Experimental Study and Correlation Models of the Density and Viscosity of 1-Hexene and 1-Heptene at Temperatures from (298 to 473) K and Pressures up to 245 MPa

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Experimental Study and Correlation Models of the Density and Viscosity of 1-Hexene and 1-Heptene at Temperatures from (298 to 473) K and Pressures up to 245 MPa

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ABSTRACT: The density and viscosity of liquid 1-hexene and 1-heptene have been simultaneously measured over the temperature range from (298 to 473) K and pressures up to 245 MPa using the hydrostatic weighing and falling-body techniques, respectively. The combined expanded uncertainty of the density, pressure, temperature, and viscosity measurements at the 95 % confidence level with a coverage factor of $k = 2$ is estimated to be 0.15 % to 0.30 %, 0.05 %, 0.02 K, and 1.5 % to 2.0 % (depending on temperature and pressure ranges), respectively. The measured densities were used to develop a Tait-type equation of state for liquid 1-hexene and 1-heptene. Theoretically based Arrhenius–Andrade and Vogel–Tamman–Fulcher (VTF) type equations with pressure-dependent coefficients were used to represent the temperature and pressure dependences of the measured viscosities for liquid 1-hexene and 1-heptene. Also the friction theory (FT) viscosity model together with derived Tait-type equation of state (EOS) was used to accurately represent measured viscosity data. The measured values of the density and viscosity of 1-hexene and 1-heptene in the liquid phase were compared in detail with reported data and with the values calculated from correlations.
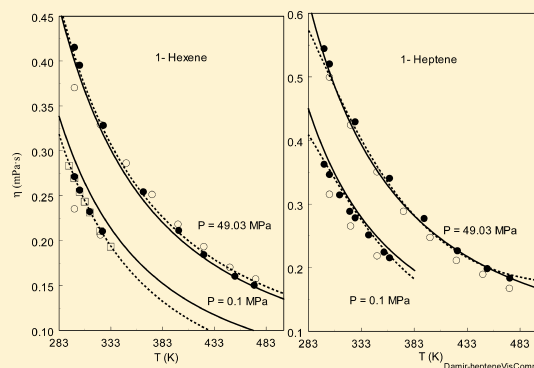
1. INTRODUCTION

As part of a continuing study[1−3] of the effect of pressure and temperature on the density and viscosity of unsaturated hydrocarbons, density and viscosity measurements have been made, using hydrostatic weighing and falling-body techniques, for 1-hexene and 1-heptene at high temperatures and at high pressures. In our previous publications[1−5] the detailed description of the construction of the measuring cell, procedure of measurements, and the uncertainty analyses have been given. The method and apparatus were successfully used for accurate measurements of the density and viscosity of n-heptane,[3] monoethylene glycol (MEG), diethylene glycol (DEG), triethylene glycol (TEG), and their binary (50 % MEG + 50 % DEG, 50 % MEG + 50 % TEG, 50 % DEG + 50 % TEG), and ternary (33.33 % MEG + 33.33 % DEG + 33.34 % TEG) mixtures at temperatures from (293 to 473) K and at pressures up to 245 MPa.[1,2] In this work the same apparatus to measure the density and viscosity of pure 1-hexene and 1-heptene at high temperatures from (298 to 473) K and high pressures (up to 245 MPa) have been used.

Accurate density and viscosity data of fluids is crucial for understanding many industrial and natural processes. In many applications these processes occur at high temperatures and high pressures. Thermodynamic and transport properties of 1-hexene and 1-heptene are needed in many industrial applications such as design calculation, heat and mass transfers equipment, chemical industry, fluid flow, developments and

utilization of energy, *etc*. For engineering utility, reliable methods for estimation of the thermodynamic and transport properties over wide ranges of temperature and pressure would be extremely valuable. However, the lack of reliable data over wide temperature and pressure ranges makes it necessary to estimate the missing properties by empirical and semiempirical methods. Therefore, new experimental data for thermodynamic and transport properties of 1-hexene and 1-heptene at high temperatures and high pressures are needed to improve and extend the range of validity of available estimation, correlation, and prediction methods. Unsaturated hydrocarbons (1-hexene and 1-heptene) are the main products of synthesis of various materials in the chemical and petrochemical industry. For maintenance of qualitative calculation methods in developing highly economical and energy-efficient technologies it is essential to have reliable data on thermodynamic and transport properties (density and viscosity). 1-Hexene and 1-heptene are industrially significant linear alpha olefins. There are a wide range of industrial applications for linear alpha olefins. 1-Hexene and 1-heptene are overwhelmingly used as co-monomers in the production of polyethylene. High density polyethylene (HDPE) and linear low density polyethylene (LLDPE) use approximately 2 % to 4 % and 8 % to 10 % of co-monomers, respectively. Currently the present

Table 1. Density Measurements of 1-Hexene and 1-Heptene

first author	year	method[a]	uncertainty % or g·cm⁻³	temp range K	pressure range MPa
			1-Hexene		
Landolt[7]	1892	NA	NA	287 to 293	0.101
Forziati[8]	1950	DB	$1\cdot10^{-4}$ g·cm⁻³	293, 298, 303	0.101
Camin[9]	1956	DB	$5\cdot10^{-5}$ g·cm⁻³	293, 298, 303	0.101
Wright[10]	1961	PYC	NA	293 to 313	0.101
Abas-zade[22]	1970	HW	0.1 %	283 to 533	up to 71
Apaev[6]	1971	HW	0.1 %	283 to 533	up to 70
Badalyan[23]	1971	SS	0.2 %	303 to 333	up to 120
Kerimov[11]	1972	HW	0.1 %	283 to 533	up to 70
Kireev[12]	1974	SS	NA	T_S	P_S
Letcher[13]	1974	PYC	NA	308, 323	0.101
Burkat[14]	1975	REF	NA	293, 298	up to 10
Guseinov[15]	1982	HW	0.3 %	146 to 293	up to 50
Galandarov[24]	1985	HW	0.3 %	146 to 293	up to 50
1Fomina[25]	986	HW	0.17 %	298 to 473	up to 245
Tojo[16]	1995	VTD	$1\cdot10^{-4}$ g·cm⁻³	298	0.101
Treszczanowicz[17]	2010	VTD	$2\cdot10^{-4}$ g·cm⁻³	298	0.101
Hasan[18]	2011	VTD	$1\cdot10^{-4}$ g·cm⁻³	298	0.101
This work	2013	HW	0.15 % to 0.30 %	298 to 473	0.098−245
			1-Heptene		
Halford[19]	1950	NA	NA	293 to 303	0.101
Badalyan[26]	1973	SS	0.2 %	303 to 353	up to 120
Galandarov[24]	1985	HW	0.3 %	167 to 293	up to 50
Kireev[12]	1974	SS	NA	T_S	P_S
Guseinov[20]	1981	HW	0.1 %	293 to 523	up to 50
Shakhverdiev[27]	1981	HW	0.1 %	293 to 523	up to 50
Fomina[25]	1986	HW	0.17 %	298 to 473	up to 245
Domanska[21]	1997	VTD	$2\cdot10^{-4}$ g·cm⁻³	298, 308	0.1
Treszczanowicz[17]	2010	VTD	$2\cdot10^{-4}$ g·cm⁻³	298	0.1
This work	2013	HW	0.15 % to 0.30 %	298 to 473	up to 245

[a]Notation: VTD, vibrating tube densimeter; PYC, pycnometer; HW, hydrostatic weighing; REF, from refractometry measurements; DB, density balance; SS, from speed of sound measurements.

experimental density and viscosity data are being used by the Russian Company "Nizhnekamenskneftexim" to produce 14 different types of LLDPE (PE5118Q) and HDPE. Another significant use of linear alpha olefins (1-hexene and 1-heptene) is for the production of linear aldehyde via the oxo synthesis (hydroformylation) for later production of a short-chain fatty acid, a carboxylic acid, by oxidation of an intermediate aldehyde, or linear alcohols for plasticizer application by hydrogenation of the aldehyde. The predominant application of 1-hexene is in the production of isoprene, methylisobutylcetone, and higher fatty alcohols, *etc*. 1-Hexene and 1-heptene also find their primary application as the hydrophobes in oil-soluble surfactants and as lubricating fluids themselves, used in making surfactants for aqueous detergent formulations, and as a catalyzer.

Accurate density (*PVT*) and viscosity measurements at high temperatures and high pressures are needed not only for industrial applications. High temperature and high pressure measurements of the thermodynamic and transport properties of fluids are the subject of scientific interest, for example, to develop accurate theoretical based models and predictive models, for deeply understanding the physical and chemical nature of the processes occurring in fluids at high temperatures and high pressures, and to develop the microscopic physical theory of the liquid state.

