



CORRELATION OF VISCOSITIES FOR BIOFUELS MIXTURES
CORRELACIÓN DE VISCOSIDADES PARA MEZCLAS DE BIOCOMBUSTIBLES

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Abstract

This paper presents the correlation that represents the relation between the variation of viscosity (η) of pure and binary chemical systems of 1-alcohols and n-alkanes with temperature and pressure, number of carbon atoms and variable concentrations. Representative gasoline hydrocarbons: iso-octane, cyclohexane, 1-hexene and pseudocumene, and alcohols: 1-butanol and 2-butanol, were used in this study. Binary mixtures were: 1-hexene + 1-butanol, cyclohexane + 1-butanol, iso-octane + 1-butanol, iso-octane + 2-butanol, pseudocumene + 1-butanol, and pseudocumene + 2-butanol. Experimental data of viscosity η were correlated with Vogel-Fulcher-Tammann equation (VFT), combined with Tait's equation. Prediction was performed using the Dymond-Assael rigid spheres model (RHS), with a modification to the model and with Eyring Theory supported by mixing laws.

Keywords: Biofuels, correlation, dynamic viscosity, mixtures.

Resumen

Este artículo presenta la correlación que representa la relación entre la variación de la viscosidad (η) de los sistemas químicos puros y binarios de 1-alcoholes y n-alcanos con la temperatura y presión, número de átomos de carbono y concentraciones variables. Se usaron hidrocarburos representativos de la gasolina: iso-octano, ciclohexano, 1-hexeno y pseudocumeno, y los alcoholes: 1-butanol y 2-butanol. Las mezclas binarias fueron: 1-hexeno + 1-butanol, ciclohexano + 1-butanol, iso-octano + 1-butanol, iso-octano + 2-butanol, pseudocumeno + 1-butanol, pseudocumeno + 2-butanol. Los datos experimentales de la η se correlacionaron con ecuación de Vogel-Fulcher-Tammann (VFT) combinado con ecuación de Tait. La predicción se realizó utilizando el modelo de las esferas rígidas (RHS) de Dymond-Assael, con una modificación al modelo y con la Teoría de Eyring apoyado en leyes de mezclas.

Palabras clave: Biocombustibles, correlación, viscosidad dinámica, mezclas.

1 Introduction

Energy consumption from non-renewable sources, energy savings and energy efficiency, are necessary measures to reduce global greenhouse gas emissions (European Union, 2003; European Union, 2007; Abramovich & Sychev, 2016; Paschke, 2017; Abramovich, 2018; Deniz & Paletto, 2018; Mozumder *et al.*, 2018; Yin *et al.*, 2018). Governments, faced with the need to control carbon dioxide emissions, encourage the use of renewable fuels as an alternative for transport (Worldwatch Institute, 2008).

For renewable fuels generation, an alternative is the formulation of gasolines that include oxygenated compounds such as alcohols (methanol, ethanol, propanol and butanol) and ethers (methyl-tert-butyl

ether, MTBE and ethyl-tert-butyl ether, ETBE) (Aguilar, 2010; Villamañan, 1979; Segovia, 1997; Chamorro, 1998; Alonso, 2002). The new blends of hydrocarbons and 1-butanol or 2-butanol are known as second generation biofuels (Zambrano *et al.*, 2016; Zambrano *et al.*, 2018; Galloni *et al.*, 2016; Qi *et al.*, 2016; Xu *et al.*, 2018). The butanol can replace gasoline as pure fuel or when blend with gasoline in internal combustion engines since its properties resemble those of gasoline (Szwaja & Naber, 2010; for pentanol, see Devarajan *et al.*, 2017). However, the lack of experimental viscosity data for 1-alcohols (methanol, ethanol, 1-propanol and 1-butanol) and 2-alcohols (2-butanol) is a problem due to the difficulty of making property measurements such as boiling point and volatility.

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The investigation of thermodynamic behavior of fluid mixtures is of great interest for industry (Montero, 1996; Whitaker, 2009; Gomes *et al.*, 2018). Models that allow the evaluation of thermodynamic properties without the need of them being quantified or measured nowadays can be used; these models have to be contrasted with experimental data to be validated (Panwar & Michael, 2018; Zhang *et al.*, 2018). Obtaining experimental results is of great importance for the development and verification of different theories or models of liquid state (Castro & Wakeham, 1992; Assael *et al.*, 1996; Baz-Rodríguez *et al.*, 2012; Simonin & Bouté, 2016).

In the literature, correlations are available to predict viscosity where some of them are empirical correlations, others use the principle of corresponding states, and more complex models together with state equations. The most well-known theories for viscosity are: friction theory, Tait equations, statistical theory of fluid association (SAFT) and the corresponding state models.

According to Quiñones-Cisneros *et al.* (2001), *f* Theory uses a cubic state equation and Chapman-Enskog limit to cover a total pressure range. Using congruence principle, with an error regarding experimental data of 2.3%, Ramos-Estrada *et al.* (2006) proposed a correlation for the prediction of density of n-alkane mixtures.

Values reported in literature about viscosity of mixtures of n-alkanes and 1-alcohols from experimental works are scarce. Assael *et al.* (1992a, 1992b), with a Vibrating Tube viscometer in the temperature range of 290 to 300 K and pressures above 70 MPa, reported n-decane and n-heptane + n-decane mixture (for concentrations of 40 and 70% by weight of n-heptane) absolute viscosity measurements with an uncertainty of 0.5%.

Sastry & Valans (1998) performed viscosity and density measurements on pentane, methanol, 1-propanol, 1-butanol, 1-pentanol, 1-hexanol, 1-heptanol, 1-octanol, 1-decanol, and 1-dodecanol at 298.15 K of temperature and atmospheric pressure in an Ubbelohde viscometer, reporting a correction in the measured data of ± 0.002 mPa·s. Canosa *et al.* (1998), with an automatic microviscometer AMV 200 Anton Paar, made viscosity measurements of methyl acetate, methanol, 1-propanol, 2-propanol, 1-butanol, and 2-butanol at 298.15 K of temperature and atmospheric pressure, with an error estimated ± 0.002 mPa·s. There were investigated the viscosities of binary mixtures of n-decane with 1-pentanol, 1-hexanol, and 1-heptanol (Estrada-Baltazar *et al.*, 2015), and also the viscosities

of binary mixtures of n-undecane with 1-heptanol, 1-octanol, 1-nonanol, and 1-decanol (Guzmán-López *et al.*, 2017). The densities of binary mixtures of n-undecane with 1-propanol, 1-butanol, 1-pentanol, and 1-hexanol were measured with a vibrating tube densimeter, and their viscosities were come with a pellet microviscometer (Iglesias-Silva *et al.*, 2016).

