

Measurement and Prediction of Biodiesel Volatility

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ABSTRACT: Vapor pressure directly affects the quality of ignition, atomization, and combustion of a fuel. Lower values lead to delayed ignition, poor atomization, and problematic combustion. Biodiesel fuels might present these problems because they have lower vapor pressure compared to that of petrodiesel. Similar to other properties, however, the magnitude of this property depends upon the composition of fatty acid alkyl esters in biodiesel; therefore, the knowledge of the relationship between these two variables is of great importance. This work reports the vapor pressures of 3 pure methyl esters and 10 biodiesel fuels. The experimental data were used to evaluate the predictive ability of Yuan's, Ceriani's, and cubic-plus-association equation of state (CPA EoS) models for its description. The results underline the good capacity of Yuan's and CPA models for describing the experimental data for all biodiesel fuels studied here, presenting an overall average temperature difference (ΔT_m) of 1.12 and 1.25 K, while the overall average deviations (OARDs) in vapor pressure are 3.41 and 0.80%, respectively.

1. INTRODUCTION

Biodiesel fuels are composed of fatty acid alkyl esters obtained by the transesterification of triglyceride compounds, using a short-chain alcohol, such as methanol or ethanol, in the presence of a catalyst. The common feedstocks for biodiesel production are vegetables oils, animal fats, and greases.^{1,2} Thus far, biodiesel fuels are seen to be the most appropriate alternative for petrodiesel fuels not only because of the economical and environmental advantages, such as nontoxicity, biodegradability, lower greenhouse effects, and domestic production, but also because biodiesel fuels are miscible with petrodiesel fuels at any proportion and, thus, compatible with the modern diesel engines.^{3–7} This technical profit is responsible for the ease and fast permeation of biodiesel fuels in the fuel markets even in the countries with plenty of petroleum resources because biodiesels help to enhance the performance of diesel engines and to safeguard the environment from the harmful emissions released in combustion of petrodiesel fuels. Many commercialized biodiesels are in forms of blends, such as B20 and B80, by having 20 and 80% of biodiesel in the mixture, respectively. B20, indeed, can reduce CO₂ emissions by 15.7%.⁸

Despite all of the advantages aforementioned, the usefulness of biodiesel fuels greatly depends upon the adequacy of their thermophysical properties. These must meet the specifications in standards, such as ASTM D6751⁹ and EN 14214.¹⁰ This concern has boosted overtime efforts to produce biodiesel with desired properties. Because these properties are manipulative (i.e., they can be changed by reformulating the composition of fatty alkyl esters), knowledge of the relationship between the physical properties and the composition of fatty alkyl esters is important.

Vapor pressures (and boiling points) express the volatility, safety, and stability of a fuel. While a higher value of this property can favor the evaporative emissions, a lower value leads to delayed ignition, poor atomization, and problematic combustion. Biodiesel fuels have lower vapor pressure and,

thus, might cause these problems. To be used in diesel engines alone or mixed with petrodiesel, this property of biodiesel must be adjusted by changing the composition of biodiesel to meet the standard values. For this purpose, because the experimental measurement is impractical, the use of predictive models is recommended. Many works in the literature have dealt with the measurement and estimation of vapor pressures for several methyl esters and biodiesels,^{11–17} but almost none of them described with detail their dependency upon the composition of fatty acid alkyl esters.

This work aims at reporting the experimental data of vapor pressures for 3 pure methyl esters and 10 biodiesel fuels and evaluating the predictive ability of Yuan's, Ceriani's, and cubic-plus-association equation of state (CPA EoS) models for their description.

2. EXPERIMENTAL SECTION

2.1. Biodiesel Sample Synthesis. The three methyl esters studied here were methyl laurate (with 97% purity from Fluka), methyl myristate (with 98% purity from SAFC), and methyl palmitate (with 97% purity from SAFC). Two of the biodiesel fuels available in our laboratory, soy A and GP (soybean + rapeseed), were obtained from Portuguese biodiesel producers, while the other eight biodiesel fuels were synthesized at our laboratory, as described in a previous work,¹⁸ by the transesterification reaction of the following vegetable oils with methanol. They are soybean (S), rapeseed (R), palm (P), and sunflower (Sf) synthesized from single-source vegetable oils and biodiesel produced from binary and ternary mixtures of oil: soybean + rapeseed (SR), rapeseed + palm (RP), soybean + palm (SP), and soybean + rapeseed + palm (SRP).