1.1. Brief Review of Reported Density and Viscosity Data for 1-Hexene and 1-Heptene. A literature survey

revealed that only limited density and viscosity data are currently available in the literature for 1-hexene and 1-heptene under pressure and at high temperature. Existing data cover only a limiting range of temperature and pressure, and contain large uncertainties and inconsistencies. Tables 1 and 2 summarize, to the best of our knowledge, the experimental measurements of the density[6−27] and viscosity[28−34] of liquid 1-hexene and 1-heptene reported in the literature. The literature search was based on the TRC/NIST archive.[35] These tables also included some missing data sources from local Russian publications and Ph.D. theses, which are not easily available for most readers. Over 26 sets for the density and 15 sets for the viscosity are included in the tables, representing about 806 density and 302 viscosity measurements in the liquid phase. However, the same experimental data, refs 6, 11,15, 20, 24, 27, 29, 32, and 33, were published twice for density and viscosity. There are only two viscosity data sources[24,32] for 1-heptene in the liquid phase. Only one source on the viscosity of gaseous 1-heptene was published by Lusternik.[34] There are some sources where the authors reported densities and other thermodynamic properties of liquid 1-hexene and 1-heptene derived from a speed of sound measurements at high pressures.[23,26] All of these density and viscosity data were used to compare with the present results. Most of these density data were measured using the VTD (vibrating tube densimeter) method[16,17] at atmospheric pressure (uncertainty is within 0.002 % to 0.04 %), pycnometric

Table 2. Viscosity Measurements of 1-Hexene and 1-Heptene

first author	year	method[a]	uncertainty %	temp range K	pressure range MPa
1-Hexene					
Wright[10]	1961	CT	NA	293 to 313	0.101
Naziev[33]	1972	FRB	3.0	291 to 373	up to 47
Guseinov[29]	1972	FRB	3.1	298 to 473	up to 50
Guseinov[30]	1977	FRB	3.1	298 to 473	up to 49
Naziev[31]	1976	FRB	3.1	303 to 473	up to 49
Naziev[32]	1977	FRB	3.1	298 to 473	up to 50
Shakhverdiev[27]	1981	FRB	2.3	298 to 473	up to 50
Guseinov[33]	1984	FRB	3.1	158 to 293	up to 50
Galandarov[24]	1985	FRB	3.1	158 to 293	up to 50
Fomina[25]	1986	FRB	1.16[b]	298 to 473	up to 245
1-Heptene					
Lusternik[34]	1973	CT	1 to 2	353 to 5760.1	0.101
Naziev[32]	1977	FRB	3.1	303 to 473	up to 50
Shakhverdiev[27]	1981	FRB	2.3	298 to 473	up to 50
Galandarov[24]	1985	FRB	3.1	173 to 293	up to 50
Fomina[25]	1986	FRB	1.16[b]	298 to 473	up to 245
This work	2013	FRB	1.5 to 2.0	298 to 473	up to 245

[a]Notation, FRB, falling or rolling body; CT, capillary tube. [b]The uncertainty was incorrectly estimated.

method[10,13] (basically at atmospheric pressure, uncertainty 0.05 % to 0.10 %), or the hydrostatic weighing technique[11,15,22] at high pressures (typical uncertainty is within 0.1 % to 0.3 %). Reported density data cover the temperature range from (146 to 533) K and pressures up to 70 MPa, while reported viscosity data cover the temperature range from (156 to 473) K and pressure range up to 50 MPa. Only in a few sources were the density[14,24,22] and viscosity[24,28,32,33] measurements performed under pressure (up to 70 and 50 MPa, respectively). For viscosity most reported data were measured using a falling-body technique (at high pressures, up to 50 MPa). The uncertainty for most reported density data is within 0.05 % (at low temperatures and low pressures, basically at atmospheric pressure) and 0.1 % to 0.3 % at high temperatures and high pressures, while the uncertainty of the reported viscosity data is within 2 % to 3 %. Most reported density data (see Table 1) were performed in the very limited temperature range, from (293 to 323) K, and at atmospheric pressure.[7−10,13,16−19,21] High-temperature, from (293 to 533) K, and high-pressure (up to 70 MPa) density measurements were performed in the works.[15,22,24] Also for viscosity of liquid 1-heptene one reported data source[10] was measured at atmospheric pressure and at temperatures between (293 and 313) K using the capillary tube method. Measurements in the works[29,30] were performed at temperatures from (298 to 473) K, while Guseinov[24,33] reported low temperature measurements of the viscosity (from mp to 293 K) and at pressures up to 50 MPa. For 1-heptene very restricted viscosity data are available in the literature. Only two viscosity data sources[24,32] for liquid 1-heptene (the same data also were published in the work[27]) are available in the literature. One of them performed at low temperatures (from mp to 293 K) and at pressures up to 50 MPa, and other one from (303 to 473) K and at pressures up to 50 MPa.

As one can see from Tables 1 and 2, previously the density and viscosity of 1-hexene and 1-heptene were measured by one of the authors of the present work (Fomina[25]) in a Ph.D. thesis in the same temperature and pressure ranges. The measurements were made using two separate apparatus for density (hydrostatic weighing) and viscosity (falling-body) measurements.

The values of density, ρ_{PT}, required for viscosity calculations (see below working eq 4 for viscosity) were taken from the separate density experiment. The measured density and viscosity data in the Ph.D. thesis[25] were not previously published in the peer-reviewed scientific journals. In the present work these density and viscosity data were critically and very carefully analyzed (the details of the calibration procedure, constructions of the measuring density and viscosity cells, uncertainty assessment, etc.). After comprehensive analysis of the density and viscosity data some accuracy and reliability problems were found. For example, the temperature dependencies of the density and viscosity data along the selected isobars reported in the Ph.D. thesis[25] shows very doubtful behavior ("zig-zag" shape) and large scattering of the measured data (reproducibility of the measurements was very low). The same behavior was also found for the pressure dependence behaviors of density and viscosity along the various isotherms. This is the result of the thermodynamic inconsistencies of the measured densities and viscosities. In the present work the quality and reliability of the previous measured by Fomina[25] density and viscosity data were improved. The details of the improvement we described in our previous publication.[1] At first both apparatus for density and viscosity measurements were combined into one (see detail in refs 1 to 3). The improvements included are as follows: the accuracy of the measurements (uncertainty assessment); reliability of the calibration procedure; temperature and pressure dependences of the different parts of the measuring cells (geometrical size of the viscometer and densimeter supply elements: falling-body and measuring tube, wires, bushes, volumes of the float, core, and buoy, etc.); rebuild some of the parts of the apparatus; improved electronic monitoring system and sensor to accurately determine the location of the core position; improved the theory of the methods and working equations were corrected. The combined and improved density and viscosity apparatus were used to check the accuracy and reliability of the previous measurements[25] for 1-hexene and 1-heptene. The results of the new measurements and their detailed numerical comparisons with the previous original

measurements[25] are presented in later sections (see sections 3.3 and 3.4). As will be shown, about 45 % of the data in the Ph.D. thesis by Fomina[25] was incorrect (69 % for 1-heptene, and 29 % for 1-hexene density data are incorrect).

Thus, the main aim of the present study was to comprehensively analyze the previous original experimental density and viscosity data by Fomina[25] and improve their accuracy and reliability by additional remeasuring of the selected suspicious experimental data points using the new improved experimental apparatus. These data considerably expand the existing density and viscosity database (see Tables 1 and 2) for 1-hexene and 1-heptene to higher temperatures, from (298 to 475) K, and pressures up to 245 MPa. In addition, the Tait-type EOS and theoretically based correlation models for the viscosity of 1-hexene and 1-heptene have been developed.

1.2. Equations of State and Correlation Models for the Viscosity of 1-Hexene and 1-Heptene. Unfortunately, no reference EOS and correlation models for viscosity of 1-hexene and 1-heptene were developed previously. Galandarov[24] developed an EOS and correlation model for viscosity of liquid 1-hexene and 1-heptene as

$$P = \rho^2 \sum_{i=0}^{5} a_i \left(\frac{T}{T_{bp}}\right)^i + \rho^8 \sum_{i=0}^{5} a_i \left(\frac{T}{T_{bp}}\right)^i \qquad (1)$$

This EOS reproduces the author's experimental pressures within 0.11 %. The correlation model for the viscosity of 1-hexene and 1-heptene developed by Galandarov[24] is

$$\eta = A(T) + B(T)N_C + \frac{1}{5}\left(\frac{P}{P_C}\right)[a(T) + b(T)N_C] \qquad (2)$$

where $A(T)$, $B(T)$, $a(T)$, and $b(T)$ are the polynomial-type functions of temperature; N_C is the number of carbon atoms in the hydrocarbon; P_C is the critical pressure. This viscosity model (eq 2) reproduced the author's experimental data within 3.6 %. Badalyan and Otpushennikov[23,26] used a quadratic equation to calculate the density of liquid 1-hexene and 1-heptene at high pressures

$$\rho = A(T) + B(T)(P - P_0) + D(T)(T)(P - P_0)^2 \qquad (3)$$

where $A(T)$, $B(T)$, and $D(T)$ are the temperature functions, P_0 = 1 atm. This equation is valid in the temperature range from (303 to 353) K (for 1-heptene) and from (303 to 333) K (for 1-hexene) at pressures up to 120 MPa.

2. EXPERIMENTAL SECTION

2.1. Viscosity Measurements. The experimental details (physical basis and the theory of the method, the apparatus, the procedure of the measurements, and the uncertainty assessment) of the viscosity measurements have been described in detail in our recent publications.[1−3] Basic geometric characteristics for five selected falling bodies are presented in Table 3.