Therefore, the investigation of physico-chemical behavior of n-alkane/alcohol binary mixtures is of great interest because second generation biofuels are in demand in the world industry to reduce greenhouse effect. This study consists from experimental data of viscosities, compared with VFT and RHS correlations and Eyring model.

2 Methodology/Theoretical framework

2.1 Data selection

Experimental data of dynamic viscosity (η) were obtained with vibrating wire viscometer technique of pure compounds selected (Zambrano, 2014): 1-Hexene (olefins), Cyclohexane (cycloparaffins), 2,2,4-Trimethylpentane (paraffins, iso-octane), 1,2,4-Trimethylbenzene (polycyclic aromatics, pseudocumene), which are representative hydrocarbons of gasoline components; and alcohols: 1-Butanol (1-alcohol) and 2-Butanol (2-alcohol). The measurement interval (temperature and pressure) was established according to compounds intensive properties (boiling temperature at atmospheric pressure and solidification point at pressure higher than atmospheric pressure).

Experimental data of dynamic viscosity (η) of binary systems of hydrocarbon and alcohol mixtures were selected (Zambrano, 2014): 1-hexene + 1-butanol, cyclohexane + 1-butanol, iso-octane + 1-butanol, iso-octane + 2-butanol, 1,2,4 trimethylbenzene + 1-butanol, and 1,2,4 trimethylbenzene + 2-butanol. For each binary system, five mixtures of composition in mole fraction of alcohol (x), $x = 0.0, 0.3, 0.5, 0.8, 1.0$ were prepared. Experimental data of the mixtures were corresponded to temperatures 293.15, 313.15, 333.15 and 353.15 K in the pressure range of 0.1-140 MPa; but limited by the solidification point at pressure higher than atmospheric pressure.

Experimental data of pure compounds were correlated with Vogel-Fulcher-Tammann equation

(VFT) combined with Tait equation (Comuñas *et al.*, 2001) using Equation (1). And, all the experimental data of Hydrocarbons and Alcohols groups were modeled with Equations (5) and (6), which is the proposal of this work to the RHS model, with Equations (7) and (8) for hydrocarbons and alcohols, respectively.

Experimental data of η of mixtures were correlated with the representation of VFT combined with Tait equation (Comuñas *et al.*, 2001) applying Equation (1). Prediction of η is made with: the rigid spheres model (RHS) proposed in this work using Equations (10), (11), (12) and (13); plus, Eyring Theory supported by mixtures laws using Equation (15). Mathematical resolution of correlations was done in an Excel Sheet using the Solver tool.

2.2 Vogel-Fulcher-Tammann equation (VFT) combined with Tait equation

Comuñas *et al.* (2001) proposed (1), as an analogy to Tait type equation for densities, in order to adjust experimental data of viscosity as a function of pressure and temperature:

$$\begin{aligned} \eta(p, T) &= \eta_0(T) \cdot \exp \left[F \cdot \ln \left(\frac{p + E(T)}{0.1 \text{ MPa} + E(T)} \right) \right] \\ &= A \cdot \exp \left[\frac{B}{T - C} \right] \cdot \exp \left[F \cdot \ln \left(\frac{p + E(T)}{0.1 \text{ MPa} + E(T)} \right) \right] \end{aligned} \quad (1)$$

$\eta_0(T)$ represents the dependence of viscosity with temperature at the reference pressure (0.1 MPa), where A , B and C are determined by preliminary adjustment of viscosity as a function of temperature at reference pressure (0.1 MPa). With $E(T) = E_0 + E_1T + E_2T^2$ where the coefficients E_0 , E_1 and E_2 are adjusted to viscosity values at different pressure of reference, and F is assumed to be independent of temperature. All the constants coefficients were obtained by adjusting experimental data of viscosity as a function of temperature and pressure by algorithm for least squares estimation of nonlinear parameters (Marquardt, 1963).

2.2.1 Rigid spheres model (RHS) and mixture compounds

Several correlations for viscosity of dense fluids are based on hard spheres model, which is an improvement of free volume theory as it is based

on the application of Enskog's kinetic theory (Hirschfelder *et al.*, 1964; Comuñas, 2002). This arises from empirical modifications of Boltzman's theory to consider the finite diameter of molecules.

But Enskog's theory is not exact since it is based on the approximation of molecular chaos. However, Alder (1967) demonstrated through molecular dynamics calculations that there are molecular movements more privileged than others. Correction factors of these correlations have been calculated for finite systems with a large number of particles by molecular dynamics (Alder *et al.*, 1970), showing that they were only a function of the quotient V/V_0 (V molar volume and V_0 volume of a system formed by N_A packed spheres of diameter σ , $V_0 = N_A \sigma^3 / 2^{1/2}$).

In addition, Dymond (1974) developed the transport coefficients as a function of reduced volume $V_r = V/V_0$ and defined the reduced viscosity (η^*) that does not depend on molecular diameter, it is calculated directly from experimental results if it is assumed that real fluid can be represented by a set of hard spheres:

$$\eta^* = \frac{16}{5} (2N_A)^{1/3} \left(\frac{\pi}{MRT} \right)^{1/2} \eta V^{2/3} = F_\eta \left(\frac{V}{V_0} \right) \quad (2)$$

M is molecular mass and R is the universal constant of gases; F_η is a function of V/V_0 . For a given fluid, obtaining V_0 is done by graphic adjustment. The adjustment is made at values close to those derived by hard sphere theory, with $\log \eta^*$ vs. $\log V/V_0$ curves. These curves are universal and are expressed as:

$$\log(\eta^*) = \sum_{i=0}^7 a_{\eta_i} \left[\frac{V}{V_0} \right]^{-1} \quad (3)$$

a_{η_i} universal coefficients and V_0 values as a function of temperature are adjusted by regression analysis. The value of molar volume of the core V_0 is characteristic of each fluid.

Universal curve is also applied to non-spherical molecules by introducing a correction element to consider "roughness" of molecules (rotation transfer capacity, as well as collision translation impulse, according to Chandler, 1975). Therefore, a coefficient of proportionality was introduced in viscosity, R_η , which considers the non-sphericity of molecules, also admitting *a priori* that this coefficient is independent of temperature and density. Assael *et al.* (1992a), Assael *et al.* (1992c), Dymond (1974), Assael *et al.* (1992d), Assael *et al.* (1992e), Assael *et al.* (1994) use this idea, assuming that there is a relationship of corresponding states between

experimentally determined viscosity of non-spherical molecules and viscosity determined with smooth hard sphere theory, redefining reduced viscosity as:

$$\log\left(\frac{\eta^*_{\text{exp}}}{R_\eta}\right) = \sum_{i=0}^7 a_{\eta_i} \left[\frac{V}{V_0}\right]^{-1} \quad (4)$$

Then, the viscosity for a system of non-spherical molecules is:

$$\eta_{\text{exp}} = \left[10^{\left(\sum_{i=0}^7 a_{\eta_i} \left[\frac{V}{V_0}\right]^{-1} \right)} \right] \cdot \left[\frac{R_\eta}{\frac{16\sqrt{\pi}}{5} (2N_A)^{1/3} \left(\frac{V^{2/3}}{\sqrt{MRT}} \right)} \right] \quad (5)$$

Adjustable parameters are V_0 (for each fluid and each temperature) and R_η (for each fluid) by means of experimental measures of viscosity in wide ranges of pressure and temperature. Molar volume ($V_0/(cm^3 \cdot mol^{-1}) = \sum_{i=0}^N \nu_i [T/K]^i$) is a function only of absolute temperature, it is calculated from atmospheric pressure conditions and used then to predict the values of high pressure viscosity.

