of 393.15 K (b), the highest value of V^E is found also at 1 MPa, but for a mole composition of x = 0.6777. In graphs (c) and (d) the difference in the excess volumes values is much higher at low pressures (1 MPa, case (c)) than at high pressures (case (d), 140 MPa). The highest value of V^E is observed at 1 MPa, at the temperature of 393.15 K and at the mole composition x = 0.6053 with an excess volume of 4.16 $cm^3 \cdot mol^{-1}$.

Figure 4 also shows the fitting curves obtained for both the two binary systems by using a Redlich-Kister polynomial of the type:

$$V^E = x(1-x)\sum_i z_i (2x-1)^{i-1} \tag{6}$$

In equation (6) z_i are the adjustable parameters, and x is the mole fraction of HFE-7200. Then, for the mixture studied in this work, x HFE-7200 + (*1*-x) 2-propanol, the solid line represents the fitting curve to the experimental data. Table 5 reports the values of the adjustable parameters, z_i, and the standard deviations obtained by using equation (6) for the pressures 0.10 MPa and at temperatures from 293.15 K to 333.15 K, and at 1.00 MPa, 70 MPa, 110 MPa and 140 MPa all at temperatures from 293.15 K to 393.15 K.

3.5. The derived thermodynamic properties.

The derived thermodynamic properties, that is, the isothermal compressibility κ_T, and isobaric expansion α_p, can give valuable information on the dependence of the volumetric properties on temperature and pressure. The isothermal compressibility, κ_T, describes the effect of pressure on the density based on the equation:

$$\kappa_T = \left(\frac{1}{\rho}\right)\left(\frac{\partial \rho}{\partial p}\right)_T = \frac{C}{\left(1 - C\ln\left(\frac{B(T)+p}{B(T)+0.1MPa}\right)\right)\left(B(T)+p\right)} \tag{7}$$

Table 6 gathers the values of isothermal compressibility for all the measured compositions of the binary mixture x HFE-7200 + (*1*-x) 2-propanol. It can be seen that the values of κ_T are higher for HFE-7200 than for any of the mixtures and for pure 2-propanol, and in the same way κ_T increases when increasing the temperature but taking into account the pressure, it promotes an effect of decrease when the higher the pressure is.

In a similar way, the isobaric expansion α_p, could also be obtained by differentiating equation (2) taking into account the temperature dependence of $\rho_0(T)$ and $B(T)$:

$$\alpha_p = -\left(\frac{1}{\rho}\right)\left(\frac{\partial \rho}{\partial T}\right)_p \tag{8}$$

Nevertheless, the estimated isobaric expansion depends on the form of functions $B(T)$ and $\rho_0(T)$ as pointed out by references [36, 37]. Then, it is better to derive the isobaric thermal expansion from the

isobaric densities. So at each pressure we suppose that $\rho_p(T) = a_0+a_1T+a_2T^2$ and consequently $(\partial\rho/\partial T)_p = a_1 + 2a_2T$. For each pressure we get a set (a_0, a_1, a_2).

By inserting the differentiated density and the calculated densities $\rho_p(T)$ into $\alpha_p = -(1/\rho(\partial\rho/\partial T)_p$ the isobaric thermal expansivity at the different *T, p* conditions has been derived:

$$\alpha_p = -\frac{a_1 + 2a_2T}{a_0 + a_1T + a_2T^2} \quad (9)$$

As mentioned, the method used to evaluate the isobaric thermal expansion coefficient may affect the accuracy of the values. The differences sometimes found for the values of this coefficient from the literature are due not only to differences in density values but also to the fitting equations, as stated in [38].

The isobaric expansion, α_p, and the isothermal compressibility, κ_T, were calculated from the above procedures. The estimated uncertainty following [14] is 1% for the isothermal compressibility and around 3% for the isobaric expansion, as recently indicated on similar high-pressure density studies [8, 9] and [39] with the same methods.

Table 7 reports the isobaric expansion, α_p. Similarly as it occurs with the isothermal compressibility, the highest values of α_p are found for HFE-7200, and the values of α_p increase with increasing temperature and decrease with increasing pressure.

3.6. Speed of Sound

Speeds of sound *c*, of binary mixtures *x* HFE-7200 + (1-*x*) 2-propanol were determined at 0.1 MPa and in the range of temperatures (293.15 – 333.15 K) by using an Anton Paar DSA 5000 density and sound velocity meter. Densities ρ, at 0.1 MPa in the same temperature range were also determined, and isentropic compressibilities κ_S, were calculated from these experimental data by means of the Laplace equation (10)

$$\kappa_S = \rho^{-1} \cdot c^{-2} \quad (10)$$

The obtained data are showed in Table 8. It can be seen that the highest values of speed of sound are found for pure 2-propanol (*x* = 0.0000), and it can be stated also that the speed of sound values decrease when increasing the temperature. By contrast, isentropic

compressibilities show the highest values at the mole fraction x = 1.0000 (pure HFE-7200), and these values increase when increasing temperature. This fact is due to the densities for HFE-7200 are quite higher than those of 2-propanol, and its values decrease in the same way as the temperature increases.

A comparison between the obtained experimental values for the two pure fluids HFE-7200 and 2-propanol has been done in order to check the goodness of our data. For HFE-7200 only one reference was found [40], giving an AAD% = 0.11, MD% = 0.23, and Bias % = $-2.83 \cdot 10^{-3}$. The results of this comparison can be seen in Figure 5. For pure 2-propanol, several references [41 - 49] were compared with our experimental data at 0.1 MPa and in our temperature interval. Almost all of the references show deviations lower than the uncertainty given for speed of sound, being reference [42] the only one that has a MD higher than 1%, with a value of 1.33%, an AAD% = 0.50 and a Bias% = -0.48 for a total of 3 points. The better values of deviations are those given by reference [45], with a MD% = AAD% = Bias% = 0.02 at the two corresponding temperatures, 293.15 and 323.15 K. The rest of the references show values of deviations in all cases lower than 1%. These results can be observed in Table 9.

Figure 6 shows the deviations between the isentropic compressibility values calculated from the pure compounds, and those calculated from the experimental speeds of sound and densities obtained at every mole fraction. In all the cases the highest values are found at compositions approximately x = 0.5000, and as occurs for isentropic compressibility, the deviations are higher when the higher the temperatures are.

4. Conclusions

High pressure densities ρ, were determined by using a vibrating tube densitometer for the binary system x HFE-7200 + (*1*-x) 2-propanol. The densities were determined along 23 isobars ranging from 0.1 to 140 MPa and in the temperature interval from 293.15 to 393.15 K for eight mole fractions. A Tait-like equation was employed to correlate the density values over the entire pressure and temperature ranges, showing a good agreement between the experimental data and the calculated ones. Isothermal compressibility κ_T, and isobaric expansion α_P, data was determined by deriving the Tait-like equation A literature comparison for the densities of both the two pure fluids was carried out since no data for the binary mixture was found in the literature. Excess volumes V^E, were also determined from the high pressure density data of the pure compounds and of the mixtures, showing positive values in the whole range of compositions. Speeds of sound c, and densities ρ, at 0.1 MPa were measured by using an Anton Paar DSA 5000 density and sound velocity meter along six

isotherms from 293.15 K to 333.15 K, and isentropic compressibilities κ_S, were calculated from these data sets.

List of symbols

AAD	Absolute Average Deviation
a_i	coefficients of isobaric thermal expansion correlation
A_i, B_i, C	coefficients of density correlation
Bias	Average Deviation
calc	calculated
exp	experimental
i	constituent identification
lit	literature
m	number of parameters
MD	Maximum Deviation
N_P	number of experimental data points which are in our p, T ranges
p	pressure
RMSD	Root Mean Square Deviation
T	temperature
V^E	excess molar volume

Greek letters

α_p	isobaric expansion
ρ	density
ρ_0	density at a reference pressure P_0
κ_S	isentropic compressibility
κ_T	isothermal compressibility
σ	standard deviation

τ period of oscillation

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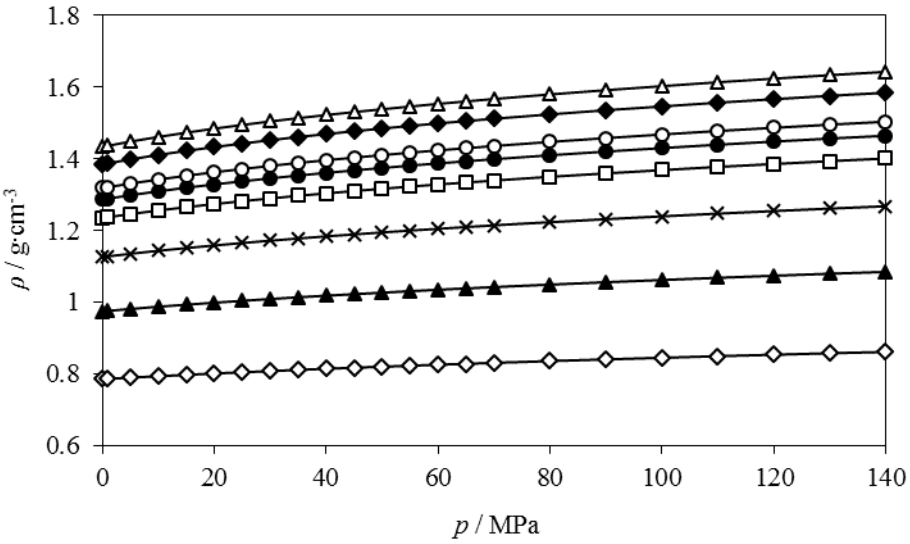
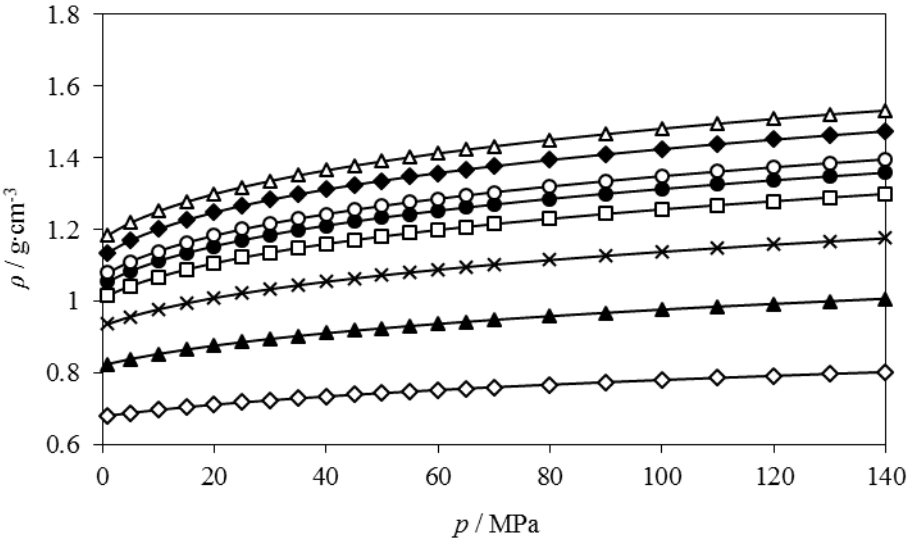


(a)