Table 3. Basic Characteristics for Five Falling-Bodies

characteristics	1	2	3	4	5
d/mm	5.947	5.969	5.999	6.018	6.047
$k = d/D$	0.975	0.978	0.983	0.986	0.991
$m \cdot 10^3$/kg	2.0180	2.040	2.086	2.092	2.115

2.2. Working Equation for Viscosity. The working equation for viscosity measurement in this method (falling-body) at any experimental T and P conditions is[1−3]

$$\eta = \exp\{[-a_0 + \ln W_{PT} + (1 - a_2)\ln \delta_{PT} + a_2 \ln D_{PT}$$
$$+ (1 + a_1)\ln \rho_{PT} + a_1 \ln G_{PT}](1 + 2a_1)^{-1}\} \qquad (4)$$

where the values of calibrating parameters a_i (i = 0,2) were determined using the calibration procedure.[1−3] Following equations were used to calculate W_{PT}, δ_{PT}, D_{PT}, and G_{PT} in the equation (4) $\ln W_{PT} = \ln(l_{p_0}^c \Delta_{3T}) - \ln \tau_{pT}$, $\delta_{PT} = D_{p_0T_0}\Delta_{1T}\Delta_{1p} - d_{p_0T_0}\Delta_{2T}\Delta_{2p}$, $G_{pT} = V_{p_0T_0}^b\Delta_T\Delta_p(\rho_b - \rho_{pT})g$, where $l_{p_0T_0}^c$, $D_{p_0T_0}$, $d_{p_0T_0}$ are the geometric size of the wire (length), measuring tube (diameter), and falling body (diameter) at calibration temperature of T_0 = 293 K and pressure of p_0=0.098 MPa; $V_{p_0T_0}^b$ is the volume of body at calibration conditions which determined by weighing procedure in water and in the air; V_{pT}^b, ρ_b, τ_{pT} are the volume, density, and falling time of the body at experimental (p,T) conditions, respectively. The effect of temperature $(\Delta_{1T}, \Delta_{2T}, \Delta_{3T}, \Delta_T)$ and pressure $(\Delta_{1p}, \Delta_{2p}, \Delta_p)$ on the viscometer supply elements were taken account using following relations: (a). measuring tube, $\Delta_{1T} = 1 + \alpha_1(T - T_0)$ and $\Delta_{1p} = 1 - p(1 - \mu_1)/E_1$; (b) body, $\Delta_{2T} = 1 + \alpha_2(T - T_0)$, $\Delta_{2p} = 1 - p(1 - \mu_2)/E_2$, $\Delta_T = 1 + 3\alpha_2(T - T_0)$, and $\Delta_P = 1 - 3p(1 - \mu_2)/E_2$; (c) bush between transducers, $\Delta_{3T} = 1 + \alpha_3(T - T_0)$. In these relations α is the linear thermal expansion coefficient of the material as a function of temperature, μ is the Poisson coefficient, and E is the Young's modulus. Calibration of the viscometer was carried out using accurate viscosity measurements for various liquids[36−38] (n-pentane,[36] n-heptane,[36] n-decane,[37] and polymethylsiloxane-5[38]) with different viscosities from (0.3184 to 191.47) mPa·s. The derived values of the calibrating parameters are: a_0 = −5.1998; a_1 = −1.0154; and a_2 = 3.4439.

2.3. Density Measurements. Measurements of the density were performed using the hydrostatic weighing method with the same apparatus as for viscosity measurements described above (see also refs 1−3).

2.4. Working Equation for Density. The density $\rho_{p,T}$ of a sample at any experimental temperatures and pressures for this method can be obtained from the relation

$$\rho_{p,T} = \frac{m - m_3 - (m_2 - m_1) - \rho_{pT_0}^s(V_{pT}^c + 0.5V_{pT}^w)}{V_{pT}^f + 0.5V_{pT}^w} \qquad (5)$$

where m is the mass of the suspending system in vacuum; m_1 is the solenoid mass without the suspending system; m_2 is the solenoid mass with the suspending system; m_3 is the correction on magnetic properties of the surrounding media and elasticity of the lead wires of the solenoid and transducer; $\rho_{pT_0}^s$ is the density of the liquid under study in the solenoid zone at temperature T_0 = 298 K and experimental pressure; V_{pT}^c is the volume of the core at experimental temperatures and pressures; V_{pT}^w is the wire volume at experimental conditions; V_{pT}^f the float volume at the experimental temperatures and pressures; temperature T_0 = 298 K and pressure p_0 = 0.098 MPa.[1−3]

2.5. Uncertainty of the Measured Data. The combined expanded uncertainty, $u(Y)$, of density and viscosity (Y) is given by[39,40]

Table 4. Samples Purity Information

chemical name	source	initial mole fraction purity	purification fraction purity	final mole method	analysis method
1-hexene	Novocherkask	0.98		0.98	GC[a]
1-heptene	Novocherkask	0.98		0.98	GC[a]

[a]Gas–liquid chromatography.

$$u(Y)^2 = \sum_{i=1}^{N} \left(\frac{\partial Y}{\partial X_i} u(X_i) \right)^2$$

(6)

where N is the number of input parameters (see Table 3 in ref 1); $u(X_i)$ are the experimental uncertainties all of the measured quantities (X_i) ref 1 in the working eqs 4 and 5 including the T and P measurements. All input parameters and their experimental uncertainties used for uncertainty analysis were reported in our recent publications.[1−3] From the uncertainty analysis the combined expanded uncertainty of the density and viscosity measurements at a 95 % confidence level with a coverage factor of $k = 2$ is estimated

to be 0.15 % to 0.30 % and 1.5 % to 2.0 %, respectively, depending on temperature and pressure ranges. The sample temperature was measured with a platinum resistance thermometer (PRT-10). Pressure in the system was generated and measured with dead-weight pressure gauges MP-600 and MP-2500 with an uncertainty of 0.05 % (below 60 MPa) to 0.10 % (above 60 MPa).

The purity information of 1-hexene and 1-heptene samples used in this study is given in Table 4. The sample density ρ_4^{25} and refractive index n_D^{25} were checked before and after measurements. The sample purity provided by the supplier was > 98.00 mol % and was used without additional purification. The purity was checked by chromatographic analysis before and after measurements.

3. RESULTS AND DISCUSSION

3.1. Density. The measured densities at temperatures from (298 to 475) K and at pressures up to 245 MPa are given in Table 5 and shown in Figures 1 to 5 in the $\rho-T$ and $\rho-P$ projections together with reported data. Table 5 included also

Table 5. Experimental Densities (kg·m^{-3}), Viscosities (mPa·s), Pressures (MPa), and Temperatures (K) of 1-Hexene and 1-Heptene[a]

T	ρ	η	T	ρ	η	T	ρ	η	T	ρ	η
				1-Hexene						1-Heptene	
	P = 0.098 MPa			P = 24.51 MPa			P = 0.098 MPa			P = 24.51 MPa	
298.15	669.71	0.271	298.15	696.93	0.337	298.15	694.51	0.362	298.15	718.23	0.451
303.15	664.87	0.256	303.15	690.93	0.321	303.15	689.57	0.346	303.15	715.00	0.431
312.92	655.77	0.232	326.00	675.10	0.274	312.83	680.92	0.314	327.47	697.97	0.351
325.17	644.12	0.210	364.73	645.55	0.214	322.39	672.17	0.288	360.06	672.86	0.278
			398.43	618.11	0.170	327.49	668.07	0.278	392.79	646.48	0.226
			423.18	598.39	0.146	340.21	655.95	0.251	424.11	619.97	0.182
			452.77	575.45	0.124	354.73	643.50	0.224	452.35	595.84	0.160
			471.92	560.56	0.115	360.03	638.93	0.215	473.70	578.48	0.148
	P = 49.03 MPa			P = 98.06 MPa			P = 49.03 MPa			P = 98.06 MPa	
298.15	714.95	0.415	298.15	744.22	0.550	298.15	734.70	0.544	298.15	765.58	0.739
303.15	711.55	0.395	303.15	741.40	0.525	303.15	733.10	0.520	303.15	761.82	0.706
326.02	694.93	0.328	325.99	729.28	0.442	327.49	718.40	0.429	327.48	746.71	0.575
364.69	670.17	0.254	364.75	706.69	0.346	359.96	699.31	0.340	359.87	730.37	0.457
398.87	645.80	0.211	398.78	687.13	0.287	392.68	676.29	0.277	392.74	714.89	0.377
423.10	630.04	0.184	422.90	672.81	0.252	424.17	653.79	0.226	424.17	697.03	0.311
453.14	608.12	0.160	453.19	656.91	0.218	452.34	628.89	0.198	452.25	676.86	0.280
471.73	598.79	0.150	471.78	646.27	0.204	473.56	612.50	0.183	473.47	665.45	0.262
	P = 147.10 MPa			P = 196.13 MPa			P = 147.10 MPa			P = 196.13 MPa	
298.15	763.36	0.705	298.15	778.91	0.876	298.15	783.57	0.942	298.15	800.85	1.226
303.15	761.37	0.670	303.15	776.19	0.840	303.15	780.46	0.903	303.15	797.46	1.162
326.05	750.05	0.561	326.12	767.98	0.694	327.63	767.87	0.741	327.63	786.42	0.925
364.83	731.74	0.437	364.63	751.74	0.540	359.74	750.76	0.587	359.75	773.85	0.726
398.25	715.97	0.363	398.37	736.05	0.444	392.61	734.09	0.480	392.46	758.90	0.591
422.74	703.54	0.319	422.71	726.21	0.389	424.04	717.45	0.400	423.82	745.35	0.489
453.28	687.84	0.277	453.14	712.63	0.338	452.28	702.95	0.355	452.22	733.49	0.434
472.02	680.82	0.260	471.55	704.21	0.315	473.33	692.30	0.333	473.28	723.12	0.407
	P = 245.16 MPa						P = 245.16 MPa				
298.15	793.17	1.093				298.15	816.79	1.499			
303.15	791.19	1.034				303.15	815.30	1.429			
326.15	783.20	0.836				327.67	805.58	1.136			
364.25	767.68	0.628				359.63	791.61	0.883			
398.35	753.74	0.516				392.40	776.73	0.709			
422.37	743.17	0.456				424.07	760.78	0.574			
453.52	732.58	0.397				452.27	750.38	0.503			
471.64	725.42	0.371				473.35	737.15	0.470			