But according to the type of fluid (paraffins, aromatics, alkanes and alcohols according to Assael *et al.* (1992a), Assael *et al.*, (1992c), Assael *et al.* (1992d), Assael *et al.* (1992e), Assael *et al.* (1994)), form of the polynomial function will depend on the number of carbons and their molecular structure; ν_i coefficients are found with least squares regression method. With this model it is possible to predict transport properties of compressed liquids at high pressure (Dymond & Assael, 1996), nevertheless the main disadvantage is that predictions are very sensitive to V/V_0 values and a precise state equation is required for the liquid (Comuñas, 2002).

For alkanes, in Assael *et al.* (1992a), V_0 and R_η parameters present a regular behavior with the chain through the expression of $V_0(T, C_n)$ and $R_\eta(C_n)$; C_n is number of carbon atoms in alkane chain. For aromatics family, Assael *et al.* (1992c) did not find a clear dependence on R_η with C_n ; and, for alcohols they obtained that R_η is temperature dependent (Assael *et al.*, 1994), contrary to the initial hypothesis that this parameter was independent of temperature.

Zambrano (2014), after analyzing experimental data of several pure compounds of different molecular structure, proposed expression (6) to obtain values of V_0 . It is a mathematically short expression that groups variations of T and C_n , fitting adequately to rough rigid spheres (RHS) model with deviations below 1%.

As Assael *et al.* (1992c) did not establish a clear dependence of R_η with C_n , Zambrano (2014) proposed expression (7) for all hydrocarbons and expression (8) for all alcohols.

$$V_0/(10^{-6}m^3 \cdot mol^{-1}) = \nu_1 + \nu_2 T^{\nu_4} + \nu_5 C_n^{\nu_6} \quad (6)$$

$$R_\eta = r_1 + r_2 C_n + r_3 C_n^2 \quad (7)$$

$$R_\eta = r_1 + r_2 T + r_3 T^2 \quad (8)$$

With rough rigid spheres model, dynamic viscosity of mixtures of N components can be predicted (Comuñas, 2002; Ciotta *et al.*, 2009). Once R_η parameters are known for each component of the mixture and $V_0(T)$ for each temperature and each component, mixing rules are used to determine the value of parameters for the mixtures per isotherm:

$$V_{0m}(T, x) = \sum_{i=0}^N x_i V_{0i}(T) \quad (9)$$

$$R_{\eta m}(T) = \sum_{i=0}^N x_i R_{\eta i} \quad (10)$$

x_i are molar fractions of pure compounds. Mixing rules are simple and work for inert gases and light alkanes, they are linear in mole fraction. But the comparison of experimental data of mixtures with values obtained from the adjustment to RHS model using linear mixing rules, presents high deviations; therefore, to decrease these deviations, quadratic mixing rule is applied to evaluate V_0 (Ciotta *et al.*, 2009):

$$V_0 = x_1^2 V_{0,1} + 2x_1 x_2 V_{0,12} + x_2^2 V_{0,2} \quad (11)$$

$$V_{0,12} = \frac{1}{2} \kappa (x_1 V_{0,1} + x_2 V_{0,2}) \quad (12)$$

$$\kappa = \alpha + \beta \{(T/K) - 300\} \quad (13)$$

2.3 Eyring theory and mixing laws

Allal *et al.* (2001) developed a model based on Eyring theory coupled with a cubic state equation to correlate and/or predict viscosity of liquid of highly non-ideal binary solutions over a wide range of temperature, pressure and composition. The purpose of mixing laws is to predict viscosity of mixtures using only viscosity and density of pure substances and their molar fraction (or other scale of composition).

Mixing law of Grunberg and Nissan (1949) is often used to predict viscosity of mixtures, but these simple mixing laws are not valid for predicting viscosities of mixtures of asymmetric size (Pensado *et al.*,

2008). Mixing law (Grunberg & Nissan, 1949) can be modified by introducing an adjustable parameter that can be representative for interactions within the studied system, but the model is no longer predictive. Dynamic viscosity data have also been discussed in terms of an excess amount (Aralaguppi *et al.*, 1991). Another quantity that is calculated from the viscosity of mixture is molar free energy of Gibbs in excess of activation of flow, $\Delta G^{\ddagger E}$, defined by viscosity equation proposed by Aralaguppi *et al.* (1991) and Glasstone *et al.* (1941):

$$\eta_m = (hN/M) \exp(\Delta G^{\ddagger E}/RT) \quad (14)$$

h Planck constant, N Avogadro number, M molecular mass of mixture, RT a usual term of energy (R universal constant of gases, T temperature) and $\Delta G^{\ddagger E} = \Delta G_m^{\ddagger} - \Delta G_{ideal}^{\ddagger}$, where ΔG_m^{\ddagger} y $\Delta G_{ideal}^{\ddagger}$ are free Gibbs molar energy of activation of mixture and free Gibbs ideal energy of an ideal mixture, respectively, with $\Delta G_{ideal}^{\ddagger} = x_1 \Delta G_1^{\ddagger} + x_2 \Delta G_2^{\ddagger}$.

For a binary mixture (Aralaguppi *et al.*, 1991; Joshi *et al.*, 1990):

$$\eta_m = \frac{1}{V_m} \exp\left(\frac{\Delta G^{\ddagger E}}{RT} + x_1 \ln \eta_1 V_1 + x_2 \ln \eta_2 V_2\right) \quad (15)$$

V_m , V_1 and V_2 molar volumes of the mixture and pure compounds 1 and 2. By regression analysis, values of $\Delta G^{\ddagger E}$ are obtained for each isotherm, depending on pressure and composition, with the experimental data of η of mixtures and pure fluids.