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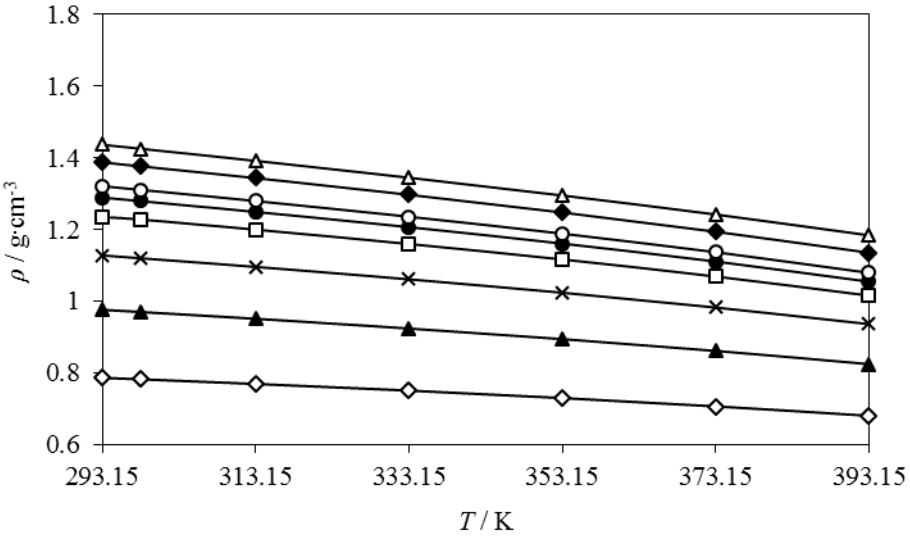

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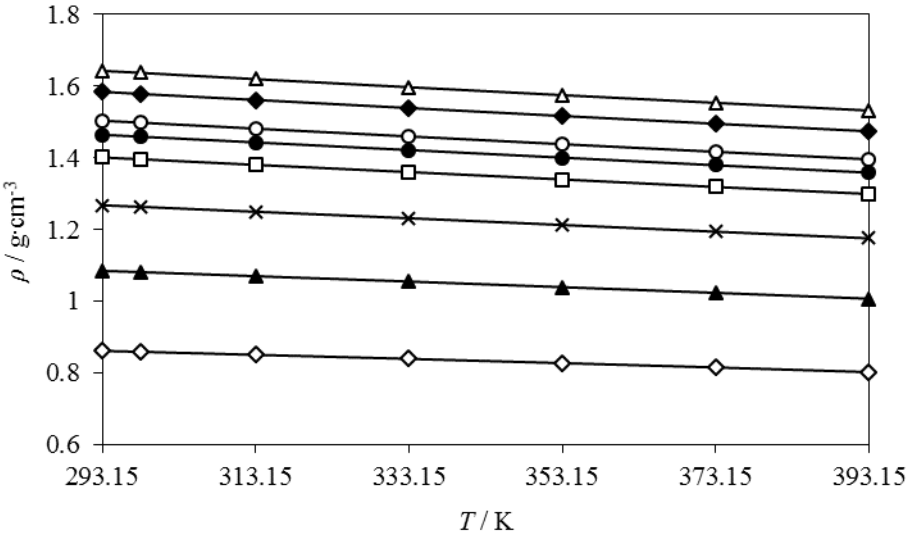


(d)

Figure 1. Experimental high pressure density values ρ, for the binary system x HFE-7200 + (1-x) 2-propanol at the eight molar compositions studied vs. (a) the pressure, p at 293.15 K, (b) the pressure, p at 393.15 K, (c) the temperature, T at 1 MPa, and (d) the temperature, T at 140 MPa. ◊; x = 0.0000, ▲; x = 0.1520, ×; x = 0.3275, □; x = 0.5019, ●; x = 0.6053, ○; x = 0.6777, ♦; x = 0.8526, Δ; x = 1.0000.
(─); Tait equation (2) to (4).

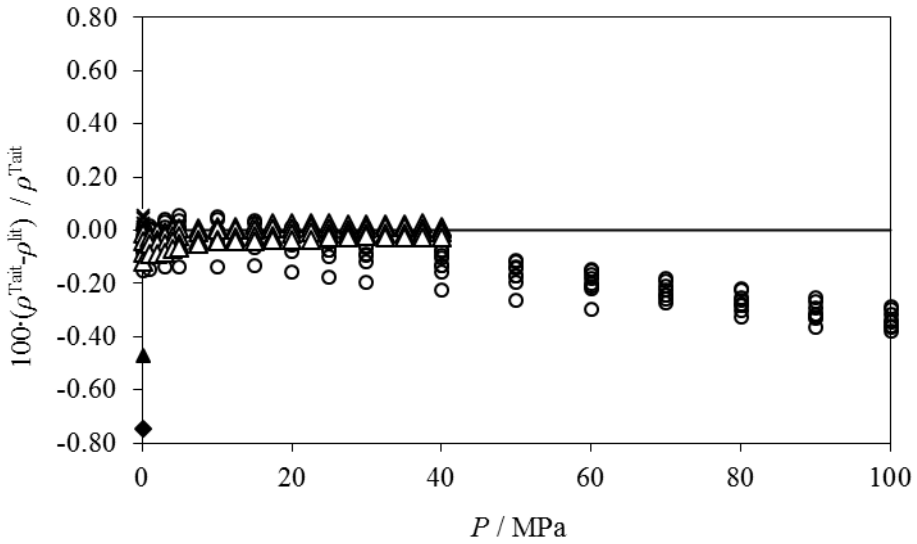


Figure 2. Deviations between the values generated by the correlation given by equations (2) to (3) and those found in the literature for the hydrofluoroether fluid HFE-7200 considering the same *p*, *T* sets. ▲; reference [4], ×; reference [21], ♦; reference [22], ○; references [23 and 24], and Δ; reference [25]

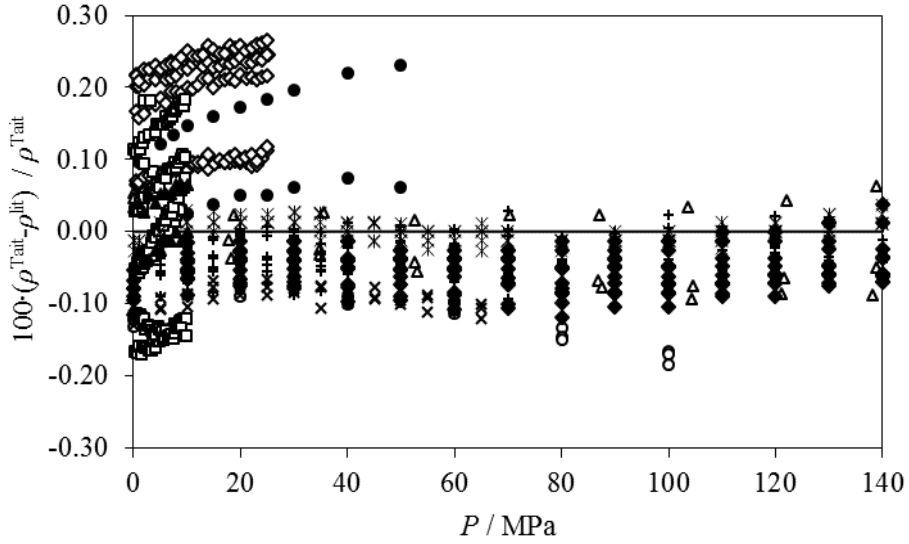
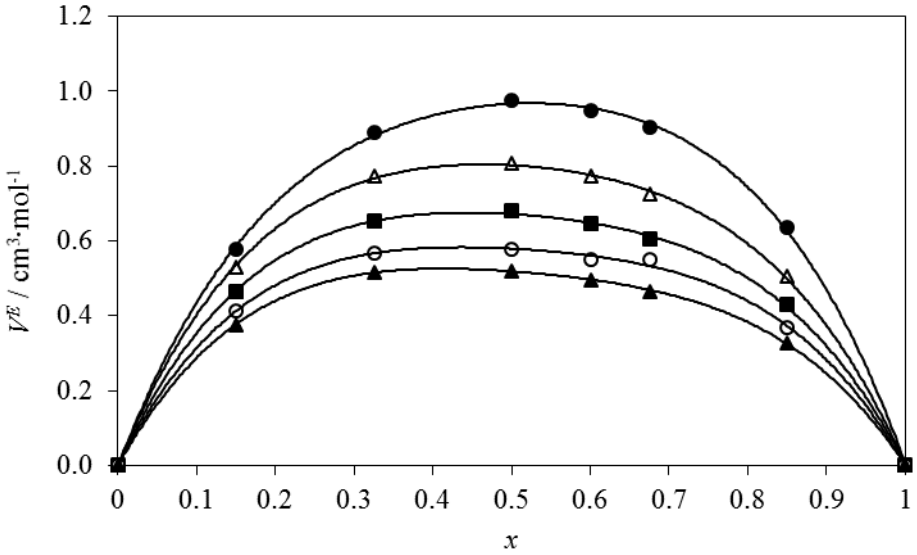


Figure 3. Obtained deviations between the values from the literature and the values generated by our correlation (equations (2) to (4)) at the same *p*, *T* sets for pure 2-propanol. Ж; reference [17], ●; reference [26], Δ; reference [27], ▼; reference [28], ○; reference [29], ×; reference [30], ◊; reference [31], □; reference [32], ♦; reference [33], ▲; reference [34], +; reference [35].



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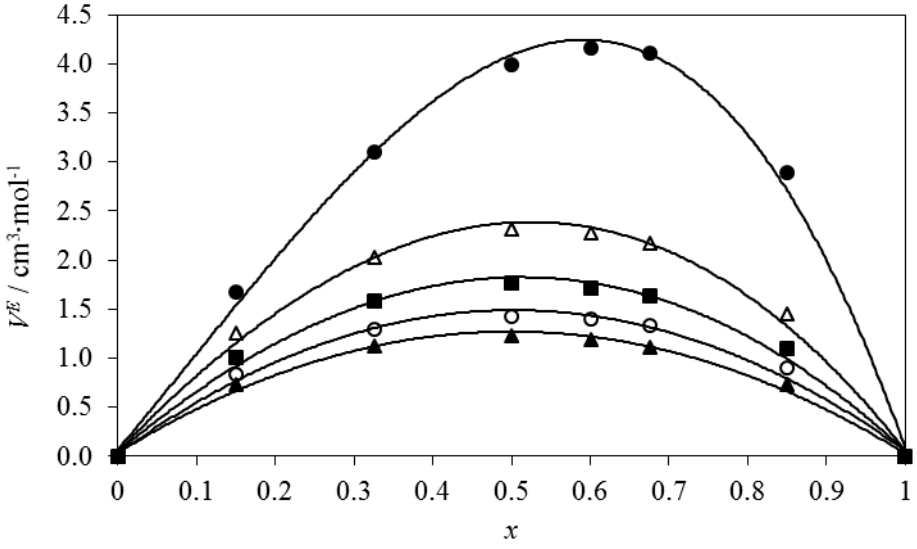

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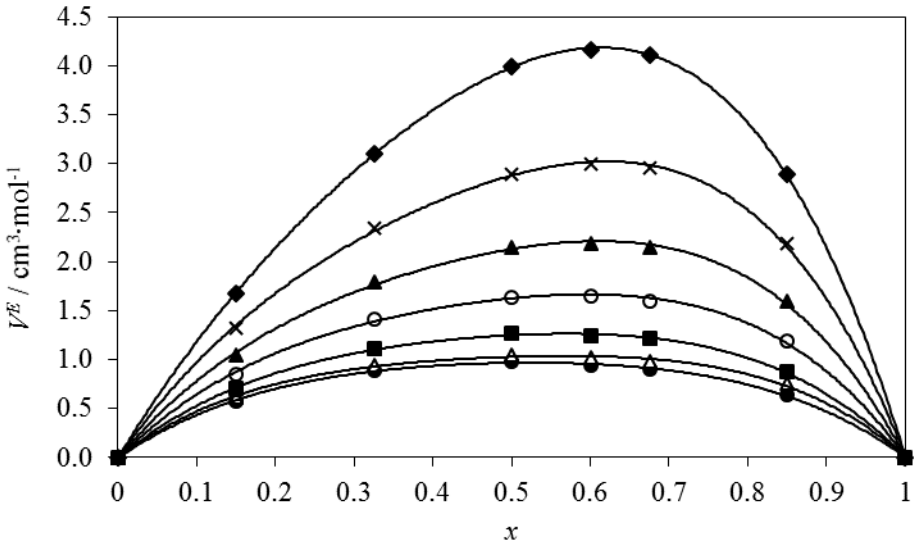