[a]Standard uncertainties u are $u(T) = 0.02$ K; $u(P) = 0.05$ %; $u(\rho) = 0.15$ % (at low pressures, $P < 100$ MPa) to 0.30 % (at high pressures, $P > 100$ MPa); $u(\eta) = 1.5$ % (at low pressures, $P < 100$ MPa) to 2.0 % (at high pressures, $P > 100$ MPa).
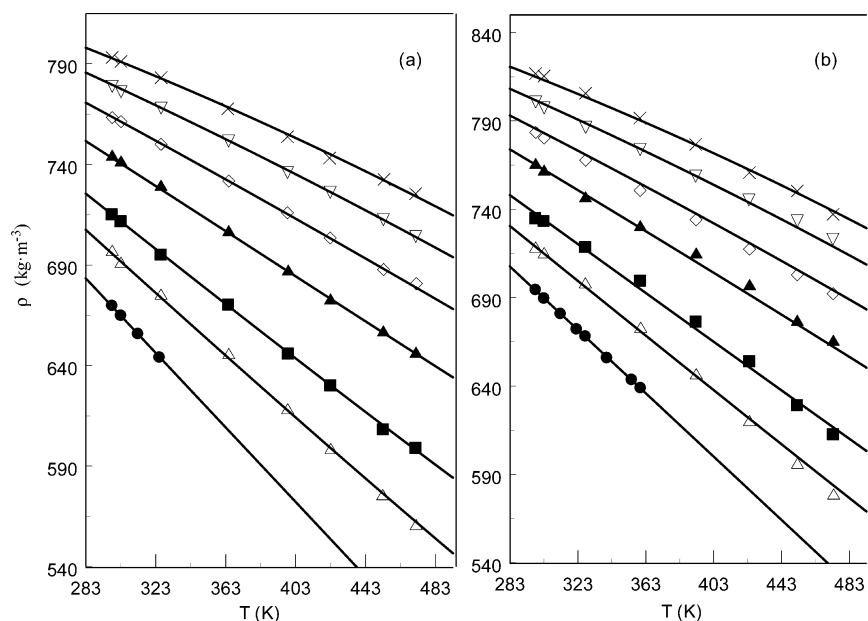
Figure 1. Measured densities of 1-hexene (a) and 1-heptene (b) as a function of temperature along the various isobars. Solid lines are calculated from the Tait equation of state (8): ●, 0.098 MPa K; △, 24.51 MPa; ■, 49.03 MPa; ▲, 98.06 MPa; ◇, 147.10 MPa; ▽, 196.13 MPa; ×, 245.16 MPa.
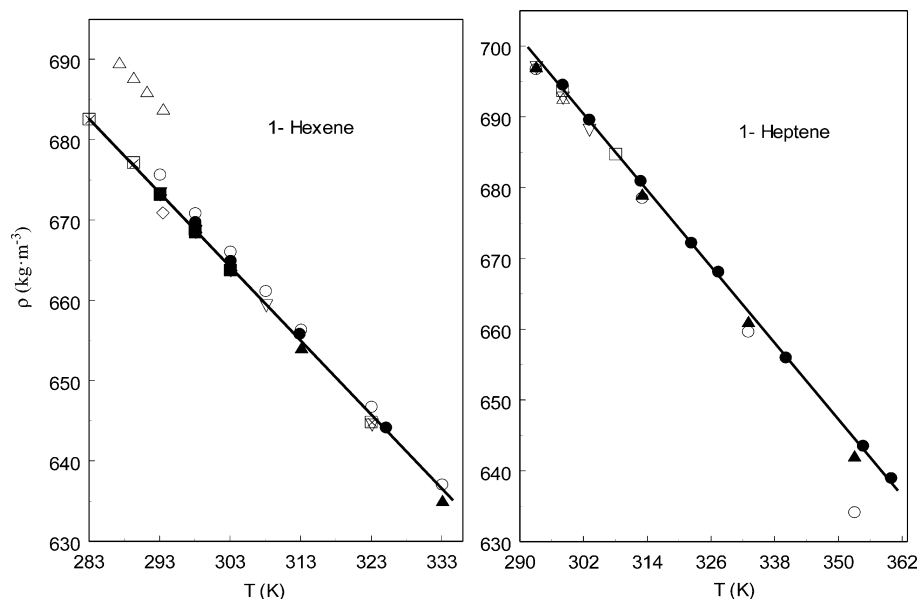

Figure 2. Measured densities of 1-hexene and 1-heptene as a function of temperature at atmospheric pressure together with literature data. Left: ●, this work; ○, Wright;[10] ▲, Kireev[12] (saturated liquid density); △, Landolt and Jahn;[7] □, Kerimov and Apaev;[11] ■, Forziati et al.;[8] ▽, Letcher and Marsicano;[13] ◇, Guseinov et al.;[15] ▼, Burkat and Richard;[14] ×, Abas-zade et al.;[22] ◆, Camin.[9] Right: ●, this work; △, Treszczanowicz et al.;[17] □, Domanska;[21] ○, Guseinov et al.; ▲, Kireev[12] (saturated liquid density); ▽, Halford.[19] Solid lines are calculated from eq 7

the original data from the Fomina[25] Ph.D. thesis and the present measured and corrected data. The present data for 1-hexene and 1-heptene extend the pressure range of measurements by other authors (see Tables 1 and 2), provide a set of densities over a wide range of experimental conditions, and can be used to develop accurate reference EOS. Figures 1 to 5 demonstrate the satisfactory consistency of the temperature and pressure dependences of the density of 1-hexene and 1-heptene measured in the present work and reported data,[7,8,10−14,17,19−27] except for the old data reported in 1892 by Landolt and Jahn.[7] Various isobars for 1-hexene and 1-heptene densities are plotted against temperature

in Figure 1. As one can see all measured isobars are almost linear functions of temperature. Figure 2 demonstrates temperature dependence of the present density data of 1-hexene and 1-heptene at atmospheric pressure together with all of the reported data from the literature (see Table 1). To accurately represent measured densities of 1-hexene and 1-heptene at atmospheric pressure, a simple linear function,

$$\rho_0(T) = a_0 + a_1 T^2 \tag{7}$$

was used, where a_i are the fitting parameters (see Table 6). Equation 7 reproduces the present density data for 1-hexene and

Table 6. Coefficients of the Tait EOS (eq 8) and Models (eq 9 and eq 13) for the Viscosity Derived from the Present Experimental Data

fluid	b_0	b_0	C_0	C_0	a_0	a_1
			Tait EOS (eq 8)			
1-hexene	93.689679	−0.120514	−0.055571	0.0005599	945.54111	−0.926295
1-heptene	97.968113	−0.111672	−0.043702	0.0005197	961.49134	−0.896652
			Viscosity (eq 9)			
1-hexene	−4.143141	0.012480	−0.0000305	865.810428	−1.682671	−0.007347
1-heptene	−3.980497	0.011094	−0.0000250	900.389043	−1.231054	0.005808
fluid	d_0	d_1	d_2	a_1	b_1	A_1
			Viscosity (eq 13)			
1-hexene	0.307330	−2.718805	9.049175	0.032871	0.026243	0.000460
1-heptene	0.991790	−8.968750	21.380824	0.012826	0.024045	−0.000597
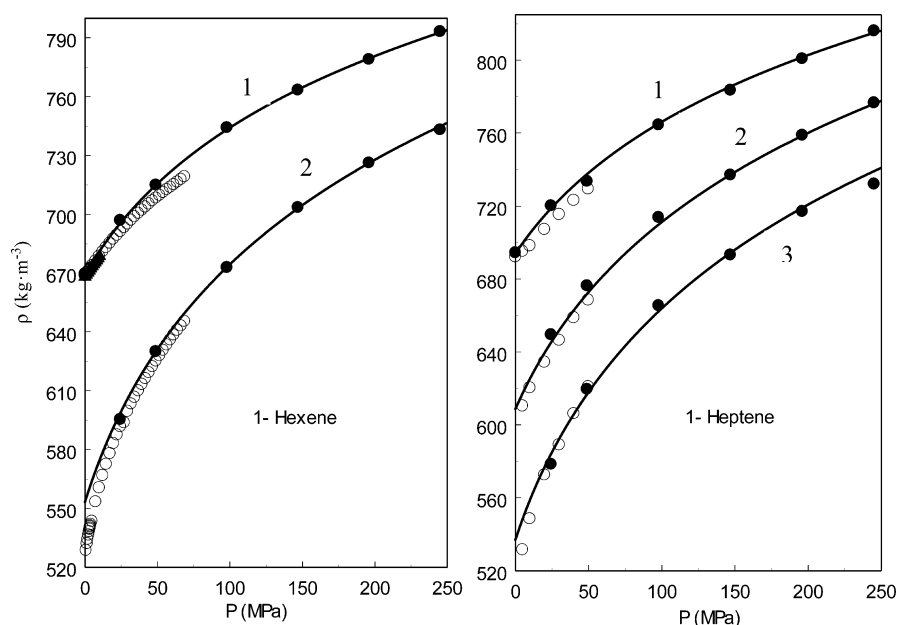
Figure 3. Measured densities of liquid 1-hexene and 1-heptene as a function of pressure along the selected isotherms together with literature data. Left: 1, 298.15 K; 2, 423.15 K; ●, this work; O, Kerimov and Apaev;[11] ▲, Burkat and Richard.[14] Right: 1, 298.15 K; 2, 393.15 K; 3, 473.15 K; ●, this work; O, Guseinov et al.[20] Solid lines are calculated from EOS (eq 8).