The biodiesel composition was characterized by gas chromatography with flame ionization detection (GC–FID) to know their methyl ester composition. Capillary GC was used to determine the methyl ester composition of the biodiesel samples. A Varian CP-3800 with FID in a split injection system with a select biodiesel for fatty acid

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Table 1. Compositions of the Biodiesels Studied, in Mass Percentage^a

FAME	S	R	P	SR	RP	SP	SRP	Sf	GP	soy A
C10		0.01	0.03		0.02	0.01	0.01			
C12		0.04	0.24	0.03	0.20	0.18	0.14	0.02	0.02	
C14	0.07	0.07	0.57	0.09	0.54	0.01	0.38	0.07	0.13	
C16	10.76	5.22	42.45	8.90	23.09	25.56	19.07	6.40	10.57	16.18
C16:1	0.07	0.20	0.13	0.15	0.17	0.11	0.14	0.09	0.13	
C18	3.94	1.62	4.02	2.76	3.02	4.04	3.30	4.22	2.66	3.82
C18:1	22.96	62.11	41.92	41.82	52.92	33.13	42.74	23.90	41.05	28.80
C18:2	53.53	21.07	9.80	37.51	15.47	31.72	28.08	64.16	36.67	50.46
C18:3	7.02	6.95	0.09	7.02	3.08	3.58	4.68	0.12	7.10	
C20	0.38	0.60	0.36	0.46	0.49	0.39	0.46	0.03	0.44	
C20:1	0.23	1.35	0.15	0.68	0.67	0.20	0.53	0.15	0.67	
C22	0.80	0.35	0.09	0.46	0.24	0.32	0.33	0.76	0.45	
C22:1	0.24	0.19	0.00	0.12	0.09	0.12	0.15	0.08	0.12	
C24		0.22	0.15			0.63				

^aS and soy A, soybean; R, rapeseed; P, palm; Sf, sunflower; SR, soybean + rapeseed; RP, rapeseed + palm; SP, soybean + palm; and SRP, soybean + rapeseed + palm.

methyl ester (FAME) column (30 m × 0.32 mm × 0.25 μm) was used to differentiate all methyl esters in analysis, including the polyunsaturated methyl esters. The column temperature was set at 120 °C and then programmed to increase to 250 °C at 4 °C/min. The detector and injector were set at 250 °C. The carrier gas was helium with a flow rate of 2 mL/min. Table 1 reports methyl ester compositions for the biodiesels selected for this work.

2.2. Measurement of Vapor Pressures. The vapor pressures of the methyl esters, biodiesels, and their mixtures studied here were measured using an ebulliometer previously used for measuring the vapor–liquid equilibrium (VLE) for several glycerol + water/alcohol systems.¹⁹ A detailed illustration of the experimental apparatus can be found on this previous work,¹⁹ and only a small description will be addressed here. The ebulliometer was composed of a boiling still with a port for liquid sampling/injection, a condenser, and a thermostatic bath to control the temperature. The pressure was kept constant through a vacuum line with a calibrated Baratron heated capacitance manometer 728 AMKS, with an accuracy of 0.50%. Approximately 20 mL of the sample was introduced into the ebulliometer. The sample, mixed with a magnetic stirrer, was then heated to its boiling point. The temperature was measured using a calibrated Pt100 temperature sensor with an uncertainty of 0.05 K. This procedure was repeated for different pressure values from 0.026 to 0.250 bar for all of the selected methyl esters and biodiesels. The boiling temperatures measured have a combined overall uncertainty of ±0.25 K.