3 Results and discussion

In Table 1, at reference pressure (0.1 MPa), experimental data of dynamic viscosity (η) of pure compounds representative of gasolines: 1-Hexene (olefins), iso-Octane (paraffins), Pseudocumene (polycyclic aromatics), Cyclohexane (cycloparaffins), and alcohols: 1-Butanol (1-alcohol) and 2-Butanol (2-alcohol). Also, in Table 1, at reference pressure (0.1 MPa), experimental data of dynamic viscosity (η) of the binary mixtures: 1-hexene + 1-butanol, iso-octane + 2-butanol, iso-octane + 1-butanol, pseudocumene + 2-butanol, pseudocumene + 1-butanol, cyclohexane + 1-butanol.

In Fig. 1, as a function of temperature at reference pressure (0.1 MPa), experimental data of dynamic

viscosity (η) of pure compounds. In Fig. 2 behavior of the dynamic viscosities (η) of the binary mixtures: 1-Hexene + 1-Butanol, Cyclohexane + 1-Butanol, and in Fig. 3 comparison of the dynamic viscosities (η) of the binary mixtures: iso-Octane + 2-Butanol, iso-Octane + 1-Butanol, Pseudocumene + 2-Butanol, Pseudocumene + 1-Butanol.

The dynamic viscosity of gasolines, determined according to ASTM D445 or ASTM D2161, at 293.15 K (20 °C) fluctuates in the range of 0.4 mPa.s - 0.6 mPa.s. And it varies from 0.8 mPa.s - 0.25 mPa.s in the range of 273.15 K - 393.15 K. Similar values of the experimental viscosities were obtained for several of the pure compounds representative of the gasolines and for several of the mixtures of the pure compounds with the alcohols (Table 1, Figs. 1 - 3).

In Tables 2 - 7 coefficients are compiled using VFT equation, and in Tables 8 - 13, upper table, coefficients using RHS model with the proposal of this study, and in the lower table, the Eyring Model supported by laws of mixing, also proposed in this study. A good adjustment of experimental data η was achieved for the mixtures of six (6) binary systems with VFT equation (Comuñas *et al.*, 2001), with RHS model proposed in this paper, and with Eyring model supported by mixing laws; coefficients of adjustments show a definite trend according to mole fraction of alcohol in the mixture, but there are evident differences in the adjustments with respect to the equation or models used. Coefficients of adjustments of experimental data η of mixtures of the six binary systems to VFT model, Tables 2 - 7, show a defined tendency according to molar fraction of alcohol in the mixture for each binary system, observing consistency in statistical values of each of the analyzes.

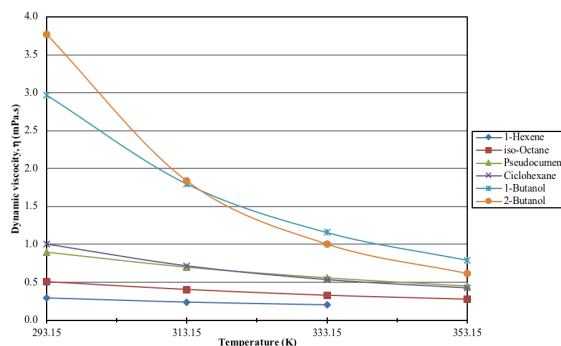


Fig. 1. Dynamic viscosities of pure compounds as a function of temperature at reference pressure (0.1 MPa).

Table 1. Experimental data of dynamic viscosities, η (mPa.s), of pure compounds and mixtures at reference pressure (0.1 MPa).

Temperature	293.15 K	313.15 K	333.15 K	353.15 K
Pure Compounds				
1-Hexene	0.2926	0.2376	0.2011	
iso-Octane	0.5064	0.4035	0.3265	0.2738
Pseudocumene	0.8929	0.6989	0.5596	0.4527
Ciclohexane	1.0055	0.7172	0.5341	0.4233
1-Butanol	2.9686	1.7968	1.1564	0.7903
2-Butanol	3.7673	1.8391	1.0067	0.6198
Mixtures (X = 1-Butanol or X = 2-Butanol)				
(1 - X) 1-Hexene + (X) 1-Butanol				
X = 0.3	0.4354	0.3422	0.2605	0.2166
X = 0.5	0.6841	0.4947	0.361	0.2796
X = 0.8	1.566	1.0044	0.6824	0.4902
(1 - X) iso-Octane + (X) 2-Butanol				
X = 0.3	0.6047	0.4647	0.3574	0.2785
X = 0.5	0.7922	0.5643	0.4132	0.3272
X = 0.8	1.6731	0.9784	0.6203	0.4165
(1 - X) iso-Octane + (X) 1-Butanol				
X = 0.3	0.651	0.4938	0.3855	0.3085
X = 0.5	0.8986	0.6427	0.4739	0.3658
X = 0.8	1.7768	1.1512	0.7766	0.5523
(1 - X) Pseudocumene + (X) 2-Butanol				
X = 0.3	0.9506	0.708	0.539	0.43
X = 0.5	1.1083	0.7802	0.5777	0.4439
X = 0.8	1.8337	1.097	0.7185	0.4963
(1 - X) Pseudocumene + (X) 1-Butanol				
X = 0.3	1.0044	0.7478	0.5848	0.4547
X = 0.5	1.2272	0.8685	0.6443	0.495
X = 0.8	1.9586	1.2541	0.8537	0.6105
(1 - X) Ciclohexane + (X) 1-Butanol				
X = 0.3	1.1394	0.7889	0.5728	0.4378
X = 0.5	1.4567	0.9664	0.6622	0.4941
X = 0.8	2.2866	1.4052	0.9017	0.6277

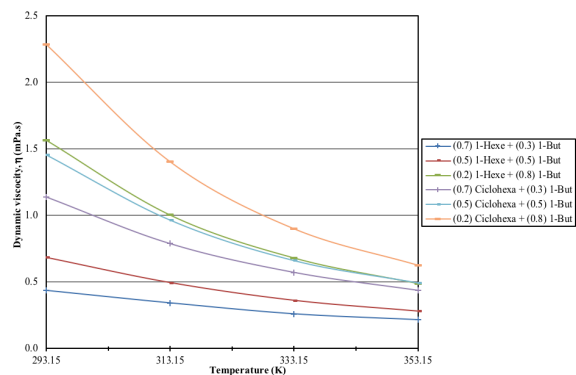


Fig. 2. Dynamic viscosities of binary mixtures (1-Hexene + 1-Butanol, Ciclohexane + 1-Butanol) as a function of temperature at reference pressure (0.1 MPa).

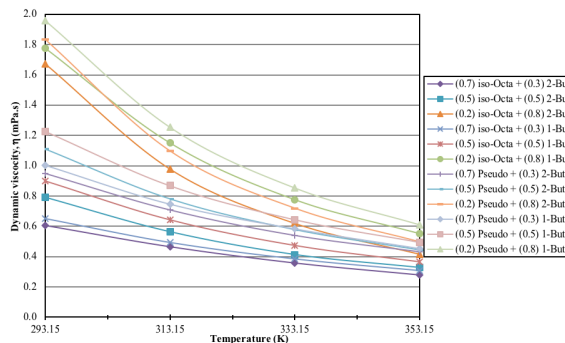


Fig. 3. Dynamic viscosities of binary mixtures (iso-Octane + 2-Butanol, iso-Octane + 1-Butanol, Pseudocumene + 2-Butanol, Pseudocumene + 1-Butanol) as a function of temperature at reference pressure (0.1 MPa).