1-heptene at atmospheric pressure at any temperatures between (260 and 371) K within 0.03 %. The measured densities for 1-hexene and 1-heptene together with the reported data at high temperatures and high pressures are depicted in Figures 3 to 5. Isothermal densities over the pressure range of the present measurements are presented in Figure 3. As one can note, the experimental isotherms deviate considerably from linearity, especially at high temperatures and low pressures (up to 100 MPa) (close to a quadratic function). As Figure 4 illustrates, the temperature behavior (ρ−T) at high pressures is very close to the linear dependence. The present density measurements for 1-hexene and 1-heptene at high pressures were compared with the data reported by other authors (see Figures 2 to 5). Figure 5 shows the comparison between the present and reported data for the density of 1-hexene and the values calculated from correlation (eq 3) derived from the speed sound measurements.[23,26] The deviation plots for the present measured densities and previously reported density data[6−27] and the values calculated from the Tait EOS are given below (detailed discussion of agreement between the present results and various reported data sources is given below).

3.2. Viscosity. The experimental results for the viscosity of 1-hexene and 1-heptene are also presented in Table 5 and

shown in Figures 6 to 10 in η−P, η−T, and η−ρ projections together with reported data from refs 28−33. Viscosity measurements were made at constant pressure, between (0.098 and 245) MPa as a function of temperature from (298 to 473) K. All measured viscosity data as a function of temperature and density along the various isobars are presented in Figures 6 and 7. As one can see, the measured viscosities monotonically decrease as the temperature increases and sharply increase at high densities (above 675 kg·m^{-3}). The present viscosity results for 1-hexene and 1-heptene together with the reported data as a function of pressure along the various isotherms are depicted in Figure 8. Figure 9 includes the present results and all of the other reported viscosity data for 1-hexene and 1-heptene at various pressures as a function of temperature. The temperature coefficient of viscosity, $\eta^{-1}(\partial\eta/\partial T)_P$, strongly depends on temperature and pressure. The values of the temperature coefficient of viscosity increases as the pressure increases (see Figure 6). At high temperatures the values of $\eta^{-1}(\partial\eta/\partial T)_P$ show very small changes with temperature. The pressure dependence of measured viscosities is close to linear at high temperatures (see Figure 8), while at low temperatures, the rate of the pressure dependence (pressure
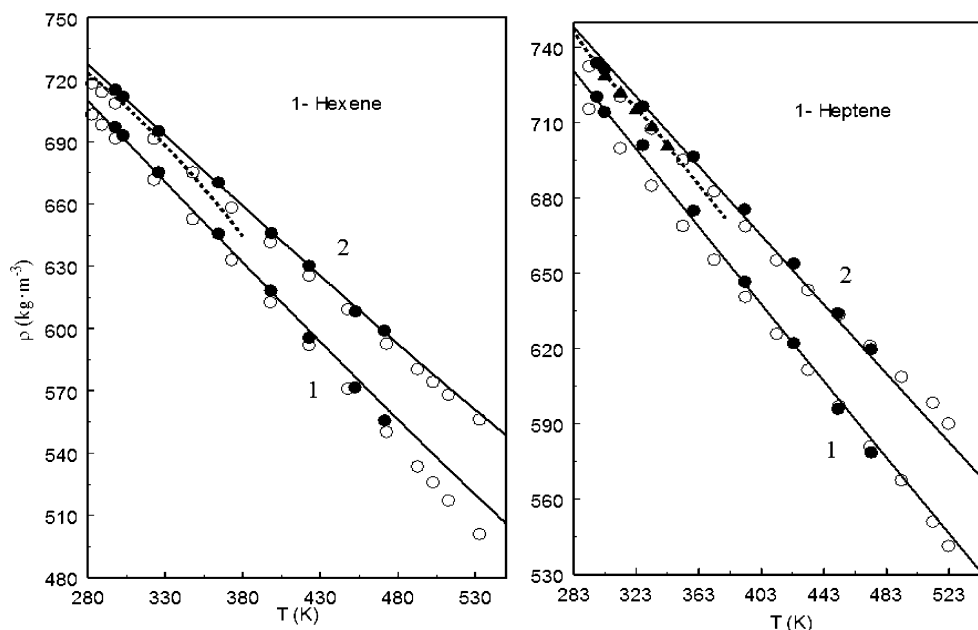
Figure 4. Measured densities of 1-hexene and 1-heptene as a function of temperature along the two selected isobars together with literature data. Left: ●, this work; ○, Kerimov and Apaev.[11] Right: ●, this work; ○, Guseinov et al.;[20] ▲, Badalyan and Otpushennikov[23] (from speed of sound measurements); 1, 24.51 MPa; 2, 49.03 K. Solid lines are calculated from EOS (eq 8); dashed line is calculated from correlation (eq 3) by Badalyan and Otpushennikov[23] (from speed of sound measurements).
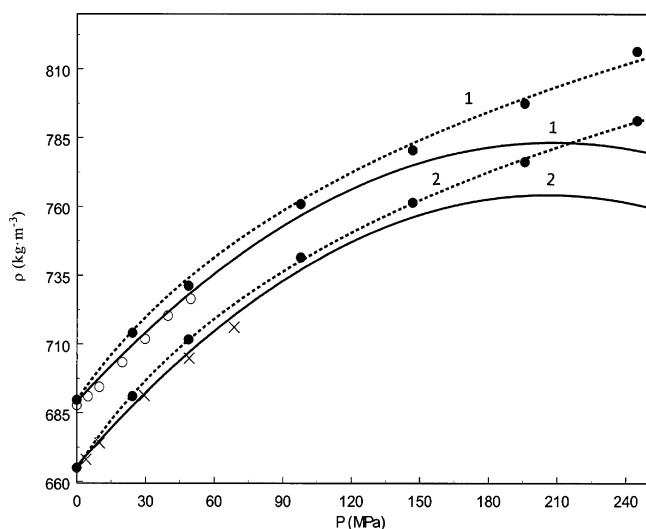

Figure 5. Measured densities of 1-hexene (1) and 1-heptene (2) as a function of pressure along the selected isotherm of 303.15 K together with literature and calculated values from speed of sound data: ●, this work; ○, Guseinov et al.[20] (1-heptene); ×, Abas-zade et al.[22] (1-hexene). Solid lines are calculated from the correlation (eq 3) using speed of sound measurements by Badalyan and Otpushennikov.[23] Dashed lines are calculated from Tait EOS (eq 8).

coefficient), $\eta^{-1}(\partial \eta/\partial P)_T$, increases considerably, especially at high pressures. The comparison between the present results for viscosities of 1-hexene and 1-heptene and reported data at selected isotherms and isobars are given in Figures 8 and 9. The present viscosity measurements for 1-hexene and 1-heptene were compared with the available data reported by other authors and the values calculated from the correlation models. The deviation plots between the present and reported data from the correlation models are presented below.

3.3. Tait-Type Equation of State for 1-Hexene and 1-Heptene. The Tait EOS gives an excellent correlation of high-pressure densities as a function of temperature in the liquid phase. The present measured densities for liquid 1-hexene and 1-heptene were used to develop an accurate simple Tait-type equation of state, which was applied previously for pure fluids and mixtures[1,2,41−63]

$$\frac{\rho - \rho_0}{\rho_0} = c \ln\left(\frac{B + P}{B + P_0}\right) \tag{8}$$