3. MODELS OF VAPOR PRESSURE

The vapor pressures or boiling points of the biodiesel fuels studied here were predicted using three different approaches: Yuan's, Ceriani's, and CPA EoS models.

3.1. Yuan's Model. Yuan et al.¹² fitted the Antoine equation (eq 1) to the experimental data of vapor pressures for several pure FAMES that compose the biodiesel fuels reported in the works of Rose et al.¹¹ and Scott et al.¹³

$$\log(P^v_i) = A - \frac{B}{C + T} \quad (1)$$

where P^v_i is the vapor pressure of FAME in Pa, T is the boiling temperature in K, and A , B , and C are the fitting parameters. To predict the vapor pressures of biodiesel fuels, these are considered to behave as an ideal solution and the vapor pressure of the mixture is given as

$$P^v_{BD} = \sum_i (x_i P^v_i) \quad (2)$$

where P^v_{BD} is the vapor pressure of biodiesel fuels in Pa and x_i is the molar composition of FAME. Because there were no fitting parameters for C16:1, the contribution of this compound was added to C16:0. The nomenclature for esters adopted here is based on the fatty acid chain length, where the $Cx:y$ ester represents the methyl ester of fatty acid with x carbons and y unsaturations.

3.2. Ceriani's Model. Ceriani and co-workers have proposed a number of group-contribution models for estimating the thermophysical properties of fatty compounds and, among these, one for the vapor pressures.¹⁵ The model for predicting vapor pressures is shown in eqs 3 and 4

$$\ln P^v_i = \sum_k N_k \left(A_{1k} + \frac{B_{1k}}{T^{1.5}} - C_{1k} \ln T - D_{1k} T \right) + \left[M_i \sum_k N_k \left(A_{2k} + \frac{B_{2k}}{T^{1.5}} - C_{2k} \ln T - D_{2k} T \right) \right] + Q \quad (3)$$

with

$$Q = (f_0 + N_{f_1}) \left(\alpha + \frac{\beta}{T^{1.5}} - \gamma \ln(T) - \delta T \right) + (s_0 + N_{cs_1}) \quad (4)$$

where N_k is the number of groups k in the molecule i , M is the component molecular weight that multiplies the "perturbation term", A_{1k} , B_{1k} , C_{1k} , D_{1k} , A_{2k} , B_{2k} , C_{2k} , and D_{2k} are parameters obtained from the regression of the experimental data, k represents the groups of component i , Q is a correction term, f_0 , f_1 , s_0 , and s_1 are optimized constants, α , β , γ , and δ are optimized parameters obtained by regression of the databank as a whole, N_c is the total number of carbon atoms in the molecule, and N_{cs} is the number of carbons of the alcohol side chain. The parameter values can be found in the study by Ceriani et al.¹⁵

3.3. CPA EoS. Recently, the CPA EoS has been extended for application in biodiesel production and purification. It was applied to describe the liquid–liquid, vapor–liquid, and solid–liquid equilibria of binary and multicomponent systems containing fatty acids, fatty acid esters, water, short alcohols, and glycerol.²⁰ Lately, it successfully described densities at high

pressures²¹ and surface tensions²² for the same biodiesels studied in this work.

This equation of state has been extensively described on the above stated publications, and therefore, it will be briefly addressed here. It consists of the combination of a cubic contribution, in this work, Soave–Redlich–Kwong (SRK), with the Wertheim term, to take explicitly into account interactions between like molecules (self-association) and different molecules (cross-association).^{23–25}

Because biodiesels are composed of fatty acid esters, which are known not to self-associate, the association term disappears. In terms of the compressibility factor, the CPA EoS appears as

$$Z = \frac{1}{1 - b\rho} - \frac{a\rho}{RT(1 + b\rho)} \quad (5)$$

where we have the energy parameter, a , the co-volume parameter, b , and the molar density, ρ .