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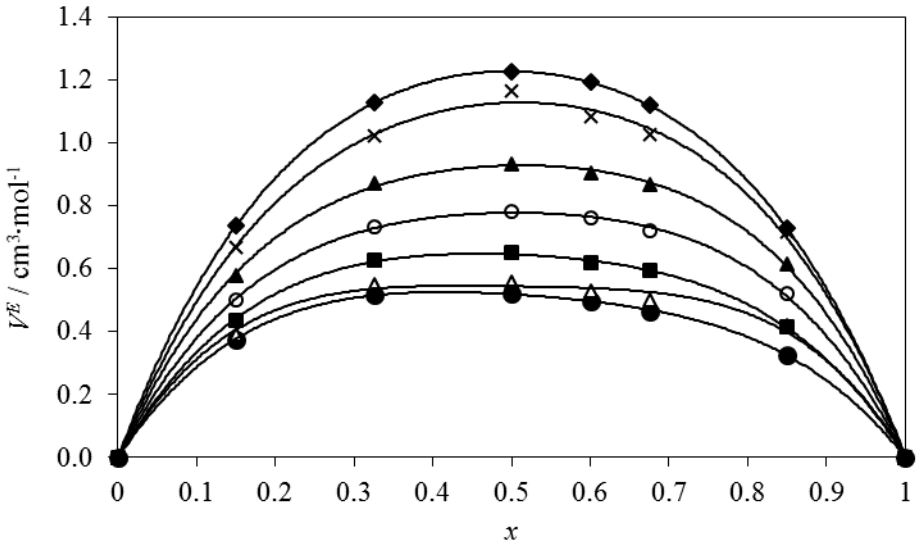

(d)

Figure 4. Experimental values for excess volumes obtained for the binary mixture *x* HFE-7200 + (1-*x*) 2-propanol as a function of the mole fraction and at different pressures *p*, (a) at 293.15 K, (b) at 393.15 K, where: ●; 1 MPa, Δ; 35 MPa, ■; 70 MPa, ○; 110 MPa, ▲; 140 MPa, and at different temperatures *T*, (c) at *p* = 1 MPa and (d) at *p* = 140 MPa where: ●; 293.15 K, Δ; 298.15 K, ■; 313.15 K, ○; 333.15 K, ▲; 353.15 K, ×; 373.15 K, ♦; 393.15 K. (─); Redlich-Kister's equation.

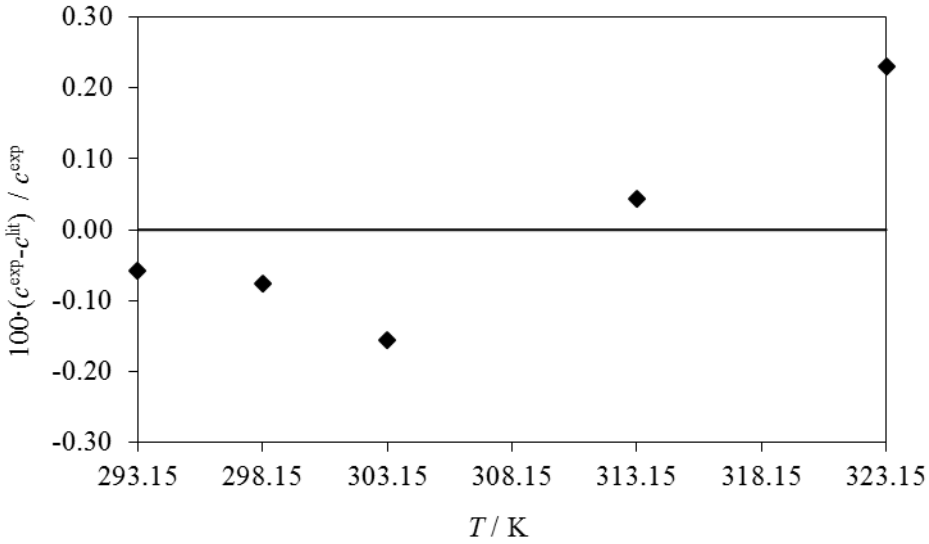

Figure 5. Deviations between the speed of sound literature values given by reference [40], and the experimental ones for HFE-7200 at 0.1 MPa and at temperatures from (293.15 to 323.15) K.

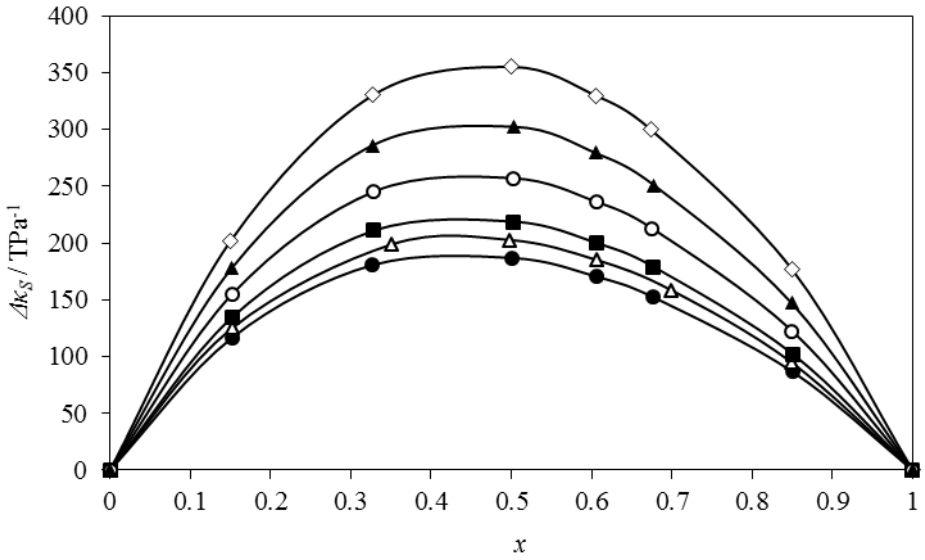

Figure 6. Deviations from isentropic compressibility $\Delta\kappa_S$, vs. the mole fraction at different temperatures for the binary mixture x HFE-7200 + (1-x) 2-propanol. ●; 293.15 K, Δ; 298.15 K, ■; 303.15 K, ○; 313.15 K, ▲; 323.15 K, ◊; 333.15 K.

Table 1. Related data for the studied chemicals.

Compound	Source	Formula	Molar mass / g·mol^{-1}	Stated purity[a]	CAS number
HFE-7200[b]	3M Company	$C_6H_5F_9O$	264.09	>99.0[c]	163702-06-5 / 163702-05-4[d]
2-propanol	Sigma-Aldrich	C_3H_8O	60.096	>99.8[e, f]	67-63-0

[a] Determined by gas chromatography (GC) by the supplier.
[b] HFE-7200 = 1-ethoxy-1,1,2,2,3,3,4,4,4-nonafluorobutane.
[c] Mass fraction purity, wt%
[d] Binary mixture of two isomers with mole fraction, x, 0.617 for CAS number 163702-06-5 and 0.383 for CAS 163702-05-4, determined by ^{1}H-NMR and ^{19}F-NMR, with an expanded uncertainty (k = 2), $U(x)$ = 0.05.
[e] The water content was checked to be less than 0.01% (mass%) by titration method by the supplier.
[f] Mole fraction purity, mol%.

Table 2. Values of experimental high pressure densities ρ, at temperatures T and pressures p for the binary mixture x HFE-7200[a] + (*1-x*) 2-propanol[b].

x	p / MPa	T / K						
		293.15	298.15	313.15	333.15	353.15	373.15	393.15
		ρ / g·cm^{-3}						
0.0000	0.10	0.7854	0.7814	0.7682	0.7494			
	1.00	0.7862	0.7821	0.7691	0.7505	0.7298	0.7066	0.6804
	5.00	0.7896	0.7856	0.7730	0.7549	0.7350	0.7128	0.6882
	10.00	0.7936	0.7898	0.7774	0.7600	0.7410	0.7199	0.6967
	15.00	0.7974	0.7937	0.7818	0.7649	0.7465	0.7263	0.7044
	20.00	0.8011	0.7973	0.7857	0.7693	0.7517	0.7320	0.7114
	25.00	0.8045	0.8009	0.7895	0.7736	0.7565	0.7377	0.7176
	30.00	0.8079	0.8043	0.7933	0.7777	0.7610	0.7429	0.7235
	35.00	0.8112	0.8077	0.7969	0.7815	0.7654	0.7478	0.7290
	40.00	0.8142	0.8108	0.8001	0.7853	0.7693	0.7522	0.7342
	45.00	0.8172	0.8138	0.8034	0.7889	0.7733	0.7566	0.7390
	50.00	0.8201	0.8167	0.8065	0.7923	0.7770	0.7607	0.7435
	55.00	0.8229	0.8197	0.8096	0.7956	0.7806	0.7647	0.7479
	60.00	0.8256	0.8225	0.8125	0.7987	0.7840	0.7686	0.7521
	65.00	0.8282	0.8252	0.8154	0.8018	0.7874	0.7721	0.7561
	70.00	0.8308	0.8276	0.8182	0.8048	0.7906	0.7756	0.7600
	80.00	0.8358	0.8328	0.8234	0.8105	0.7967	0.7823	0.7672
	90.00	0.8405	0.8375	0.8285	0.8159	0.8026	0.7885	0.7739
	100.00	0.8450	0.8423	0.8331	0.8209	0.8080	0.7944	0.7802
	110.00	0.8494	0.8464	0.8378	0.8258	0.8132	0.7999	0.7862
	120.00	0.8535	0.8508	0.8421	0.8304	0.8181	0.8053	0.7918
	130.00	0.8576	0.8548	0.8464	0.8348	0.8228	0.8102	0.7972
	140.00	0.8612	0.8587	0.8504	0.8392	0.8273	0.8151	0.8023
0.1520	0.10	0.9747	0.9686	0.9495	0.9222			
	1.00	0.9760	0.9699	0.9509	0.9239	0.8943	0.8614	0.8246
	5.00	0.9813	0.9754	0.9571	0.9312	0.9030	0.8721	0.8384
	10.00	0.9875	0.9819	0.9642	0.9395	0.9128	0.8839	0.8527
	15.00	0.9933	0.9879	0.9709	0.9471	0.9216	0.8942	0.8651
	20.00	0.9988	0.9934	0.9770	0.9540	0.9297	0.9033	0.8761
	25.00	1.0040	0.9988	0.9827	0.9606	0.9371	0.9120	0.8858
	30.00	1.0090	1.0039	0.9884	0.9668	0.9440	0.9199	0.8947
	35.00	1.0137	1.0088	0.9936	0.9725	0.9506	0.9273	0.9031
	40.00	1.0183	1.0134	0.9985	0.9781	0.9565	0.9339	0.9106
	45.00	1.0225	1.0179	1.0033	0.9834	0.9624	0.9403	0.9178
	50.00	1.0267	1.0221	1.0079	0.9884	0.9679	0.9465	0.9244
	55.00	1.0308	1.0263	1.0123	0.9932	0.9731	0.9522	0.9307
	60.00	1.0347	1.0303	1.0165	0.9977	0.9782	0.9577	0.9368
	65.00	1.0385	1.0341	1.0206	1.0022	0.9830	0.9630	0.9425
	70.00	1.0421	1.0377	1.0246	1.0064	0.9877	0.9680	0.9480