where Tait adjustable parameters $c(T)$ and $B(T)$ are functions of temperature only and can be calculated from the best fit of the isotherms, and ρ_0 is the density of liquid at a reference pressure P_0 ($P_0 = 0.098$ MPa) (see eq 7). Previously (Abdulagatov et al.[1,2,59−62]) a Tait-type EOS (eq 8) was successfully used to accurately represent the density measurements for pure alcohols (methanol, ethanol, 1-propanol), (MEG, DEG, TEG), n-heptane, ionic liquids [BMIM][BF$_4$] (1-butyl-3-methylimidazolium tetrafluoroborate), [BMIM][PF$_6$] (1-n-butyl-3-methylimidazolium hexafluorophospate), [BMIM$^+$][OcSO$_4^-$]1-butyl-3-methylimidazolium octylsulfate, and their binary mixtures (ethanol + [BMIM][BF$_4$], methanol + [BMIM][BF$_4$], methanol + [BMIM][PF$_6$], and methanol + [BMIM$^+$][OcSO$_4^-$]). The Tait-type EOS was also studied by many other researchers (see, for example, refs 41−59). This EOS was successfully applied for pure fluids and binary mixtures and recommended for use for accurate representation of experimental high-pressure density data in the liquid phase. The Tait eq 8 was applied to the present density measurements for liquid 1-hexene and 1-heptene. The explicit functional form of the temperature functions $B(T)$ and $c(T)$ in the Tait equation (eq 8) were created using "Eureqa"[64] (symbolic regression software). The optimal structure of the temperature functions $B(T)$ and $c(T)$ in eq 8 for our density measurements of 1-hexene and 1-heptene is $B = b_0 + b_1 T$ and $c = c_0 + c_1 T$; that is, both $B(T)$ and $c(T)$ are simple linear functions of temperature. The derived values of adjusting coefficients b_i and c_i from the present measured densities for 1-hexene and 1-heptene are given in Table 6. Zúñiga-Moreno
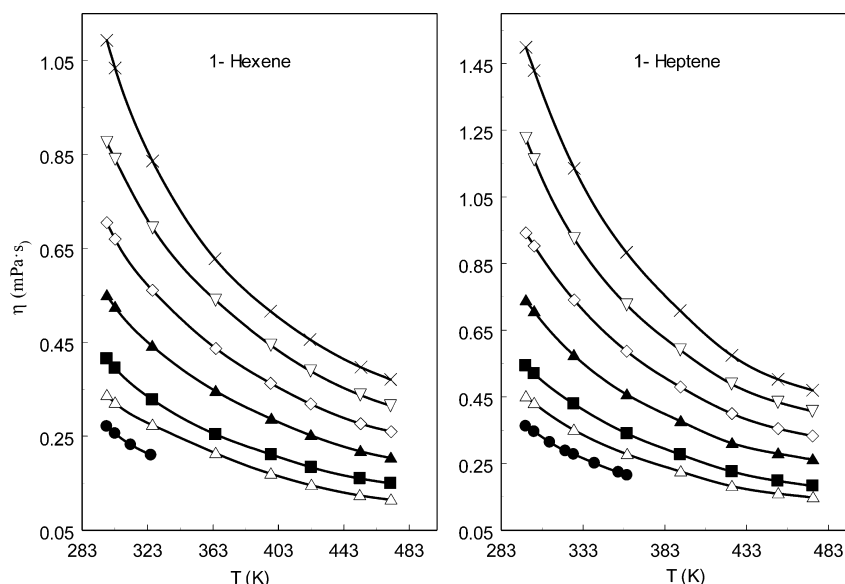
Figure 6. Measured viscosities of 1-hexene and 1-heptene as a function of temperature along the various isobars. Solid lines are smoothed values: ●, 0.098 MPa K; △, 24.51 MPa; ■, 49.03 MPa; ▲, 98.06 MPa; ◇, 147.10 MPa; ▽, 196.13 MPa; ×, 245.16 MPa.
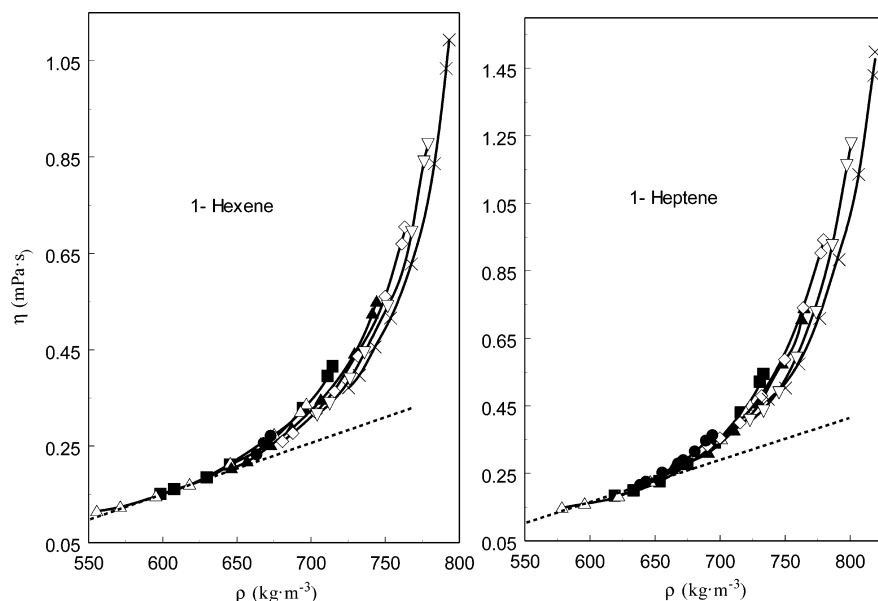

Figure 7. Measured viscosities of 1-hexene and 1-heptene as a function of density along the various isobars. ●, 0.098 MPa K; △, 24.51 MPa; ■, 49.03 MPa; ▲, 98.06 MPa; ◇, 147.10 MPa; ▽, 196.13 MPa; ×, 245.16 MPa. Dashed lines are the linear part of the $\eta-\rho$ dependence curves.

and Galicia-Luna[52] also found a linear temperature function for $B(T)$, although some other researchers[53,54] considered $B(T)$ as a quadratic function of temperature. Cibulka and Ziková[51] used a cubic temperature function for $B(T)$ and a linear temperature function for $c(T)$ to extend the validity of the Tait EOS for 1-propanol to 534 K. Tomida et al.[65] developed a Tait-type EOS for ionic liquids where $B(T)$ and $c(T)$ are independent of temperature (constants).

The present and reported data for density (see Table 1) of 1-hexene and 1-heptene were compared with the values calculated from the Tait EOS (eq 8). The deviation statistics between the measured and calculated results for 1-hexene and 1-heptene are given in Table 7. The average absolute deviations (AAD) between the measured values of density and those calculated from the Tait EOS (eq 8) for 1-hexene and 1-heptene are 0.10 % and 0.29 %, respectively, which are close

to their experimental uncertainty. Figure 11 shows the deviation plots between the present and reported density data from refs 6−27 and those calculated with eq 8 for 1-hexene and 1-heptene. The AAD for the reported data of 1-hexene and 1-heptene[6−27] are within 0.5 % to 0.6 %, respectively. Our results are basically systematically higher than the reported data.[6,11,12,15,20] Probably this is due to incorrect calibration of the measuring cell in the previous publications. In previous publications[6,11,12,15,20] the authors used very old and inaccurate data for calibrating fluids. The present density measurements for 1-hexene and 1-heptene are in satisfactory agreement with the data derived from the speed of sound measurements by Badalyan and Otpushennikov.[23,26] The deviation is within 0.35 % to 0.50 % (our results systematically higher).

The present measured and corrected density data for 1-hexene and 1-heptene (in total 71 data points, 69 % of the
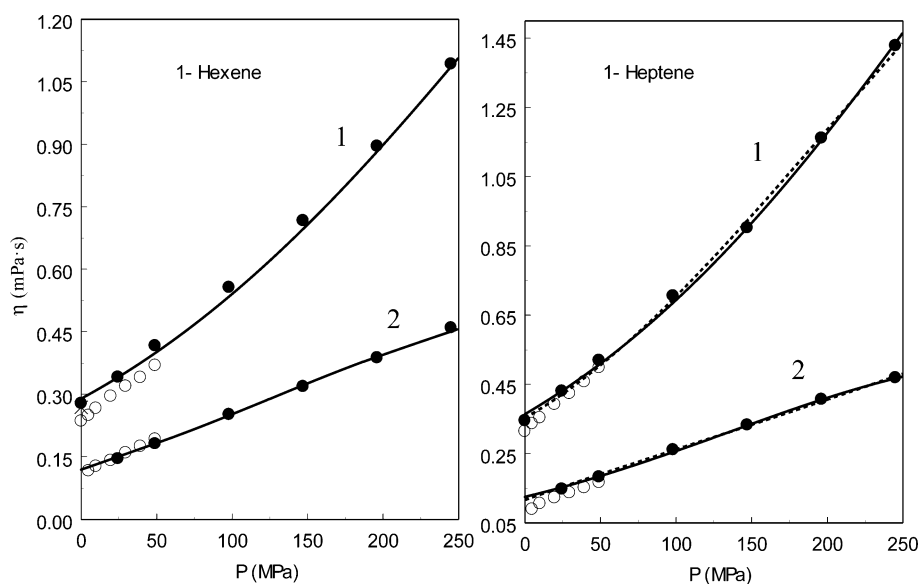
Figure 8. Measured viscosities of 1-hexene and 1-heptene as a function of pressure together with literature data along the selected isotherms. Solid lines are calculated from eq 9. Dashed lines are calculated from eq 13. 1-Hexene: 1, 298.15 K; 2, 423.15 K; ●, this work; ○, Naziev et al.[31] 1-Heptene: 1, 303.15 K; 2, 473.15 K; ●, this work; ○, Naziev et al.[32]
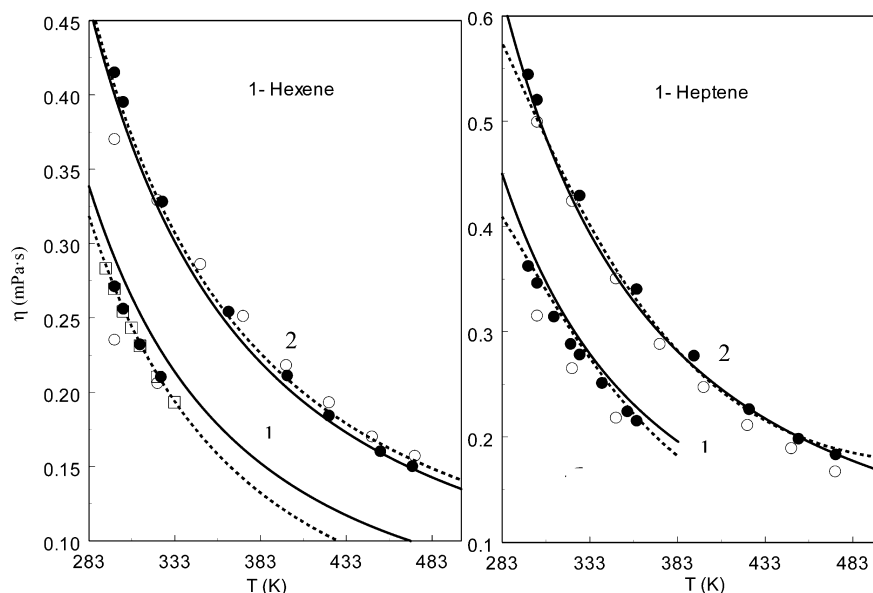