Table 2. Coefficients and statistics of the equation VFT for η of mixture (1-x) 1-Hexene + (x) 1-Butanol

X = 1-Butanol (fraction)	X = 0.0	X = 0.3	X = 0.5	X = 0.8	X = 1.0
A (mPa·s)	0.010296	0.008854	0.007948	0.009139	0.011849
B (K)	1050.344	1060.249	1063.73	1068.318	1068.232
C (K)	-20.8278	21.373	54.39	85.516	99.922
E ₀ (MPa)	0.952313	0.893788	0.753429	0.701818	0.946033
E ₁ (MPa/K)	0.610431	0.772156	0.689103	0.736057	0.961762
E ₂ (MPa/K ²)	-0.001261	-0.001057	-0.000567	-0.000537	-0.001261
F	0.811207	1.468608	1.677896	1.679897	1.633896
AAD (Abs Average Dev. %)	0.62	1.41	1.39	1.069	1.12
Bias (Average Dev.%)	0.13	0.62	0.83	0.59	0.057
MD (Abs. Max. Dev.%)	2.33	2.29	2.42	2.47	2.38
RMS (Sqr. Root Mean %)	0.84	1.58	1.58	1.29	1.31
Standard Dev. (mPa·s)	0.0033	0.0076	0.011	0.018	0.037

Table 3. Coefficients and statistics of the equation VFT for η of mixture (1-x) Ciclohexane + (x) 1-Butanol.

X = 1-Butanol (fraction)	X = 0.0	X = 0.3	X = 0.5	X = 0.8	X = 1.0
A (mPa·s)	0.012098	0.011116	0.010212	0.00979	0.011849
B (K)	1061.14	1065.732	1066.589	1069.902	1068.232
C (K)	53.1065	62.989	78.209	97.065	99.922
E ₀ (MPa)	0.900262	0.89627	0.754713	0.701735	0.946033
E ₁ (MPa/K)	0.665291	0.625172	0.488076	0.59508	0.961762
E ₂ (MPa/K ²)	-0.001247	-0.001057	-0.000567	-0.000488	-0.001261
F	1.30016	1.256979	1.279366	1.499093	1.633896
AAD (Abs Average Dev. %)	0.98	0.88	0.98	1.24	1.12
Bias (Average Dev.%)	0.3	0.51	0.29	-0.17	0.057
MD (Abs. Max. Dev.%)	2.62	2.34	2.33	2.21	2.38
RMS (Sqr. Root Mean %)	1.23	1.12	1.2	1.38	1.31
Standard Dev. (mPa·s)	0.014	0.013	0.014	0.023	0.037

Table 4. Coefficients and statistics of the equation VFT for η of mixture (1-x) iso-Octane + (x) 1-Butanol.

X = 1-Butanol (fraction)	X = 0.0	X = 0.3	X = 0.5	X = 0.8	X = 1.0
A (mPa·s)	0.013663	0.011784	0.01046	0.010464	0.011849
B (K)	1053.543	1061.195	1063.73	1068.284	1068.232
C (K)	1.5209	28.733	54.39	85.225	99.922
E ₀ (MPa)	0.895194	0.89208	0.752861	0.701445	0.946033
E ₁ (MPa/K)	0.792	0.713657	0.59912	0.680099	0.961762
E ₂ (MPa/K ²)	-0.001248	-0.001057	-0.000567	-0.000547	-0.001261
F	1.639677	1.555158	1.680003	1.679671	1.633896
AAD (Abs Average Dev. %)	0.99	1.21	0.99	1.3	1.12
Bias (Average Dev.%)	0.35	0.46	-0.12	0.27	0.057
MD (Abs. Max. Dev.%)	2.49	2.42	2.35	2.23	2.38
RMS (Sqr. Root Mean %)	1.2	1.39	1.2	1.47	1.31
Standard Dev. (mPa·s)	0.0083	0.013	0.012	0.034	0.037

Table 5. Coefficients and statistics of the equation VFT for η of mixture (1-x) iso-Octane + (x) 2-Butanol.

X = 2-Butanol (fraction)	X = 0.0	X = 0.3	X = 0.5	X = 0.8	X = 1.0
A (mPa·s)	0.013663	0.010529	0.009209	0.005711	0.005043
B (K)	1053.543	1061.633	1063.73	1069.939	1071.345
C (K)	1.5209	31.483	54.39	104.83	131.268
E ₀ (MPa)	0.895194	0.781575	0.753318	0.641357	-3.807156
E ₁ (MPa/K)	0.792	0.614066	0.598874	0.592676	1.141258
E ₂ (MPa/K ²)	-0.001248	-0.000636	-0.000567	-0.000313	-0.000372
F	1.639677	1.726718	1.748949	1.992079	3.246164
AAD (Abs Average Dev. %)	0.99	1.27	1.12	1.13	1.22
Bias (Average Dev.%)	0.35	0.24	0.46	-0.083	0.7
MD (Abs. Max. Dev.%)	2.49	2.5	2.47	2.32	2.46
RMS (Sqr. Root Mean %)	1.2	1.4	1.37	1.31	1.4
Standard Dev. (mPa·s)	0.0083	0.012	0.012	0.02	0.058

Table 6. Coefficients and statistics of the equation VFT for η of mixture (1-x) Pseudocumene + (x) 1-Butanol.

X = 1-Butanol (fraction)	X = 0.0	X = 0.3	X = 0.5	X = 0.8	X = 1.0
A (mPa·s)	0.020268	0.016279	0.013864	0.011366	0.011849
B (K)	1056.129	1062.108	1064.579	1068.336	1068.232
C (K)	14.351	35.582	55.724	85.738	99.922
E ₀ (MPa)	0.918859	0.898696	0.408135	0.589666	0.946033
E ₁ (MPa/K)	1.144714	0.683318	1.060617	0.716754	0.961762
E ₂ (MPa/K ²)	0.003561	0.001147	0.003709	-0.000327	-0.001261
F	5.465709	2.783975	5.559397	1.797448	1.633896
AAD (Abs Average Dev. %)	1.19	1.22	1.045	0.83	1.12
Bias (Average Dev.%)	0.66	0.49	0.78	0.28	0.057
MD (Abs. Max. Dev.%)	2.34	2.38	2.26	2.34	2.38
RMS (Sqr. Root Mean %)	1.35	1.42	1.23	1.02	1.31
Standard Dev. (mPa·s)	0.015	0.017	0.016	0.02	0.037

Table 7. Coefficients and statistics of the equation VFT for η of mixture (1-x) Pseudocumene + (x) 2-Butanol.