	80.00	1.0492	1.0449	1.0321	1.0145	0.9963	0.9774	0.9583
	90.00	1.0558	1.0517	1.0392	1.0222	1.0046	0.9862	0.9678
	100.00	1.0621	1.0582	1.0459	1.0293	1.0123	0.9945	0.9767
	110.00	1.0682	1.0641	1.0524	1.0362	1.0196	1.0023	0.9849
	120.00	1.0740	1.0702	1.0584	1.0426	1.0264	1.0097	0.9926
	130.00	1.0796	1.0757	1.0643	1.0489	1.0330	1.0166	1.0000
	140.00	1.0847	1.0812	1.0699	1.0549	1.0392	1.0233	1.0071
0.3275	0.10	1.1263	1.1184	1.0937	1.0587			
	1.00	1.1280	1.1201	1.0958	1.0612	1.0238	0.9824	0.9361
	5.00	1.1352	1.1277	1.1043	1.0714	1.0362	0.9981	0.9565
	10.00	1.1436	1.1364	1.1140	1.0828	1.0498	1.0146	0.9770
	15.00	1.1513	1.1444	1.1229	1.0932	1.0619	1.0289	0.9941
	20.00	1.1585	1.1518	1.1311	1.1025	1.0728	1.0412	1.0090
	25.00	1.1654	1.1589	1.1388	1.1113	1.0827	1.0527	1.0219
	30.00	1.1719	1.1655	1.1461	1.1194	1.0918	1.0632	1.0337
	35.00	1.1780	1.1719	1.1529	1.1270	1.1004	1.0728	1.0445
	40.00	1.1839	1.1778	1.1594	1.1342	1.1081	1.0814	1.0543
	45.00	1.1894	1.1836	1.1656	1.1411	1.1158	1.0898	1.0634
	50.00	1.1949	1.1890	1.1714	1.1475	1.1229	1.0976	1.0721
	55.00	1.2001	1.1944	1.1772	1.1537	1.1296	1.1050	1.0801
	60.00	1.2050	1.1996	1.1824	1.1595	1.1360	1.1121	1.0879
	65.00	1.2098	1.2044	1.1878	1.1652	1.1422	1.1187	1.0951
	70.00	1.2145	1.2091	1.1928	1.1707	1.1481	1.1251	1.1020
	80.00	1.2234	1.2182	1.2023	1.1810	1.1591	1.1371	1.1149
	90.00	1.2317	1.2267	1.2113	1.1906	1.1696	1.1481	1.1267
	100.00	1.2396	1.2348	1.2197	1.1997	1.1791	1.1585	1.1378
	110.00	1.2473	1.2423	1.2278	1.2082	1.1884	1.1681	1.1480
	120.00	1.2544	1.2497	1.2354	1.2162	1.1969	1.1772	1.1577
	130.00	1.2613	1.2567	1.2427	1.2241	1.2051	1.1859	1.1668
	140.00	1.2678	1.2634	1.2496	1.2315	1.2128	1.1941	1.1755
0.5019	0.10	1.2352	1.2260	1.1972	1.1567			
	1.00	1.2373	1.2281	1.1998	1.1598	1.1167	1.0691	1.0158
	5.00	1.2460	1.2373	1.2102	1.1724	1.1322	1.0889	1.0421
	10.00	1.2561	1.2477	1.2220	1.1864	1.1490	1.1093	1.0676
	15.00	1.2654	1.2574	1.2327	1.1988	1.1636	1.1267	1.0885
	20.00	1.2740	1.2663	1.2425	1.2101	1.1767	1.1416	1.1062
	25.00	1.2821	1.2747	1.2517	1.2206	1.1885	1.1553	1.1217
	30.00	1.2898	1.2825	1.2604	1.2302	1.1994	1.1677	1.1356
	35.00	1.2971	1.2900	1.2685	1.2391	1.2095	1.1791	1.1483
	40.00	1.3039	1.2971	1.2760	1.2477	1.2187	1.1893	1.1599
	45.00	1.3105	1.3038	1.2833	1.2557	1.2276	1.1991	1.1706
	50.00	1.3168	1.3102	1.2901	1.2633	1.2359	1.2082	1.1805
	55.00	1.3229	1.3164	1.2969	1.2705	1.2438	1.2168	1.1899
	60.00	1.3286	1.3224	1.3031	1.2773	1.2513	1.2250	1.1989

	65.00	1.3342	1.3281	1.3092	1.2840	1.2584	1.2327	1.2072
	70.00	1.3396	1.3334	1.3151	1.2902	1.2653	1.2401	1.2152
	80.00	1.3500	1.3440	1.3262	1.3022	1.2781	1.2540	1.2300
	90.00	1.3596	1.3539	1.3365	1.3134	1.2901	1.2667	1.2436
	100.00	1.3686	1.3632	1.3462	1.3237	1.3012	1.2786	1.2563
	110.00	1.3775	1.3719	1.3555	1.3337	1.3117	1.2898	1.2680
	120.00	1.3857	1.3805	1.3643	1.3429	1.3216	1.3001	1.2790
	130.00	1.3936	1.3884	1.3727	1.3518	1.3310	1.3100	1.2894
	140.00	1.4011	1.3961	1.3806	1.3603	1.3398	1.3188	1.2993
0.6053	0.10	1.2869	1.2770	1.2465	1.2034			
	1.00	1.2892	1.2794	1.2493	1.2067	1.1610	1.1108	1.0547
	5.00	1.2986	1.2893	1.2606	1.2205	1.1781	1.1326	1.0838
	10.00	1.3096	1.3007	1.2734	1.2358	1.1965	1.1551	1.1117
	15.00	1.3196	1.3111	1.2850	1.2493	1.2124	1.1739	1.1343
	20.00	1.3289	1.3207	1.2957	1.2615	1.2266	1.1900	1.1535
	25.00	1.3376	1.3297	1.3055	1.2728	1.2393	1.2048	1.1702
	30.00	1.3459	1.3381	1.3149	1.2832	1.2510	1.2181	1.1851
	35.00	1.3537	1.3462	1.3235	1.2928	1.2619	1.2302	1.1986
	40.00	1.3611	1.3538	1.3316	1.3019	1.2717	1.2412	1.2110
	45.00	1.3680	1.3610	1.3395	1.3105	1.2813	1.2517	1.2224
	50.00	1.3748	1.3678	1.3468	1.3186	1.2902	1.2615	1.2331
	55.00	1.3813	1.3745	1.3539	1.3263	1.2986	1.2707	1.2430
	60.00	1.3875	1.3809	1.3606	1.3336	1.3066	1.2794	1.2526
	65.00	1.3934	1.3870	1.3672	1.3407	1.3142	1.2876	1.2614
	70.00	1.3992	1.3927	1.3734	1.3475	1.3216	1.2955	1.2699
	80.00	1.4102	1.4040	1.3853	1.3602	1.3351	1.3101	1.2856
	90.00	1.4205	1.4144	1.3962	1.3721	1.3479	1.3237	1.3000
	100.00	1.4301	1.4244	1.4066	1.3831	1.3597	1.3363	1.3133
	110.00	1.4395	1.4336	1.4165	1.3935	1.3709	1.3481	1.3258
	120.00	1.4482	1.4427	1.4257	1.4034	1.3813	1.3592	1.3375
	130.00	1.4567	1.4512	1.4347	1.4129	1.3912	1.3696	1.3484
	140.00	1.4645	1.4593	1.4431	1.4218	1.4006	1.3795	1.3588
0.6777	0.10	1.3188	1.3086	1.2768	1.2322			
	1.00	1.3212	1.3110	1.2797	1.2358	1.1886	1.1369	1.0794
	5.00	1.3311	1.3215	1.2917	1.2503	1.2066	1.1599	1.1102
	10.00	1.3426	1.3334	1.3052	1.2663	1.2259	1.1836	1.1395
	15.00	1.3531	1.3443	1.3173	1.2805	1.2426	1.2033	1.1631
	20.00	1.3628	1.3543	1.3284	1.2932	1.2574	1.2203	1.1831
	25.00	1.3719	1.3637	1.3388	1.3050	1.2708	1.2356	1.2006
	30.00	1.3805	1.3725	1.3485	1.3159	1.2830	1.2495	1.2161
	35.00	1.3887	1.3810	1.3575	1.3259	1.2943	1.2622	1.2302
	40.00	1.3963	1.3888	1.3659	1.3354	1.3046	1.2736	1.2430
	45.00	1.4036	1.3963	1.3741	1.3445	1.3146	1.2845	1.2548
	50.00	1.4106	1.4034	1.3817	1.3528	1.3237	1.2947	1.2659

	55.00	1.4174	1.4103	1.3892	1.3608	1.3325	1.3041	1.2762
	60.00	1.4238	1.4170	1.3961	1.3685	1.3408	1.3132	1.2860
	65.00	1.4300	1.4233	1.4029	1.3759	1.3487	1.3217	1.2952
	70.00	1.4360	1.4293	1.4094	1.3828	1.3564	1.3299	1.3040
	80.00	1.4474	1.4409	1.4217	1.3960	1.3704	1.3452	1.3202
	90.00	1.4580	1.4518	1.4331	1.4083	1.3837	1.3591	1.3352
	100.00	1.4681	1.4622	1.4438	1.4197	1.3960	1.3722	1.3490
	110.00	1.4777	1.4717	1.4541	1.4306	1.4074	1.3844	1.3618
	120.00	1.4868	1.4811	1.4636	1.4408	1.4183	1.3958	1.3739
	130.00	1.4955	1.4899	1.4729	1.4506	1.4286	1.4066	1.3852
	140.00	1.5037	1.4983	1.4816	1.4599	1.4382	1.4169	1.3960
0.8526	0.10	1.3851	1.3737	1.3404	1.2931			
	1.00	1.3877	1.3764	1.3436	1.2970	1.2476	1.1940	1.1355
	5.00	1.3986	1.3879	1.3567	1.3130	1.2675	1.2195	1.1691
	10.00	1.4112	1.4009	1.3714	1.3307	1.2886	1.2453	1.2008
	15.00	1.4226	1.4127	1.3848	1.3462	1.3069	1.2668	1.2264
	20.00	1.4331	1.4236	1.3969	1.3600	1.3230	1.2850	1.2478
	25.00	1.4430	1.4338	1.4080	1.3728	1.3374	1.3016	1.2665
	30.00	1.4524	1.4434	1.4186	1.3846	1.3506	1.3166	1.2830
	35.00	1.4612	1.4524	1.4284	1.3954	1.3629	1.3302	1.2981
	40.00	1.4694	1.4609	1.4375	1.4057	1.3739	1.3424	1.3118
	45.00	1.4773	1.4690	1.4463	1.4154	1.3846	1.3541	1.3244
	50.00	1.4849	1.4767	1.4546	1.4244	1.3946	1.3649	1.3362
	55.00	1.4922	1.4842	1.4625	1.4330	1.4039	1.3752	1.3472
	60.00	1.4990	1.4913	1.4700	1.4413	1.4128	1.3849	1.3577
	65.00	1.5057	1.4981	1.4773	1.4491	1.4213	1.3939	1.3674
	70.00	1.5121	1.5045	1.4843	1.4566	1.4295	1.4027	1.3767
	80.00	1.5244	1.5170	1.4975	1.4708	1.4446	1.4189	1.3941
	90.00	1.5359	1.5286	1.5098	1.4840	1.4587	1.4338	1.4098
	100.00	1.5465	1.5397	1.5212	1.4962	1.4717	1.4477	1.4245
	110.00	1.5569	1.5499	1.5322	1.5078	1.4841	1.4607	1.4381
	120.00	1.5666	1.5601	1.5425	1.5187	1.4956	1.4729	1.4510
	130.00	1.5759	1.5693	1.5523	1.5292	1.5065	1.4844	1.4629
	140.00	1.5847	1.5784	1.5617	1.5391	1.5169	1.4953	1.4743
1.0000	0.10	1.4339	1.4228	1.3884	1.3407			
	1.00	1.4366	1.4256	1.3918	1.3448	1.2952	1.2421	1.1839
	5.00	1.4482	1.4377	1.4056	1.3616	1.3161	1.2684	1.2183
	10.00	1.4613	1.4515	1.4211	1.3801	1.3381	1.2951	1.2508
	15.00	1.4734	1.4639	1.4351	1.3963	1.3571	1.3173	1.2770
	20.00	1.4845	1.4754	1.4478	1.4108	1.3739	1.3362	1.2991
	25.00	1.4948	1.4862	1.4595	1.4242	1.3889	1.3533	1.3183
	30.00	1.5047	1.4961	1.4706	1.4364	1.4026	1.3688	1.3354
	35.00	1.5139	1.5057	1.4808	1.4478	1.4153	1.3829	1.3509
	40.00	1.5225	1.5145	1.4903	1.4585	1.4268	1.3956	1.3651