Figure 9. Measured viscosities for 1-hexene and 1-heptene as a function of temperature together with literature data along the selected isobars. Solid line is calculated from correlation model (eq 9). Left: ●, this work; ○, Naziev et al.;[28] □, Wright.[10] Right: ●, this work; ○, Naziev et al.;[32] 1, 49.03 MPa; 2, 0.101 MPa; Dashed lines are calculated from eq 13

original experimental data from Fomina[25] Ph.D. thesis) were detailed compared with the original data reported in the Ph.D. thesis by Fomina.[25] The results are presented in the deviation plot (see Figure 12). As one can see from Figure 12 there are large differences between the present and Fomina[25] density data, namely, the maximum deviations in density are reached to 0.77 % for 1-hexene and 1.06 % for 1-heptene, which are considerably higher than their experimental uncertainty. The standard deviations for 1-hexene and 1-heptene are 0.42 % and 0.55 %, respectively.

3.4. Viscosity Correlation. The best theoretically based model for temperature dependence of the viscosity is the well-known Arrhenius−Andrade type equation,[65−68]

$$\eta(T) = b_0 \exp\left(\frac{b_1}{T}\right) \quad \text{or} \quad \ln \eta(T) = \ln b_0 + \frac{b_1}{T} \tag{9}$$

$$\ln b_0 = a_0 + a_1 P + a_2 P^2 \quad \text{and} \quad b_1 = a_3 + a_4 P + a_5 P^2 \tag{10}$$

where b_0 is the viscosity, $\eta = \eta_\infty$ at the high temperature limit ($T \to \infty$), $b_1 = \varepsilon_a / R$, and $\varepsilon_a = \Delta H$ is the flow activation energy (enthalpy of activation), where T is in K and P in MPa. Equation 9 was theoretically confirmed by Eyring's absolute rate theory (Glasstone et al.[65]). This equation was successfully applied previously to represent experimental viscosity data for aqueous solutions[69−72] and ionic liquids.[65] For some fluids and fluid mixtures the experimental curve $\ln \eta$ versus T^{-1} is not a straight line at high temperatures (see, for example refs 69−75) and in this case
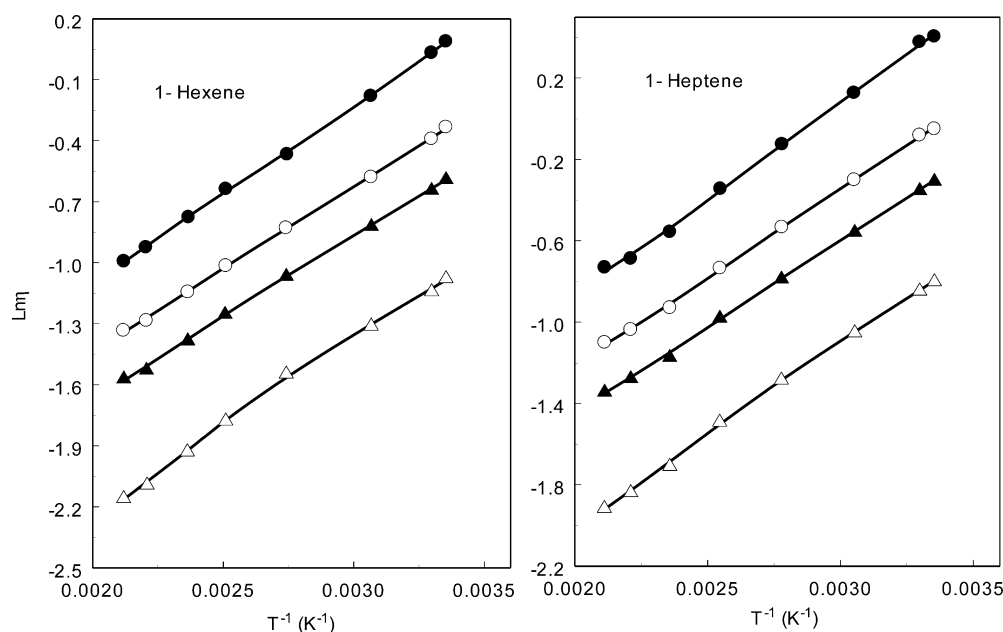
Figure 10. Measured values of $\ln \eta$ as a function of T^{-1} along the various isobars for 1-hexene and 1-heptene. $\triangle$, 49.03 MPa; $\blacktriangle$, 98.06 MPa; $\bigcirc$, 147.10 MPa; $\bullet$, 245.16 MPa. Solid lines are calculated from correlation model (eq 13).

Table 7. Deviation Statistics between the Present Measured Densities and Viscosities and the Values Calculated from Tait EOS (eq 8), and Viscosity Correlations (eq 9) and (eq 13) for 1-Hexene and 1-Heptene[a]

fluids	AAD (%)	bias (%)	SD (%)	SE (%)	max. dev. (%)
		Density			
1-hexene	0.10	0.01	0.14	0.02	0.3
1-heptene	0.29	0.02	0.37	0.05	0.9
		Viscosity (eq 9)			
1-hexene	2.38	−0.25	3.26	0.45	8.9
1-heptene	2.20	−0.40	2.85	0.38	6.0
		Viscosity (eq 12)			
1-hexene	1.37	−0.18	2.10	0.29	7.8
1-heptene	1.74	−0.04	2.15	0.29	4.6

[a]Notation: AAD, average absolute deviation; SD, standard deviation; SE, standard error; max. dev., maximum deviation.

the Arrhenius−Andrade relation (eq 9) can be slightly modified to extend the temperature range where the model is valid as

$$\eta(T) = b_0 \exp\left(\frac{b_1}{T} + \frac{b_2}{T^2}\right) \quad \text{or}$$

$$\ln \eta(T) = \ln b_0 + \frac{b_1}{T} + \frac{b_2}{T^2} \tag{11}$$

In our previous publications,[1,2] the viscosity data for MEG, DEG, TEG, and their binary mixtures at high temperatures and high pressures were successfully fitted to eq 11. In the present study the original Arrhenius−Andrade equation (eq 9) was applied to the viscosity measurements of 1-hexene and 1-heptene. As one can note from Figure 10, the experimental $\ln \eta$ versus T^{-1} curves for 1-hexene and 1-heptene are almost linear. Also, the applicability and accuracy of the Vogel−Tamman−Fulcher (VTF) model[76−78] for representation of the present viscosity measurements for 1-hexene and 1-heptene were examined. The temperature behavior of the viscosity along the various isobars can be described using the modified Andrade's equation,[79]
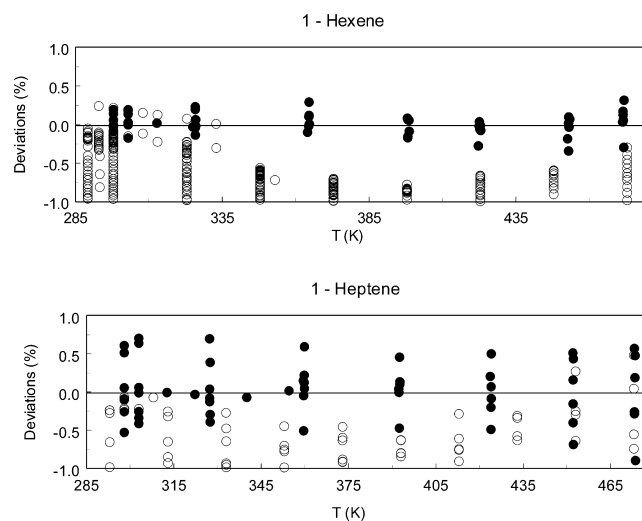

Figure 11. Percentage deviations, $\delta\rho = 100((\rho^{cal} - \rho^{exp})/\rho^{exp})$, of the present experimental densities for liquid 1-hexene and 1-heptane from the values calculated from Tait-type EOS (eq 8): $\bigcirc$, the reported data from refs 6−27; $\bullet$, this work.

$$\eta(T) = \eta_\infty \exp\left(\frac{DT_0}{T - T_0}\right) \text{or} \ln \eta(T) = \ln \eta_\infty + \frac{DT_0}{T - T_0} \tag{12}$$