X = 2-Butanol (fraction)	X = 0.0	X = 0.3	X = 0.5	X = 0.8	X = 1.0
A (mPa·s)	0.020268	0.01478	0.011928	0.001323	0.005043
B (K)	1056.129	1062.416	1077.243	1941.331	1071.345
C (K)	14.351	38.104	55.45	24.707	131.268
E ₀ (MPa)	0.918859	0.925548	0.763728	-2.452095	-3.807156
E ₁ (MPa/K)	1.144714	0.920427	0.306068	-0.065456	1.141258
E ₂ (MPa/K ²)	0.003561	0.002767	0.002346	0.00298	-0.000372
F	5.465709	4.531228	2.937613	2.91086	3.246164
AAD (Abs Average Dev. %)	1.19	1.21	1.29	1.077	1.22
Bias (Average Dev.%)	0.66	0.92	0.94	0.87	0.7
MD (Abs. Max. Dev.%)	2.34	2.21	2.39	2.15	2.46
RMS (Sqr. Root Mean %)	1.35	1.36	1.47	1.22	1.4
Standard Dev. (mPa·s)	0.015	0.014	0.016	0.02	0.058

Nevertheless, the adjustment of experimental data of η to VFT equation is acceptable, coefficients of the adjustment to modified RHS model proposed in this paper, including statistics adjustment, are included in upper tables of Tables 8 - 13. ν_i ($\nu_1, \nu_2, \dots, \nu_6$) which are coefficients to calculate V_0 and r_i (r_1, r_2, r_3) which are coefficients to calculate R_η of pure compounds (Tables 8 - 13), are the basis of the proposal for use in RHS model. a_i (a_0, a_1, \dots, a_7), and $x = 0,0$ and $x = 1.0$ are the universal coefficients of RHS model and constants for pure compounds; α and β are obtained to use in quadratic mixing rule and evaluate V_0 of mixture. Standard deviations of mixtures ($x = 0.3, 0.5$, and 0.8) for the six binary systems are accepted with respect to expanded uncertainty ($k = 2$) of viscosity measurement. In lower tables of Tables 8 - 13, statistic of the adjustment of experimental data of η of mixtures to Eyring model supported by mixing, expression laws (15), are satisfactory for blends of the six binary systems, with standard deviations lower than the expanded uncertainty ($k = 2$) of 0.011 mPa·s.

In mixtures with same type of alcohol (1-alcohol or 2-alcohol), tendency of η increase is defined by the molecular structure of the other compound of mixture: with linear unsaturated molecular structures (alkenes) lower η is observed, comparing with mixtures from compounds of linear aliphatic molecular structures, followed by aromatics and cyclic aliphatics; aromatic molecular structures have lower η , than cyclic aliphatic molecular structures with same number of carbons in the ring or cycle (in cyclic aliphatics, their chains

are saturated, with a lower molar volume). η in the mixture with aromatic compounds is higher than with aliphatic compounds; possibly due to lack of strong interactions between iso-octane and 1-butanol, that only have intermolecular dispersion forces, making molar volume of their mixture higher than that obtained for pseudocumene + 1-butanol mixture, that has greater molecular interaction due to stability of the electronic structure (resonance) presented by the aromatics. For mixtures with same hydrocarbon, η decreases with the branched chain alcohol of 2-butanol with respect to 1-butanol. This is possibly due to alcohol isomerism, since the molar volume in mixture with fluids of linear molecules (1-alcohol) is lower than the molar volume occupied with fluids of branched molecules (2-alcohol).

In literature there is little information of η for the mixtures treated here, to validate experimental data in the range of 293.15 K - 353.15 K and 0.1 MPa - 140 MPa. For example, Nath (2002) measures velocity of sound in the mixture of n-butanol + 2,2,4-trimethylpentane at 288.15 K and atmospheric pressure to calculate apparent sound velocity in excess and isentropic compressibility of the mixture. In González *et al.* (2004) dynamic viscosity of 2-butanol is determined with octane, decane and dodecane alkanes (C8, C10 and C12) at various temperatures and atmospheric pressure; even though C8 (n-octane) is a linear aliphatic, it is an isomer with different molecular structure, as well as with thermophysical properties different from iso-octane.

Table 8. Coefficients and statistics of modified RHS Model in this work and Eyring Model for η of mixture (1-x) 1-Hexene + (x) 1-Butanol.

X = 1-Butanol (fraction)	X = 0.0	X = 0.3	X = 0.5	X = 0.8	X = 1.0
v ₁	27.30885				31.12019
v ₂	0.0102				0.02546
v ₃	3553.81165				3553.81716
v ₄	-0.96338				-0.90631
v ₅	2.70247				0.64931
v ₆	1.37625				0.95413
a		2.24257	2.40385	2.13672	
b		0.00334	0.00208	0.0008	
r ₁	1.07454				54.95703
r ₂	0.54717				-0.27721
r ₃	-0.0911				0.00036
a ₀	1.0945	1.0868	1.1145	0.9834	1.0945
a ₁	-9.2632	-9.2948	-9.2565	-9.2888	-9.2632
a ₂	71.0385	70.8029	70.7925	71.0393	71.0385
a ₃	-301.9012	-302.431	-302.5745	-301.9038	-301.9012
a ₄	797.69	797.0597	796.8043	797.6822	797.69
a ₅	-1221.977	-1222.3374	-1222.5088	-1221.9745	-1221.977
a ₆	987.5574	987.5465	987.5832	987.5742	987.5574
a ₇	-319.4636	-319.3245	-319.1645	-319.4429	-319.4636
AAD (Desv. med. abs. %)	1.075	1.13	1.072	0.62	1.5
Bias (Average Dev.%)	-0.17	-0.03	-0.011	-0.057	-0.28
MD (Abs. Max. Dev.%)	2.46	3.13	3.88	1.37	4.86
RMS (Sqr. Root Mean %)	1.28	1.4	1.36	0.74	1.98
Standard Dev. (mPa·s)	0.0040	0.0064	0.0088	0.0083	0.037

Eyring Model (Gibbs Free Energy of Flow Activation)				
Temperature (K)	293.15	313.15	333.15	353.15
AAD (Abs Average Dev. %)	0.02	0.036	0.1	0.17
Bias (Average Dev.%)	-0.0028	-0.0087	-0.0083	-0.057
MD (Abs. Max. Dev.%)	0.15	0.24	0.7	1.25
RMS (Sqr. Root Mean %)	0.04	0.066	0.19	0.33
Standard Dev. (mPa·s)	0.0002	0.0003	0.0007	0.0009
Gibbs Free Energy of Flow Activation (Joule.mol ⁻¹) @ p = 0.1 - 70 MPa				
AAD (Abs Average Dev. %)	0.000028	0.000023	0.000023	0.000027
Bias (Average Dev.%)	0.0000025	-0.000022	-0.000021	-0.00001
MD (Abs. Max. Dev.%)	0.00011	0.00011	0.00012	0.00012
RMS (Sqr. Root Mean %)	0.000041	0.000047	0.000047	0.000044
Standard Dev. (Joule.mol ⁻¹)	0.00028	0.052	0.078	0.00042

Table 9. Coefficients and statistics of modified RHS Model in this work and Eyring Model for η of mixture (1-x) Cyclohexane + (x) 1-Butanol.