45.00	1.5308	1.5230	1.4995	1.4686	1.4379	1.4077	1.3781
50.00	1.5387	1.5311	1.5081	1.4780	1.4482	1.4188	1.3902
55.00	1.5463	1.5388	1.5164	1.4870	1.4579	1.4294	1.4016
60.00	1.5535	1.5463	1.5243	1.4955	1.4672	1.4395	1.4124
65.00	1.5605	1.5534	1.5319	1.5037	1.4759	1.4489	1.4225
70.00	1.5672	1.5602	1.5392	1.5115	1.4845	1.4579	1.4321
80.00	1.5800	1.5732	1.5529	1.5263	1.5002	1.4747	1.4500
90.00	1.5919	1.5854	1.5657	1.5400	1.5148	1.4902	1.4662
100.00	1.6031	1.5969	1.5776	1.5527	1.5283	1.5045	1.4815
110.00	1.6139	1.6076	1.5890	1.5647	1.5411	1.5179	1.4955
120.00	1.6240	1.6180	1.5997	1.5760	1.5530	1.5305	1.5087
130.00	1.6337	1.6278	1.6100	1.5868	1.5643	1.5423	1.5211
140.00	1.6428	1.6372	1.6197	1.5972	1.5751	1.5537	1.5321

[a] Composition of HFE-7200, with its corresponding uncertainty, was given in Table 1.

[b] Estimated expanded uncertainties (k = 2) are: temperature, $U(T)$ = ± 0.03 K; pressure, $U(p)$ = ±0.04 MPa; mole fraction, $U(x)$ = $\pm 5 \cdot 10^{-4}$; density, $U(\rho)$ = ±0.7 kg·m^{-3}.

Table 3. Parameters and deviations for density correlation by using the Tamman-Tait equation for the mixture *x* HFE-7200[a] + (*1*-*x*) 2-propanol.

Parameters	*x*							
	0.0000	0.1520	0.3275	0.5019	0.6053	0.6777	0.8526	1.0000
A_0 / g·cm^{-3}	1.238217	1.590277	1.921285	2.163775	2.232172	2.262014	2.184386	2.222441
A_1 / g·cm^{-3} K^{-1}	$-3.279986\cdot10^{-3}$	$-4.287405\cdot10^{-3}$	$-5.470008\cdot10^{-3}$	$-6.360817\cdot10^{-3}$	$-6.344043\cdot10^{-3}$	$-6.197039\cdot10^{-3}$	$-4.623221\cdot10^{-3}$	$-4.364889\cdot10^{-3}$
A_2 / g·cm^{-3} K^{-2}	$9.436122\cdot10^{-6}$	$1.196245\cdot10^{-5}$	$1.498874\cdot10^{-5}$	$1.729270\cdot10^{-5}$	$1.699920\cdot10^{-5}$	$1.632308\cdot10^{-5}$	$1.099809\cdot10^{-5}$	$9.763048\cdot10^{-6}$
A^3 / g·cm^{-3} K^{-3}	$-1.198655\cdot10^{-8}$	$-1.533770\cdot10^{-8}$	$-1.902113\cdot10^{-8}$	$-2.181810\cdot10^{-8}$	$-2.167670\cdot10^{-8}$	$-2.099945\cdot10^{-8}$	$-1.544841\cdot10^{-8}$	$-1.380877\cdot10^{-8}$
B_0 / MPa	309.7820	314.6991	306.3666	296.5245	293.2964	292.0680	286.8810	276.3470
B_1 / MPa K^{-1}	-0.978167	-1.165526	-1.213514	-1.211458	-1.215491	-1.220966	-1.215997	-1.168877
B_2 / MPa K^{-2}	$6.718266\cdot10^{-4}$	$1.051842\cdot10^{-3}$	$1.194813\cdot10^{-3}$	$1.236862\cdot10^{-3}$	$1.262329\cdot10^{-3}$	$1.281457\cdot10^{-3}$	$1.299226\cdot10^{-3}$	$1.248849\cdot10^{-3}$
C	0.08744809	0.08685676	0.08656384	0.08636395	0.08624520	0.08620237	0.08597850	0.08572617
AAD[b] / (%)	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01
MD[c] / (%)	0.04	0.04	0.06	0.08	0.09	0.09	0.10	0.10
Bias[d] / (%)	$5.52\cdot10^{-5}$	$2.09\cdot10^{-5}$	$1.32\cdot10^{-6}$	$-2.02\cdot10^{-5}$	$-5.67\cdot10^{-5}$	$1.89\cdot10^{-5}$	$-4.48\cdot10^{-5}$	$-4.59\cdot10^{-4}$
σ^e / (g·cm^{-3})	0.11	0.16	0.20	0.22	0.23	0.23	0.31	0.27
RMSD[f] / (g·cm^{-3})	0.11	0.16	0.20	0.22	0.22	0.23	0.30	0.26

[a] Composition of HFE-7200, with its corresponding uncertainty, was given in Table 1.

N is the number of experimental data points and *m* is the number of parameters.

[b] Absolute Average Deviation: $\mathrm{AAD} = \frac{100}{N}\sum_{i=1}^{N}\left|\frac{\rho_i^{exp}-\rho_i^{calc}}{\rho_i^{exp}}\right|$

[c] Maximum deviation: $\mathrm{MD} = \mathrm{Max}\left(100\left|\frac{\rho_i^{exp}-\rho_i^{calc}}{\rho_i^{exp}}\right|\right)$

[d] Average Deviation: $\mathrm{Bias} = \frac{100}{N}\sum_{i=1}^{N}\frac{\rho_i^{exp}-\rho_i^{calc}}{\rho_i^{exp}}$

[e] Standard Deviation: $\sigma = \sqrt{\frac{\sum_{i=1}^{N}(\rho_i^{exp}-\rho_i^{calc})^2}{N\text{-}m}}$

[f] Root Mean Square Deviation: $\mathrm{RMSD} = \sqrt{\frac{\sum_{i=1}^{N}(\rho_i^{exp}-\rho_i^{calc})^2}{N}}$

Table 4. Literature comparison between the values generated using the Tait-like equation at exactly the same experimental *p*, *T* sets given for HFE-7200[a] for several literature references.

Reference	Year	N_P	T_{min} / K	T_{max} / K	P_{min} / MPa	P_{max} / MPa	AAD / %	MD / %	Bias / %
At Atmospheric Pressure									
Warrier and Teja [4]	2011	2	297.80	298.20	0.1	0.1	0.44	0.47	-0.44
Rausch *et al.* [21]	2015	15	293.15	363.15	0.1	0.1	0.04	0.06	-0.04
Murata *et al.* [22]	2002	1	296.15	296.15	0.1	0.1	0.75	0.75	-0.75
At High Pressure									
Fang *et al.* [23 and 24]	2014 - 2015	126	293.33	362.72	0.10	100.00	0.13	0.38	-0.13
Piñeiro *et al.* [25]	2003	80	298.15	323.15	0.10	40.00	0.03	0.12	-0.02

[a] Composition of HFE-7200, with its corresponding uncertainty, was given in Table 1.
N_P Number of data points which are in our *p*, *T* ranges.

Table 5. Values of parameters z_i of equation (6) and the corresponding standard deviation, σ, for the binary system x HFE-7200[a] + (*1*-x) 2-propanol for all the temperatures measured T, at different pressures p.

	z_1	z_2	z_3	$\sigma (V^E)$/ $cm^3 \cdot mol^{-1}$
T / K		(p = 0.10 MPa)		
293.15	3.9066	0.2586	1.8454	0.01
298.15	4.2365	0.8903	2.7890	0.02
313.15	5.1291	1.3157	2.7740	0.04
333.15	6.6412	2.2488	3.6086	0.06
T / K		(p = 1.00 MPa)		
293.15	3.8644	0.2162	1.8120	0.01
298.15	4.1922	0.8662	2.7045	0.04
313.15	5.0660	1.2628	2.9083	0.04
333.15	6.5910	2.1445	3.6355	0.05
353.15	8.5969	3.3976	4.5572	0.06
373.15	11.6002	5.3423	5.7151	0.08
393.15	16.0255	8.0954	6.0922	0.12
T / K		(p = 70.00 MPa)		
293.15	2.6680	0.0000	1.6825	0.02
298.15	2.8787	0.2371	2.3223	0.01
313.15	3.4175	0.2678	2.2462	0.03
333.15	4.1804	0.5302	2.5789	0.03
353.15	5.0716	0.8184	2.7855	0.04
373.15	6.0799	1.0669	3.1775	0.06
393.15	7.1293	1.2353	3.4803	0.07
T / K		(p = 110.00 MPa)		
293.15	2.2786	0.0000	1.5878	0.02
298.15	2.4436	0.1205	2.2456	0.01
313.15	2.8939	0.1297	1.9117	0.02
333.15	3.4994	0.3855	2.3211	0.03
353.15	4.2129	0.5966	2.5047	0.04
373.15	4.9713	0.7401	2.8253	0.05
393.15	5.8006	0.9295	2.9419	0.06
T / K		(p = 140.00 MPa)		
293.15	2.0536	0.0000	1.4306	0.02
298.15	2.1714	0.0000	1.9986	0.01
313.15	2.5687	0.0000	1.5985	0.01
333.15	3.1085	0.0285	1.7880	0.01
353.15	3.7093	0.0983	1.9751	0.01
373.15	4.5080	0.1267	1.7365	0.02

	393.15	4.9025	0.0000	1.7151	0.01

[a] Composition of HFE-7200, with its corresponding uncertainty, was given in Table 1.