This equation slightly differs from the previous model (eq 9). The eq 12 for the present measured viscosity data for 1-hexene and 1-heptene was applied. This model was also previously used successfully by other authors (see, for example, refs 78−81) to represent measured viscosities for 1-n-alkenediols, 2-alkylamines, and polyethers. As was shown in our earlier publications,[1−3] the modified Andrade equation (eq 12) represents slightly better than the original model (12). Equation 9 reproduces the present viscosity data for 1-hexene and 1-heptene within 2.38 % and 2.20 %, respectively. A deviation plot for the measured data and calculated values from
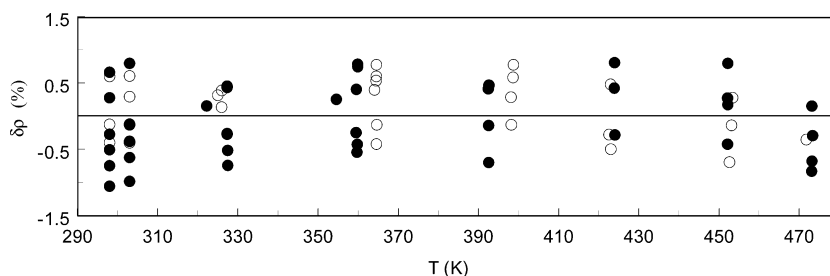
Figure 12. Percentage deviations, $\delta\rho = 100((\rho^{(25)} - \rho^{\exp})/\rho^{\exp})$, of the present experimental densities for 1-hexene (●) and 1-heptene (○) from the data reported in ref 25 as a function of temperature for various pressures from 0.1 MPa to 245 MPa.
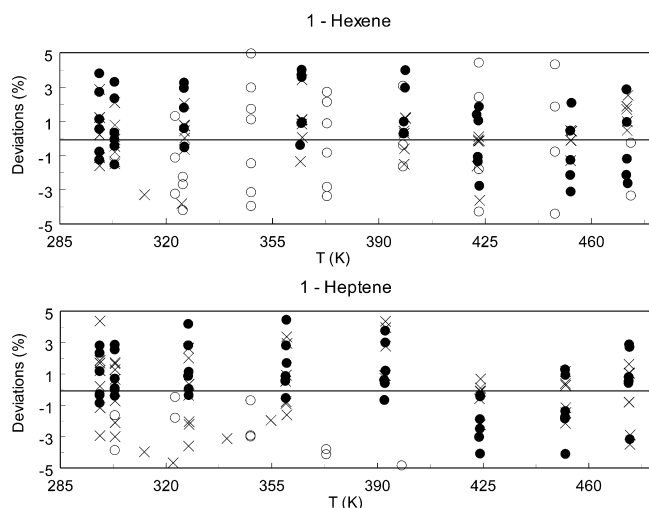

Figure 13. Percentage deviations, $\delta\eta = 100((\eta^{\text{cal}} - \eta^{\exp})/\eta^{\exp})$, of the present experimental viscosities for 1-hexene and 1-heptene from the values calculated from the correlations (eq 9) and (eq 12) in the temperature range from (298 to 473) K and at pressures up to 245 MPa. ●, this work (eq 9); ○, the literature data from refs 28−; ×, this work (eq 13).

eq 9 for the viscosity of 1-hexene and 1-heptene is shown in Figure 13. In general, the agreement between the present viscosity data for 1-hexene and 1-heptene and most of the reported data is close to the experimental uncertainty (within 2.5 %). Good agreement within 0.43 % to 0.78 % was found between the present and reported by Wright[10] viscosity data for 1-hexene at atmospheric pressure. Large differences (up to 10 %) are observed between the present viscosity data and those reported by Naziev et al.[32] For 1-heptene the present viscosity data agree with the reported by Naziev et al.[32] data within (4 to 9) %, our results are systematically higher than reported data. Acceptable agreements from (2 to 5) % were found

between the data reported by Guseinov et al.[30] and the present data for viscosity of 1-hexene at high pressures and high temperatures.

The present measured and corrected viscosity data (40 data points, 36 % of the data from the original Fomina[25] Ph.D. thesis) were detailed compared with the data previously reported in the Ph.D. thesis by Fomina.[25] The results are shown in the deviation plot (see Figure 14). The discrepancies (standard deviations) between the present data and that previous reported in the Ph.D. thesis[25] for 1-hexene and 1-heptene are within 1.58 % and 1.65 %, respectively, while the maximum deviations are 4.12 % and 3.17 %, respectively.

Quinones−Cisneros and Deiters[82] developed a generalization of the friction theory (FT) for viscosity modeling. The friction theory approach relates the viscosity of a fluid to its EOS. This method provides a good description of the viscosity of fluids over wide temperature and pressure ranges. Quinones−Cisneros and Deiters[82] used a new EOS (previously FT was restricted to use a van der Waals type EOS) to increase the accuracy of viscosity predictions. The range of validity of the correlation is (300 to 550) K and the maximum pressure is up to 150 MPa

$$\eta(T, P) = \eta_0(T) + k_r P_r + k_a P_a + k_{rr} P_r^2 + k_{aa} P_a^2 \tag{13}$$

where

$$k_a = (a_0 + a_1 \psi_1 + a_2 \psi_2)\Gamma \tag{14}$$

$$k_r = (b_0 + b_1 \psi_1 + b_2 \psi_2)\Gamma \tag{15}$$

$$k_{rr} = (B_0 + B_1 \psi_1 + B_2 \psi_2)\Gamma^3 \tag{16}$$

$$k_{aa} = (A_0 + A_1 \psi_1 + A_2 \psi_2)\Gamma^3 \tag{17}$$

Repulsive pressure (thermal pressure):

$$P_r = T(\partial P/\partial T)_V \tag{18}$$

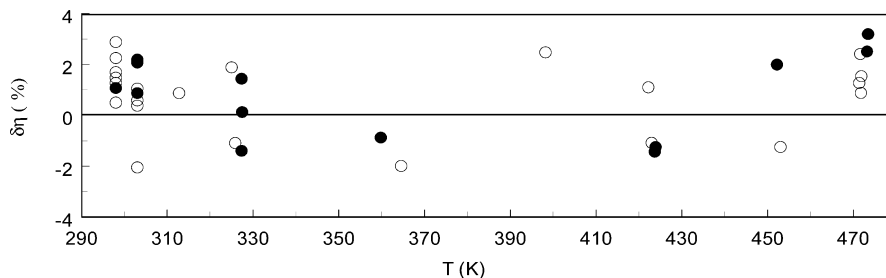**Figure 14.** Percentage deviations, $\delta\eta = 100((\eta^{(25)} - \eta^{\exp})/\eta^{\exp})$, of the present experimental viscosities for 1-hexene (●) and 1-heptene (○) from the data reported in ref 25 as a function of temperature for various pressures from 0.1 to 245 MPa.

Attractive pressure (internal pressure):

$$P_a = P - P_r \quad (-P_a = -(\partial U / \partial V)_T) \tag{19}$$

$$\psi_1 = \exp(\Gamma) - 1, \quad \psi_2 = \exp(\Gamma^2) - 1, \quad \text{and}$$

$$\Gamma = 100/T \tag{20}$$

The values of attractive (P_a), repulsive (P_r), and the total (P) pressures can be calculated using the Tait EOS (eq 8). In this work the temperature functions eq 14 to eq 17 were slightly simplified (kept only one term). The temperature function $\eta_0(T)$ in eq 13 can be presented as simple function

$$\eta_0(T) = d_0 + d_1\Gamma + d_2\Gamma^2 \tag{21}$$

Equation 13 was applied to the present viscosity data for 1-hexene and 1-heptene. The derived values of the coefficients are presented in Table 6. The deviation statistics are given in Table 7. As one can see the values of AAD for 1-hexene and 1-heptene are 1.74 % and 1.37 %, respectively. Therefore, the viscosity model (eq 13) based on the friction theory[82] much better represents the present data.

4. CONCLUSIONS

New density and viscosity data for liquid 1-hexene and 1-heptene have been simultaneously measured over the temperature range from (298 to 473) K and at pressures up to 245 MPa using the hydrostatic weighing and falling-body techniques. The measurements were performed along seven isobars (0.098, 24.51, 49.03, 98.06, 147.10, 196.13, and 245. 16) MPa as a function of temperature between (298 and 473) K. A Tait-type equation of state of liquid 1-hexene and 1-heptene with a linear temperature function for $B(T)$ and $c(T)$ has been developed using the measured (P, ρ, T) data. The AAD between the present and reported data and the values calculated with the Tait-type EOS of the density for 1-hexene are 0.10 % (for the present data) and 0.5 % (for reported data), while for 1-heptene are 0.2 % (for the present data) and 0.6 % (for reported data). Theoretically based Arrhenius–Andrade and Vogel–Tamman–Fulcher type equations with pressure-dependent coefficients have been used to describe the temperature and pressure dependences of the measured viscosities for liquid 1-hexene and 1-heptene. The developed correlation for the viscosity of liquid 1-hexene and 1-heptene represents the measured values of viscosity within 2.38 % and 2.20 %, respectively. More accurate representation of the present viscosity data was achieved with the model based on friction theory for which the AAD for 1-hexene and 1-heptene are 1.74 % and 1.37 %, respectively.

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Notes
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