X = 1-Butanol (fraction)	X = 0.0	X = 0.3	X = 0.5	X = 0.8	X = 1.0
v ₁	27.28227				31.12019
v ₂	0.01885				0.02546
v ₃	3553.81176				3553.81716
v ₄	-0.96757				-0.90631
v ₅	4.28916				0.64931
v ₆	1.07868				0.95413
a		1.77851	1.9512	2.18268	
b		0.00167	0.00128	0.00031	
r ₁	1.1342				54.95703
r ₂	0.78991				-0.27721
r ₃	-0.13518				0.00036
a ₀	1.0945	1.0207	1.0012	1.0026	1.0945
a ₁	-9.2632	-9.289	-9.3067	-9.2786	-9.2632
a ₂	71.0385	71.0313	71.0129	71.0429	71.0385
a ₃	-301.9012	-301.9059	-301.9267	-301.906	-301.9012
a ₄	797.69	797.6847	797.6638	797.6761	797.69
a ₅	-1221.977	-1221.9769	-1221.9925	-1221.9804	-1221.977
a ₆	987.5574	987.5649	987.5561	987.5708	987.5574
a ₇	-319.4636	-319.4536	-319.4585	-319.4445	-319.4636
AAD (Desv. med. abs. %)	1.045	1.33	1.24	1.028	1.5
Bias (Average Dev.%)	-0.092	0.055	0.055	-0.13	-0.28
MD (Abs. Max. Dev.%)	3.094	4.4	2.96	2.22	4.86
RMS (Sqr. Root Mean %)	1.32	1.59	1.45	1.21	1.98
Standard Dev. (mPa·s)	0.012	0.017	0.019	0.018	0.037

Eyring Model (Gibbs Free Energy of Flow Activation)				
Temperature (K)	293.15	313.15	333.15	353.15
AAD (Abs Average Dev. %)	0.0038	0.013	0.029	0.077
Bias (Average Dev.%)	0.0001	0.0021	0.0021	0.021
MD (Abs. Max. Dev.%)	0.016	0.059	0.15	0.39
RMS (Sqr. Root Mean %)	0.0065	0.021	0.049	0.13
Standard Dev. (mPa·s)	0.0001	0.0002	0.0004	0.0007
Gibbs Free Energy of Flow Activation (Joule.mol ⁻¹) @ p = 0.1 - 40 MPa				
AAD (Abs Average Dev. %)	0.000039	0.000033	0.000029	0.000025
Bias (Average Dev.%)	-0.000011	0.000004	-0.000002	0.000004
MD (Abs. Max. Dev.%)	0.00013	0.00009	0.00011	0.000083
RMS (Sqr. Root Mean %)	0.000056	0.000046	0.000044	0.000036
Standard Dev. (Joule.mol ⁻¹)	0.00021	0.0074	0.00019	0.00015

Table 10. Coefficients and statistics of modified RHS Model in this work and Eyring Model for η of mixture (1-x) iso-Octane + (x) 1-Butanol.

X = 1-Butanol (fraction)	X = 0.0	X = 0.3	X = 0.5	X = 0.8	X = 1.0
v ₁	28.28268				31.12019
v ₂	-0.00104				0.02546
v ₃	3553.8115				3553.8171
v ₄	-0.94479				-0.90631
v ₅	2.23187				0.64931
v ₆	1.60914				0.95413
a		2.4243	2.54516	2.67642	
b		0.00267	0.00186	0.00134	
r ₁	1.04761				54.95703
r ₂	0.38062				-0.27721
r ₃	-0.04321				0.00036
a ₀	1.0945	0.7365	0.7115	0.61	1.0945
a ₁	-9.2632	-8.7963	-8.838	-8.4732	-9.2632
a ₂	71.0385	71.353	71.3257	71.6539	71.0385
a ₃	-301.9012	-302.4888	-302.4679	-302.5477	-301.9012
a ₄	797.69	796.2192	796.2958	795.9021	797.69
a ₅	-1221.977	-1223.2233	-1223.1462	-1223.1803	-1221.977
a ₆	987.5574	987.3574	987.3755	988.0752	987.5574
a ₇	-319.4636	-318.994	-319.024	-317.9123	-319.4636
AAD (Desv. med. abs. %)	1.33	2.11	2.07	1.16	1.5
Bias (Average Dev.%)	-0.49	0.58	0.8	-0.38	-0.28
MD (Abs. Max. Dev.%)	5.1	4.14	7.58	3.05	4.86
RMS (Sqr. Root Mean %)	1.79	2.39	2.98	1.39	1.98
Standard Dev. (mPa·s)	0.01	0.02	0.022	0.021	0.037

Eyring Model (Gibbs Free Energy of Flow Activation)				
Temperature (K)	293.15	313.15	333.15	353.15
AAD (Abs Average Dev. %)	0.0048	0.011	0.024	0.051
Bias (Average Dev.%)	0.0036	0.000094	0.0046	-0.0055
MD (Abs. Max. Dev.%)	0.03	0.15	0.31	0.76
RMS (Sqr. Root Mean %)	0.009	0.027	0.055	0.13
Standard Dev. (mPa·s)	0.0001	0.0002	0.0003	0.0005
Gibbs Free Energy of Flow Activation (Joule.mol ⁻¹) @ p = 0.1 - 140 MPa				
AAD (Abs Average Dev. %)	0.000024	0.000021	0.000023	0.000022
Bias (Average Dev.%)	-0.000007	-0.000014	-0.000022	-0.000019
MD (Abs. Max. Dev.%)	0.00011	0.00011	0.00011	0.00011
RMS (Sqr. Root Mean %)	0.000041	0.000039	0.000045	0.000046
Standard Dev. (Joule.mol ⁻¹)	0.0071	0.008	0.044	0.011

Table 11. Coefficients and statistics of modified RHS Model in this work and Eyring Model for η of mixture (1-x) iso-Octane + (x) 2-Butanol.