Table 6. Values of isothermal compressibility $\kappa_T \cdot 10^4$, for the system x HFE-7200[a] + (1-x) 2-propanol as function of pressure p, and at different temperatures T[b].

x	p / MPa	T / K						
		293.15	298.15	313.15	333.15	353.15	373.15	393.15
		$\kappa_T.10^4$ / MPa^{-1}						
0.0000	0.10	10.8	11.2	12.6	14.9			
	1.00	10.7	11.1	12.4	14.7	17.8	22.3	29.2
	5.00	10.2	10.6	11.8	13.9	16.6	20.4	26.0
	10.00	9.7	10.1	11.2	12.9	15.3	18.5	23.0
	15.00	9.3	9.6	10.5	12.1	14.2	16.9	20.6
	20.00	8.8	9.1	10.0	11.4	13.2	15.6	18.7
	25.00	8.5	8.7	9.5	10.8	12.4	14.4	17.1
	30.00	8.1	8.3	9.1	10.3	11.7	13.5	15.8
	35.00	7.8	8.0	8.7	9.8	11.0	12.6	14.7
	40.00	7.5	7.7	8.3	9.3	10.5	11.9	13.7
	45.00	7.2	7.4	8.0	8.9	10.0	11.3	12.9
	50.00	7.0	7.1	7.7	8.5	9.5	10.7	12.1
	55.00	6.7	6.9	7.4	8.2	9.1	10.2	11.5
	60.00	6.5	6.7	7.1	7.9	8.7	9.7	10.9
	65.00	6.3	6.5	6.9	7.6	8.4	9.3	10.4
	70.00	6.1	6.3	6.7	7.3	8.0	8.9	9.9
	80.00	5.8	5.9	6.3	6.8	7.5	8.2	9.1
	90.00	5.5	5.6	5.9	6.4	7.0	7.6	8.4
	100.00	5.2	5.3	5.6	6.0	6.5	7.1	7.8
	110.00	5.0	5.0	5.3	5.7	6.2	6.7	7.3
	120.00	4.7	4.8	5.1	5.4	5.8	6.3	6.8
	130.00	4.5	4.6	4.8	5.2	5.5	6.0	6.5
	140.00	4.3	4.4	4.6	4.9	5.3	5.7	6.1
0.1520	0.10	13.7	14.3	16.4	20.1			
	1.00	13.5	14.1	16.1	19.7	24.7	32.0	43.5
	5.00	12.8	13.3	15.1	18.2	22.4	28.2	36.8
	10.00	12.0	12.4	14.0	16.6	20.1	24.6	31.0
	15.00	11.3	11.7	13.1	15.3	18.2	21.9	26.8
	20.00	10.7	11.0	12.3	14.2	16.7	19.7	23.7
	25.00	10.1	10.4	11.5	13.3	15.4	18.0	21.3
	30.00	9.6	9.9	10.9	12.4	14.3	16.5	19.3
	35.00	9.2	9.4	10.3	11.7	13.4	15.3	17.7
	40.00	8.8	9.0	9.8	11.1	12.5	14.3	16.3
	45.00	8.4	8.6	9.4	10.5	11.8	13.3	15.1
	50.00	8.1	8.3	9.0	10.0	11.2	12.6	14.2
	55.00	7.8	8.0	8.6	9.5	10.6	11.9	13.3
	60.00	7.5	7.7	8.2	9.1	10.1	11.2	12.5
	65.00	7.2	7.4	7.9	8.7	9.6	10.7	11.9
	70.00	7.0	7.1	7.6	8.4	9.2	10.2	11.3

	80.00	6.5	6.7	7.1	7.8	8.5	9.3	10.2
	90.00	6.1	6.3	6.7	7.2	7.9	8.6	9.4
	100.00	5.8	5.9	6.3	6.8	7.3	8.0	8.7
	110.00	5.5	5.6	5.9	6.4	6.9	7.4	8.1
	120.00	5.2	5.3	5.6	6.0	6.5	7.0	7.5
	130.00	5.0	5.1	5.3	5.7	6.1	6.6	7.1
	140.00	4.8	4.8	5.1	5.4	5.8	6.2	6.7
0.3275	0.10	16.2	17.0	19.8	24.9			
	1.00	16.0	16.7	19.5	24.3	31.2	41.6	58.2
	5.00	15.0	15.6	18.0	22.1	27.6	35.4	46.9
	10.00	13.9	14.5	16.5	19.8	24.2	30.0	37.9
	15.00	12.9	13.5	15.2	18.0	21.5	26.1	31.9
	20.00	12.1	12.6	14.1	16.5	19.4	23.1	27.6
	25.00	11.4	11.8	13.1	15.2	17.7	20.7	24.4
	30.00	10.8	11.2	12.3	14.1	16.3	18.8	21.9
	35.00	10.2	10.6	11.6	13.2	15.1	17.3	19.8
	40.00	9.7	10.0	11.0	12.4	14.1	16.0	18.2
	45.00	9.3	9.6	10.4	11.7	13.2	14.8	16.8
	50.00	8.9	9.1	9.9	11.1	12.4	13.9	15.6
	55.00	8.5	8.7	9.5	10.5	11.7	13.0	14.6
	60.00	8.2	8.4	9.0	10.0	11.1	12.3	13.7
	65.00	7.9	8.1	8.7	9.6	10.5	11.7	12.9
	70.00	7.6	7.7	8.3	9.1	10.1	11.1	12.2
	80.00	7.1	7.2	7.7	8.4	9.2	10.1	11.0
	90.00	6.6	6.7	7.2	7.8	8.5	9.2	10.1
	100.00	6.2	6.3	6.7	7.3	7.9	8.5	9.3
	110.00	5.9	6.0	6.3	6.8	7.4	8.0	8.6
	120.00	5.6	5.7	6.0	6.4	6.9	7.4	8.0
	130.00	5.3	5.4	5.7	6.1	6.5	7.0	7.5
	140.00	5.0	5.1	5.4	5.8	6.2	6.6	7.1
0.5019	0.10	18.1	19.0	22.4	28.5			
	1.00	17.8	18.7	21.9	27.7	36.2	49.0	70.0
	5.00	16.5	17.3	20.1	24.9	31.4	40.7	54.3
	10.00	15.2	15.9	18.2	22.0	27.0	33.7	42.6
	15.00	14.1	14.7	16.6	19.8	23.8	28.8	35.2
	20.00	13.2	13.7	15.3	18.0	21.2	25.2	30.1
	25.00	12.3	12.8	14.2	16.5	19.2	22.5	26.3
	30.00	11.6	12.0	13.3	15.2	17.6	20.3	23.4
	35.00	11.0	11.3	12.5	14.2	16.2	18.5	21.2
	40.00	10.4	10.7	11.7	13.3	15.0	17.0	19.3
	45.00	9.9	10.2	11.1	12.5	14.0	15.8	17.7
	50.00	9.4	9.7	10.5	11.8	13.1	14.7	16.4
	55.00	9.0	9.2	10.0	11.1	12.4	13.8	15.3
	60.00	8.6	8.8	9.5	10.6	11.7	13.0	14.4

	65.00	8.3	8.5	9.1	10.1	11.1	12.2	13.5
	70.00	8.0	8.1	8.7	9.6	10.6	11.6	12.8
	80.00	7.4	7.6	8.1	8.8	9.6	10.5	11.5
	90.00	6.9	7.0	7.5	8.2	8.9	9.6	10.5
	100.00	6.5	6.6	7.0	7.6	8.2	8.9	9.6
	110.00	6.1	6.2	6.6	7.1	7.7	8.3	8.9
	120.00	5.8	5.9	6.2	6.7	7.2	7.7	8.3
	130.00	5.5	5.6	5.9	6.3	6.7	7.2	7.8
	140.00	5.2	5.3	5.6	6.0	6.4	6.8	7.3
0.6053	0.10	18.9	20.0	23.6	30.2			
	1.00	18.6	19.6	23.1	29.4	38.5	52.5	75.3
	5.00	17.2	18.1	21.0	26.1	33.2	43.1	57.4
	10.00	15.8	16.5	19.0	23.0	28.3	35.3	44.5
	15.00	14.6	15.2	17.3	20.6	24.8	30.0	36.5
	20.00	13.6	14.1	15.9	18.6	22.0	26.1	31.1
	25.00	12.7	13.2	14.7	17.1	19.9	23.2	27.1
	30.00	11.9	12.4	13.7	15.7	18.1	20.9	24.0
	35.00	11.3	11.6	12.8	14.6	16.7	19.0	21.7
	40.00	10.7	11.0	12.0	13.6	15.4	17.4	19.7
	45.00	10.1	10.4	11.4	12.8	14.4	16.1	18.1
	50.00	9.7	9.9	10.8	12.0	13.5	15.0	16.8
	55.00	9.2	9.5	10.2	11.4	12.7	14.1	15.6
	60.00	8.8	9.0	9.8	10.8	12.0	13.2	14.6
	65.00	8.5	8.7	9.3	10.3	11.3	12.5	13.7
	70.00	8.1	8.3	8.9	9.8	10.8	11.8	13.0
	80.00	7.5	7.7	8.2	9.0	9.8	10.7	11.7
	90.00	7.0	7.2	7.6	8.3	9.0	9.8	10.6
	100.00	6.6	6.7	7.1	7.7	8.3	9.0	9.8
	110.00	6.2	6.3	6.7	7.2	7.8	8.4	9.0
	120.00	5.9	6.0	6.3	6.8	7.3	7.8	8.4
	130.00	5.6	5.7	6.0	6.4	6.8	7.3	7.9
	140.00	5.3	5.4	5.7	6.0	6.5	6.9	7.4
0.6777	0.10	19.4	20.5	24.3	31.2			
	1.00	19.1	20.1	23.7	30.3	39.9	54.5	78.1
	5.00	17.7	18.5	21.6	26.9	34.2	44.4	59.0
	10.00	16.2	16.9	19.4	23.6	29.1	36.2	45.5
	15.00	14.9	15.5	17.6	21.1	25.3	30.7	37.2
	20.00	13.9	14.4	16.2	19.0	22.5	26.6	31.6
	25.00	12.9	13.4	15.0	17.4	20.2	23.6	27.5
	30.00	12.1	12.6	13.9	16.0	18.4	21.2	24.4
	35.00	11.4	11.8	13.0	14.8	16.9	19.3	21.9
	40.00	10.8	11.2	12.2	13.8	15.6	17.7	19.9
	45.00	10.3	10.6	11.5	13.0	14.6	16.3	18.3
	50.00	9.8	10.1	10.9	12.2	13.6	15.2	16.9

	55.00	9.3	9.6	10.4	11.5	12.8	14.2	15.8
	60.00	8.9	9.2	9.9	10.9	12.1	13.4	14.7
	65.00	8.6	8.8	9.4	10.4	11.5	12.6	13.9
	70.00	8.2	8.4	9.0	9.9	10.9	11.9	13.1
	80.00	7.6	7.8	8.3	9.1	9.9	10.8	11.8
	90.00	7.1	7.2	7.7	8.4	9.1	9.9	10.7
	100.00	6.7	6.8	7.2	7.8	8.4	9.1	9.8
	110.00	6.3	6.4	6.7	7.3	7.8	8.4	9.1
	120.00	5.9	6.0	6.4	6.8	7.3	7.9	8.5
	130.00	5.6	5.7	6.0	6.4	6.9	7.4	7.9
	140.00	5.3	5.4	5.7	6.1	6.5	7.0	7.5
0.8526	0.10	20.4	21.5	25.6	33.0			
	1.00	20.0	21.1	25.0	32.0	42.1	57.5	81.5
	5.00	18.4	19.4	22.6	28.2	35.8	46.3	60.9
	10.00	16.8	17.6	20.2	24.6	30.2	37.5	46.6
	15.00	15.5	16.1	18.3	21.8	26.2	31.6	37.9
	20.00	14.3	14.9	16.7	19.7	23.2	27.3	32.1
	25.00	13.4	13.8	15.4	17.9	20.8	24.1	27.9
	30.00	12.5	12.9	14.3	16.4	18.9	21.6	24.7
	35.00	11.8	12.1	13.4	15.2	17.3	19.6	22.2
	40.00	11.1	11.5	12.5	14.2	16.0	18.0	20.1
	45.00	10.5	10.8	11.8	13.3	14.9	16.6	18.5
	50.00	10.0	10.3	11.2	12.5	13.9	15.4	17.1
	55.00	9.5	9.8	10.6	11.8	13.0	14.4	15.9
	60.00	9.1	9.3	10.1	11.1	12.3	13.5	14.9
	65.00	8.7	8.9	9.6	10.6	11.6	12.8	14.0
	70.00	8.4	8.6	9.2	10.1	11.1	12.1	13.2
	80.00	7.8	7.9	8.5	9.2	10.0	10.9	11.9
	90.00	7.2	7.4	7.8	8.5	9.2	10.0	10.8
	100.00	6.8	6.9	7.3	7.9	8.5	9.2	9.9
	110.00	6.4	6.5	6.8	7.4	7.9	8.5	9.2
	120.00	6.0	6.1	6.4	6.9	7.4	8.0	8.5
	130.00	5.7	5.8	6.1	6.5	7.0	7.5	8.0
	140.00	5.4	5.5	5.8	6.2	6.6	7.0	7.5
1.0000	0.10	20.9	22.0	26.1	33.4			
	1.00	20.4	21.5	25.4	32.4	42.4	57.2	79.7
	5.00	18.8	19.7	23.0	28.5	36.0	46.1	59.8
	10.00	17.1	17.9	20.5	24.8	30.3	37.3	45.9
	15.00	15.7	16.4	18.5	22.0	26.3	31.4	37.5
	20.00	14.5	15.1	16.9	19.8	23.2	27.2	31.7
	25.00	13.5	14.0	15.6	18.0	20.8	24.0	27.6
	30.00	12.7	13.1	14.5	16.5	18.9	21.5	24.4
	35.00	11.9	12.3	13.5	15.3	17.3	19.6	22.0
	40.00	11.2	11.6	12.6	14.2	16.0	17.9	20.0

45.00	10.6	10.9	11.9	13.3	14.9	16.5	18.3
50.00	10.1	10.4	11.2	12.5	13.9	15.4	16.9
55.00	9.6	9.9	10.7	11.8	13.0	14.4	15.8
60.00	9.2	9.4	10.1	11.2	12.3	13.5	14.7
65.00	8.8	9.0	9.7	10.6	11.6	12.7	13.9
70.00	8.4	8.6	9.2	10.1	11.0	12.0	13.1
80.00	7.8	8.0	8.5	9.2	10.0	10.9	11.8
90.00	7.3	7.4	7.9	8.5	9.2	9.9	10.7
100.00	6.8	6.9	7.3	7.9	8.5	9.2	9.8
110.00	6.4	6.5	6.9	7.4	7.9	8.5	9.1
120.00	6.0	6.1	6.5	6.9	7.4	7.9	8.5
130.00	5.7	5.8	6.1	6.5	7.0	7.4	7.9
140.00	5.4	5.5	5.8	6.2	6.6	7.0	7.5

[a] Composition of HFE-7200, with its corresponding uncertainty, was given in Table 1.
[b] Estimated expanded uncertainty (k=2): temperature $U(T)$ = ±0.03 K, pressure $U(p)$ = ±0.04 MPa, isothermal compressibility $U(\kappa_T)$ = ±0.001 κ_T.

Table 7. Values of isobaric expansion $\alpha_P \cdot 10^4$, for the binary mixture x HFE-7200[a] + (1-x) 2-propanol as function of pressure p, and at different temperatures T[b].

x	p / MPa	T / K						
		293.15	298.15	313.15	333.15	353.15	373.15	393.15
				$\alpha_P.10^4$ / K^{-1}				
0.0000	0.10	9.90	10.33	11.66	13.53			
	1.00	9.78	10.20	11.51	13.36	15.35	17.52	19.91
	5.00	9.51	9.89	11.06	12.72	14.49	16.42	18.52
	10.00	9.44	9.77	10.79	12.22	13.76	15.42	17.22
	15.00	9.18	9.48	10.40	11.70	13.09	14.58	16.19
	20.00	8.99	9.26	10.09	11.25	12.50	13.83	15.26
	25.00	8.77	9.02	9.78	10.86	12.00	13.22	14.53
	30.00	8.54	8.77	9.49	10.49	11.55	12.68	13.89
	35.00	8.37	8.58	9.25	10.19	11.18	12.23	13.35
	40.00	8.26	8.46	9.06	9.91	10.81	11.76	12.77
	45.00	8.08	8.27	8.85	9.65	10.51	11.41	12.36
	50.00	7.92	8.10	8.65	9.41	10.22	11.07	11.98
	55.00	7.84	8.00	8.51	9.21	9.94	10.72	11.55
	60.00	7.73	7.88	8.36	9.01	9.70	10.43	11.20
	65.00	7.55	7.70	8.17	8.81	9.49	10.21	10.97
	70.00	7.43	7.57	8.01	8.63	9.28	9.95	10.67
	80.00	7.20	7.33	7.74	8.30	8.89	9.50	10.15
	90.00	6.98	7.10	7.48	8.01	8.56	9.13	9.74
	100.00	6.84	6.95	7.29	7.77	8.26	8.78	9.32
	110.00	6.67	6.77	7.09	7.52	7.97	8.45	8.94
	120.00	6.51	6.60	6.91	7.32	7.75	8.20	8.67
	130.00	6.32	6.41	6.70	7.10	7.52	7.95	8.40
	140.00	6.21	6.30	6.57	6.94	7.33	7.73	8.15
0.1520	0.10	11.95	12.40	13.81	15.82			
	1.00	11.74	12.18	13.56	15.53	17.67	20.03	22.66
	5.00	11.02	11.43	12.73	14.56	16.55	18.73	21.14
	10.00	10.30	10.69	11.90	13.62	15.47	17.48	19.69
	15.00	9.71	10.09	11.23	12.85	14.59	16.48	18.55
	20.00	9.27	9.63	10.74	12.30	13.97	15.77	17.74
	25.00	8.79	9.13	10.18	11.67	13.25	14.96	16.81
	30.00	8.50	8.83	9.87	11.32	12.87	14.54	16.34
	35.00	8.07	8.39	9.38	10.77	12.25	13.83	15.54
	40.00	7.83	8.15	9.13	10.49	11.94	13.49	15.17
	45.00	7.51	7.82	8.77	10.09	11.49	12.99	14.59
	50.00	7.26	7.56	8.49	9.79	11.16	12.62	14.19
	55.00	7.21	7.51	8.45	9.76	11.14	12.61	14.19
	60.00	6.86	7.16	8.07	9.34	10.68	12.11	13.63
	65.00	6.65	6.94	7.84	9.07	10.38	11.76	13.24
	70.00	6.42	6.71	7.59	8.81	10.10	11.46	12.91

	80.00	6.12	6.40	7.25	8.44	9.69	11.00	12.40
	90.00	5.80	6.08	6.93	8.10	9.32	10.62	11.99
	100.00	5.54	5.81	6.64	7.79	9.00	10.26	11.61
	110.00	5.30	5.57	6.39	7.53	8.71	9.96	11.28
	120.00	5.09	5.36	6.18	7.30	8.47	9.70	11.00
	130.00	4.90	5.16	5.97	7.08	8.24	9.45	10.74
	140.00	4.71	4.97	5.77	6.87	8.01	9.21	10.48
0.3275	0.10	14.29	14.67	15.87	17.58			
	1.00	14.15	14.53	15.71	17.41	19.26	21.32	23.62
	5.00	13.22	13.57	14.65	16.20	17.90	19.76	21.82
	10.00	12.53	12.86	13.87	15.32	16.89	18.61	20.51
	15.00	11.93	12.24	13.20	14.56	16.04	17.64	19.40
	20.00	11.41	11.70	12.61	13.90	15.29	16.80	18.45
	25.00	10.93	11.21	12.08	13.30	14.62	16.04	17.59
	30.00	10.50	10.77	11.59	12.76	14.01	15.36	16.82
	35.00	10.10	10.36	11.15	12.26	13.45	14.73	16.12
	40.00	9.74	9.99	10.74	11.81	12.95	14.17	15.49
	45.00	9.39	9.63	10.36	11.38	12.47	13.64	14.89
	50.00	9.07	9.30	10.00	10.98	12.03	13.14	14.34
	55.00	8.83	9.05	9.73	10.68	11.69	12.77	13.93
	60.00	8.48	8.69	9.35	10.26	11.22	12.25	13.34
	65.00	8.21	8.41	9.04	9.92	10.85	11.84	12.89
	70.00	7.95	8.15	8.76	9.60	10.50	11.45	12.46
	80.00	7.46	7.65	8.22	9.01	9.85	10.73	11.66
	90.00	7.07	7.25	7.79	8.54	9.32	10.15	11.03
	100.00	6.81	6.98	7.50	8.22	8.97	9.76	10.60
	110.00	6.59	6.75	7.25	7.95	8.67	9.44	10.24
	120.00	6.38	6.54	7.02	7.70	8.40	9.13	9.91
	130.00	6.19	6.35	6.82	7.47	8.15	8.86	9.61
	140.00	6.02	6.17	6.63	7.26	7.92	8.61	9.33
0.5019	0.10	14.81	15.20	16.40	18.13			
	1.00	13.86	14.36	15.91	18.15	20.63	23.39	26.52
	5.00	13.56	13.93	15.09	16.76	18.58	20.59	22.82
	10.00	13.04	13.32	14.20	15.46	16.82	18.30	19.93
	15.00	12.57	12.79	13.48	14.45	15.51	16.64	17.88
	20.00	12.11	12.29	12.85	13.65	14.50	15.42	16.42
	25.00	11.66	11.82	12.30	12.97	13.69	14.46	15.29
	30.00	11.19	11.33	11.77	12.39	13.04	13.75	14.50
	35.00	10.76	10.89	11.29	11.86	12.46	13.10	13.78
	40.00	10.40	10.52	10.89	11.42	11.98	12.57	13.20
	45.00	10.06	10.18	10.53	11.02	11.54	12.09	12.68
	50.00	9.77	9.88	10.21	10.67	11.16	11.68	12.23
	55.00	9.70	9.81	10.15	10.63	11.14	11.68	12.24
	60.00	9.24	9.34	9.64	10.06	10.50	10.96	11.45