X = 2-Butanol (fraction)	X = 0.0	X = 0.3	X = 0.5	X = 0.8	X = 1.0
v ₁	28.28268				31.30519
v ₂	-0.00099				0.00293
v ₃	3553.81152				3553.81741
v ₄	-0.94478				-0.8797
v ₅	2.23187				1.2744
v ₆	1.60916				1.36464
a		2.27495	2.32569	2.24795	
b		0.00284	0.00311	0.00372	
r ₁	1.04761				55.07006
r ₂	0.38062				-0.28414
r ₃	-0.04321				0.00038
a ₀	1.0945	0.9702	0.9621	0.95	1.0945
a ₁	-9.2632	-8.9135	-8.9502	-8.9408	-9.2632
a ₂	71.0385	71.1493	71.1272	71.2096	71.0385
a ₃	-301.9012	-302.6287	-302.6034	-302.5241	-301.9012
a ₄	797.69	796.2505	796.3275	796.4621	797.69
a ₅	-1221.977	-1223.0127	-1222.9273	-1222.4308	-1221.977
a ₆	987.5574	987.6361	987.6872	988.6968	987.5574
a ₇	-319.4636	-318.7177	-318.6928	-317.3719	-319.4636
AAD (Desv. med. abs. %)	1.33	2.18	2.79	4.4	1.82
Bias (Average Dev.%)	-0.66	0.28	0.74	-0.64	-0.34
MD (Abs. Max. Dev.%)	5.2	6.48	6.91	15.53	6.97
RMS (Sqr. Root Mean %)	1.82	2.7	3.32	5.3	2.42
Standard Dev. (mPa·s)	0.011	0.022	0.029	0.076	0.059

Eyring Model (Gibbs Free Energy of Flow Activation)				
Temperature (K)	293.15	313.15	333.15	353.15
AAD (Abs Average Dev. %)	0.011	0.022	0.04	0.049
Bias (Average Dev.%)	0.000027	-0.0072	0.013	0.015
MD (Abs. Max. Dev.%)	0.12	0.31	0.35	0.48
RMS (Sqr. Root Mean %)	0.024	0.058	0.082	0.1
Standard Dev. (mPa·s)	0.0002	0.0003	0.0004	0.0004
Gibbs Free Energy of Flow Activation (Joule.mol ⁻¹) @ p = 0.1 Mpa				
AAD (Abs Average Dev. %)	0.000029	0.000028	0.000029	0.000022
Bias (Average Dev.%)	0.000008	0.000006	-0.000006	-0.000022
MD (Abs. Max. Dev.%)	0.000078	0.000075	0.00011	0.000096
RMS (Sqr. Root Mean %)	0.000039	0.000038	0.000045	0.00004
Standard Dev. (Joule.mol ⁻¹)	0.0004	0.0088	0.00031	0.00021

Table 12. Coefficients and statistics of modified RHS Model in this work and Eyring Model for η of mixture (1-x) Pseudocumene + (x) 1-Butanol.

X = 1-Butanol (fraction)	X = 0.0	X = 0.3	X = 0.5	X = 0.8	X = 1.0
v ₁	28.33704				31.12019
v ₂	-0.04647				0.02546
v ₃	3553.81146				3553.81716
v ₄	-1.30135				-0.90631
v ₅	3.83641				0.64931
v ₆	1.38101				0.95413
a		2.09054	2.18004	2.85119	
b		0.00257	0.00188	0.00175	
r ₁	0.81286				54.95703
r ₂	0.11402				-0.27721
r ₃	-0.00991				0.00036
a ₀	1.0945	1.81468	1.90853	1.21254	1.0945
a ₁	-9.26324	-8.84568	-9.12382	-9.47022	-9.26324
a ₂	71.0385	70.74176	70.48657	70.9554	71.0385
a ₃	-301.9012	-304.23623	-304.20233	-302.22912	-301.9012
a ₄	797.69	793.85204	794.26197	796.9853	797.69
a ₅	-1221.977	-1223.6778	-1223.1787	-1222.5759	-1221.977
a ₆	987.5574	990.15031	990.3538	987.51097	987.5574
a ₇	-319.4636	-314.33591	-314.42373	-319.56859	-319.4636
AAD (Desv. med. abs. %)	2.0091	1.81	1.47	2.99	1.5
Bias (Average Dev.%)	0.74	-0.15	-0.12	-0.018	-0.28
MD (Abs. Max. Dev.%)	5.53	6.78	4.51	11.96	4.86
RMS (Sqr. Root Mean %)	2.49	2.29	1.8	3.95	1.98
Standard Dev. (mPa·s)	0.025	0.024	0.024	0.062	0.037

Eyring Model (Gibbs Free Energy of Flow Activation)				
Temperature (K)	293.15	313.15	333.15	353.15
AAD (Abs Average Dev. %)	0.0044	0.007	0.018	0.022
Bias (Average Dev.%)	0.00093	0.002	0.0079	0.012
MD (Abs. Max. Dev.%)	0.044	0.093	0.17	0.2
RMS (Sqr. Root Mean %)	0.0088	0.016	0.035	0.04
Standard Dev. (mPa·s)	0.0001	0.0001	0.0003	0.0003
Gibbs Free Energy of Flow Activation (Joule.mol ⁻¹) @ p = 0.1 - 140 MPa				
AAD (Abs Average Dev. %)	0.000024	0.000024	0.000024	0.000025
Bias (Average Dev.%)	-0.000021	-0.000019	-0.00002	-0.00002
MD (Abs. Max. Dev.%)	0.00012	0.00013	0.00011	0.00012
RMS (Sqr. Root Mean %)	0.000045	0.000043	0.000047	0.000048
Standard Dev. (Joule.mol ⁻¹)	0.00026	0.019	0.022	0.092

Conclusions

The best method to obtain information of physico-chemical properties is experimental determination, but for many fluids of industrial interest it is not possible to measure viscosity in a wide range of pressure and temperature, being necessary to rely on theoretical calculations, in addition to its direct measurement. Having predictive methods, although with greater error or deviation from experimental data, viscosity values estimation and their dependence on pressure, temperature or density, or the molecular fraction for fluid mixtures, is provided.

Hard sphere model, with linear mixing rules for roughness factor R_η and nucleus molar volume V_0 , gives qualitative correct predictions in terms of dependence of viscosity on temperature, pressure and composition. The model is sensitive to molar volume, when linear mixing rules are used. The relative low performance of hard sphere model is not surprising, considering that mixtures can be highly asymmetric, in addition with using simple mixing rules that do not contain adjustable parameters. Analytically it is verified that viscosity of mixtures can be correlated for each isotherm, using equations (5), (3) and (10). V_0 is treated as an adjustable parameter for each isotherm and composition.

The generation of renewable fuels is a solution to reduce greenhouse gas emissions, therefore an alternative is the formulation of gasolines that include oxygenated compounds such as alcohols (1-butanol and 2-butanol) known as second generation biofuels.

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