	65.00	9.04	9.13	9.42	9.83	10.26	10.71	11.18
	70.00	8.80	8.89	9.16	9.55	9.95	10.37	10.82
	80.00	8.42	8.50	8.76	9.12	9.50	9.90	10.31
	90.00	8.08	8.16	8.41	8.75	9.10	9.48	9.87
	100.00	7.77	7.85	8.08	8.41	8.74	9.10	9.47
	110.00	7.50	7.58	7.80	8.12	8.44	8.79	9.14
	120.00	7.27	7.34	7.56	7.86	8.18	8.51	8.86
	130.00	7.04	7.11	7.33	7.62	7.93	8.26	8.59
	140.00	6.84	6.91	7.13	7.42	7.73	8.04	8.38
0.6053	0.10	15.04	15.45	16.74	18.59			
	1.00	14.24	14.73	16.28	18.51	20.98	23.73	26.86
	5.00	13.90	14.26	15.39	17.00	18.77	20.73	22.90
	10.00	13.08	13.41	14.46	15.95	17.58	19.36	21.33
	15.00	12.39	12.70	13.68	15.07	16.58	18.23	20.04
	20.00	12.05	12.28	12.99	13.99	15.08	16.25	17.52
	25.00	11.51	11.73	12.39	13.32	14.33	15.41	16.58
	30.00	11.03	11.23	11.85	12.72	13.65	14.65	15.74
	35.00	10.59	10.77	11.36	12.17	13.04	13.98	14.98
	40.00	10.18	10.36	10.91	11.67	12.49	13.36	14.30
	45.00	9.80	9.97	10.49	11.21	11.97	12.79	13.66
	50.00	9.45	9.61	10.10	10.78	11.50	12.26	13.07
	55.00	9.22	9.38	9.85	10.51	11.20	11.94	12.72
	60.00	8.85	8.99	9.43	10.04	10.69	11.38	12.11
	65.00	8.55	8.69	9.11	9.69	10.30	10.94	11.63
	70.00	8.32	8.45	8.85	9.41	10.00	10.62	11.28
	80.00	7.94	8.07	8.45	8.99	9.55	10.14	10.77
	90.00	7.60	7.72	8.09	8.61	9.14	9.71	10.31
	100.00	7.30	7.42	7.78	8.28	8.80	9.34	9.92
	110.00	7.03	7.15	7.50	7.98	8.49	9.02	9.58
	120.00	6.79	6.90	7.24	7.72	8.21	8.73	9.28
	130.00	6.57	6.68	7.02	7.49	7.98	8.50	9.03
	140.00	6.39	6.50	6.83	7.30	7.78	8.28	8.81
0.6777	0.10	14.88	15.38	16.97	19.26			
	1.00	14.46	14.94	16.47	18.67	21.10	23.82	26.91
	5.00	14.13	14.47	15.56	17.12	18.82	20.70	22.80
	10.00	13.54	13.79	14.58	15.69	16.90	18.22	19.67
	15.00	12.98	13.17	13.77	14.61	15.52	16.51	17.58
	20.00	12.47	12.62	13.09	13.75	14.46	15.22	16.03
	25.00	11.99	12.12	12.50	13.03	13.60	14.21	14.86
	30.00	11.56	11.66	11.98	12.43	12.90	13.41	13.94
	35.00	11.22	11.30	11.56	11.92	12.30	12.70	13.12
	40.00	10.88	10.96	11.17	11.47	11.79	12.12	12.47
	45.00	10.51	10.57	10.78	11.06	11.36	11.67	11.99
	50.00	10.25	10.31	10.47	10.70	10.94	11.19	11.45

	55.00	10.23	10.28	10.45	10.68	10.92	11.17	11.43
	60.00	9.76	9.80	9.93	10.10	10.27	10.46	10.65
	65.00	9.52	9.56	9.67	9.83	9.99	10.16	10.33
	70.00	9.30	9.34	9.44	9.58	9.72	9.87	10.02
	80.00	8.94	8.97	9.04	9.15	9.25	9.36	9.48
	90.00	8.60	8.62	8.68	8.77	8.85	8.94	9.03
	100.00	8.32	8.34	8.38	8.44	8.50	8.56	8.62
	110.00	8.04	8.05	8.09	8.14	8.20	8.25	8.30
	120.00	7.82	7.83	7.86	7.89	7.92	7.95	7.98
	130.00	7.59	7.59	7.62	7.65	7.68	7.71	7.75
	140.00	7.39	7.40	7.41	7.43	7.45	7.47	7.49
0.8526	0.10	15.48	15.88	17.11	18.90			
	1.00	14.85	15.29	16.67	18.66	20.87	23.32	26.09
	5.00	14.44	14.74	15.68	17.03	18.50	20.12	21.92
	10.00	13.78	13.99	14.64	15.56	16.55	17.63	18.81
	15.00	13.14	13.30	13.77	14.43	15.15	15.91	16.74
	20.00	12.60	12.71	13.06	13.56	14.09	14.65	15.25
	25.00	12.10	12.19	12.46	12.83	13.23	13.65	14.09
	30.00	11.64	11.71	11.93	12.23	12.54	12.87	13.22
	35.00	11.25	11.30	11.47	11.70	11.94	12.19	12.45
	40.00	10.92	10.96	11.08	11.26	11.43	11.62	11.81
	45.00	10.55	10.58	10.69	10.84	11.00	11.16	11.33
	50.00	10.26	10.29	10.37	10.49	10.61	10.73	10.85
	55.00	10.55	10.55	10.55	10.53	10.52	10.49	10.46
	60.00	9.75	9.76	9.81	9.87	9.93	9.99	10.05
	65.00	9.52	9.53	9.57	9.61	9.66	9.70	9.75
	70.00	9.27	9.28	9.31	9.36	9.40	9.44	9.48
	80.00	8.92	8.92	8.93	8.93	8.94	8.94	8.94
	90.00	8.55	8.55	8.56	8.56	8.56	8.56	8.55
	100.00	8.27	8.26	8.25	8.23	8.21	8.18	8.15
	110.00	7.97	7.97	7.96	7.94	7.91	7.89	7.86
	120.00	7.78	7.77	7.73	7.69	7.64	7.59	7.53
	130.00	7.52	7.51	7.49	7.45	7.41	7.37	7.32
	140.00	7.31	7.30	7.28	7.24	7.20	7.15	7.10
1.0000	0.10	15.42	15.75	16.79	18.28			
	1.00	10.55	11.33	13.74	17.19	20.99	25.27	30.17
	5.00	9.01	9.76	12.10	15.41	19.04	23.07	27.65
	10.00	8.14	8.83	10.93	13.90	17.11	20.66	24.63
	15.00	7.30	7.95	9.95	12.77	15.81	19.13	22.82
	20.00	6.63	7.26	9.20	11.91	14.81	17.97	21.46
	25.00	6.11	6.72	8.59	11.20	13.98	17.00	20.32
	30.00	5.62	6.22	8.06	10.61	13.33	16.26	19.48
	35.00	5.22	5.81	7.61	10.11	12.75	15.60	18.72
	40.00	4.87	5.45	7.22	9.67	12.26	15.04	18.07

45.00	4.57	5.14	6.88	9.29	11.83	14.56	17.52
50.00	4.29	4.85	6.57	8.95	11.45	14.12	17.02
55.00	4.25	4.82	6.55	8.93	11.44	14.13	17.04
60.00	3.81	4.36	6.05	8.36	10.80	13.39	16.19
65.00	3.61	4.16	5.82	8.12	10.53	13.09	15.84
70.00	3.41	3.96	5.61	7.89	10.27	12.80	15.52
80.00	3.07	3.61	5.24	7.48	9.81	12.29	14.95
90.00	2.78	3.31	4.93	7.14	9.44	11.88	14.49
100.00	2.51	3.04	4.64	6.82	9.10	11.50	14.06
110.00	2.28	2.80	4.39	6.56	8.81	11.18	13.71
120.00	2.07	2.59	4.17	6.32	8.55	10.89	13.39
130.00	1.88	2.40	3.97	6.10	8.31	10.64	13.11
140.00	1.73	2.25	3.81	5.93	8.13	10.44	12.90

[a] Composition of HFE-7200, with its corresponding uncertainty, was given in Table 1.
[b] Estimated expanded uncertainty (k=2): temperature $U(T)$ = ±0.03 K, pressure $U(p)$ = ±0.04 MPa, isobaric expansion $U(\alpha_P)$ = ±0.003 α_P.

Table 8. Experimental speeds of sound c, densities ρ, and calculated isentropic compressibilities κ_S, at different temperatures and at 0.1 MPa for the binary system x HFE-7200[a] + (1-x) 2-propanol[b].

T / K	x	c / m·s^{-1}	ρ / g·cm^{-3}	κ_S / TPa^{-1}
293.15	0.0000	1157.54	0.78546	950
	0.1517	931.61	0.97447	1182
	0.3270	802.01	1.12622	1380
	0.5016	729.80	1.23522	1520
	0.6055	700.59	1.28720	1583
	0.6762	684.39	1.31853	1619
	0.8505	654.40	1.38484	1686
	1.0000	637.83	1.43427	1714
298.15	0.0000	1139.71	0.78127	985
	0.1518	913.88	0.96845	1236
	0.3511	772.59	1.13518	1476
	0.4975	714.45	1.22380	1601
	0.6057	683.91	1.27742	1674
	0.6994	663.41	1.31768	1724
	0.8484	638.73	1.37317	1785
	1.0000	622.13	1.42306	1816
303.15	0.0000	1122.56	0.77700	1021
	0.1520	896.39	0.96232	1293
	0.3281	767.25	1.11099	1529
	0.5027	696.29	1.21713	1695
	0.6068	667.45	1.26787	1770
	0.6772	651.84	1.29814	1813
	0.8510	622.54	1.36284	1893
	1.0000	606.46	1.41162	1926
313.15	0.0000	1087.20	0.76821	1101
	0.1526	861.01	0.94996	1420
	0.3288	733.22	1.09477	1699
	0.5017	663.82	1.19732	1895
	0.606	635.32	1.24692	1987
	0.6757	620.05	1.27628	2038
	0.8498	591.35	1.33989	2134
	1.0000	575.75	1.38853	2173
323.15	0.0000	1051.78	0.75907	1191
	0.1518	827.09	0.93593	1562
	0.3268	700.69	1.07643	1892
	0.5036	630.75	1.17833	2133
	0.6054	603.51	1.22564	2240
	0.6776	588.19	1.25528	2303
	0.8492	560.51	1.31658	2418

	1.0000	545.46	1.36515	2462
333.15	0.0000	1015.29	0.74942	1294
	0.1501	794.18	0.92030	1723
	0.3275	667.60	1.05879	2119
	0.5007	599.56	1.15645	2406
	0.6047	572.22	1.20354	2538
	0.6738	557.64	1.23131	2612
	0.8499	529.89	1.29295	2755
	1.0000	515.64	1.34102	2805

[a] Composition of HFE-7200, with its corresponding uncertainty, was given in Table 1.
[b] Estimated expanded uncertainties ($k = 2$) are: temperature $U(T) = \pm 0.01$ K, $U(p_{0.1}) = 10^{-3}$ MPa, mole fraction, $U(x) = \pm 5 \cdot 10^{-4}$, speed of sound $U(c) = \pm 1$ m·s^{-1}, density $U(\rho) = \pm 9 \cdot 10^{-4}$ g·cm^{-3}, isentropic compressibility $U(\kappa_S) = \pm 0.50\ \kappa_S$.

Table 9. Literature comparison between the values generated using the Tait-like equation at exactly the same experimental *p*, *T* sets given for HFE-7200 for several literature references.

Reference	Year	N_P	T_{min} / K	T_{max} / K	AAD / %	MD / %	Bias / %
Dubey and Kaur [41]	2014	4	293.15	313.15	0.84	0.95	-0.84
Sastry *et al.* [42]	2014	3	303.15	323.15	0.50	1.33	-0.48
González *et al.* [43]	2013	2	298.15	313.15	0.09	0.11	-0.09
Singh *et al.* [44]	2013	3	298.15	313.15	0.08	0.10	0.08
Calvar *et al.* [45]	2012	2	293.15	323.15	0.02	0.02	0.02
Vercher *et al.* [46]	2011	1	298.15	298.15	0.14	0.14	0.14
González *et al.* [47]	2007	2	298.15	313.15	0.18	0.20	0.18
Pereiro and Rodríguez [48]	2007	3	293.15	303.15	0.11	0.14	0.11
Rodríguez *et al.* [49]	2001	4	293.15	313.15	0.09	0.13	0.09

N_P Number of data points which are in our *p*, *T* ranges.

> New density data for the mixture HFE-7200 + 2-propanol

> The pressure and temperature intervals are 0.10 – 140.00 MPa and 298.15 – 393.15 K

> 1264 data at 6 compositions were used to fit coefficients of a Tait-like equation

> Excess volumes have been calculated from the experimental data

> The isobaric expansivity and the isothermal compressibility have been derived