The energy parameter, a , is described as having a Soave-type reduced temperature dependency.

$$a(T) = a_0[1 + c_1(1 - \sqrt{T_r})]^2 \quad (6)$$

The classical van der Waals one-fluid mixing rules are used for computing the energy and co-volume parameters when the CPA EoS is extended for mixtures.

$$a = \sum_i \sum_j x_i x_j a_{ij} \quad a_{ij} = \sqrt{a_i a_j} (1 - k_{ij}) \quad b = \sum_i x_i b_i \quad (7)$$

The three pure-component parameters in the cubic term (a_0 , c_1 , and b) are regressed simultaneously from vapor pressure and liquid density pure-component data to overcome some of the SRK handicaps in what concerns the liquid-phase density description.

3.3. Evaluation of Models. The predictive ability of the models aforementioned was evaluated by simply calculating the relative deviations (RDs) between predicted and experimental values of vapor pressures according to eq 8

$$\text{RD} (\%) = \frac{P_{i,\text{calc}}^v - P_{i,\text{exp}}^v}{P_{i,\text{exp}}^v} \times 100 \quad (8)$$

or the average temperature deviation (ΔT_m) between the experimental and predicted normal boiling points (eq 9).

$$\Delta T_m (\text{K}) = \frac{\sum_n |(T_{\text{exp}} - T_{\text{calc}})|}{N_p} \quad (9)$$

The overall average relative deviation (OARD) was calculated through eq 10, where N_s is the number of systems studied and the average relative deviation (ARD) is the summation of the modulus of RD over N_p experimental data points.

$$\text{OARD} (\%) = \frac{\sum_n \text{ARD}}{N_s} \quad (10)$$

4. RESULTS AND DISCUSSION

The experimental vapor pressures for 3 pure methyl esters and 10 biodiesel fuels measured at different temperatures are presented in Tables 2 and 3. The upper temperature limit of the measurements, ca. 550 K, is imposed by the degradation of the biodiesel at higher temperatures under the measurement conditions.

Table 2. Experimental Boiling Point for Methyl Esters

C12		C14		C16	
T_b (K)	P^v (kPa)	T_b (K)	P^v (kPa)	T_b (K)	P^v (kPa)
441.40	5.07	449.14	2.63	492.30	5.27
451.90	8.11	467.17	5.27	504.05	7.90
460.55	10.64	478.96	8.00	512.85	10.64
467.15	13.17	487.43	10.64	520.15	13.37
472.45	15.71	494.51	13.37	534.45	20.37
480.70	20.37	499.64	15.71	549.05	30.40
488.05	25.43	508.05	20.27	560.10	40.63
494.15	30.40	515.70	25.33	569.70	50.76
504.60	40.63	522.17	30.40	577.60	60.90
512.84	50.76	532.89	40.63	584.55	71.03
519.85	60.90	541.49	50.76	590.50	81.06
525.50	70.93	548.77	60.90	595.90	91.19
531.15	81.16	555.11	71.03	600.90	101.43
		560.70	81.06		
		565.85	91.29		
		570.46	101.33		

The experimental data of the vapor pressure for the three pure methyl esters measured here were compared to those previously reported in the literature,^{11,16} and they were found to be in acceptable agreement with an average deviation of 1.70% for methyl laurate (C12:0), 3.45% for methyl myristate (C14:0), and 1.62% for methyl palmitate (C16:0), as shown in Figure 1. As expected, the vapor pressures are lower (higher boiling points) for the long-chain fatty acid esters and, thus, for biodiesels with larger amounts of these esters in their composition. For example, the palm biodiesel presented a higher vapor pressure than rapeseed biodiesel because the first has a higher percentage of methyl palmitate (C16:0) and the second is richer in methyl oleate (C18:1).

For further completeness, Antoine equation parameters for the three fatty acid esters considered were regressed and presented in Table 4.

The CPA pure-compound parameters for the FAMES that compose the biodiesels studied were previously estimated²¹ using recently published density experimental data, in the temperature range of 283.15–373.15 K, and used to successfully describe high-pressure densities⁷ and surface tensions¹⁴ of the selected biodiesels. However, when extrapolated for the temperature range of interest for this work, 450–600 K, poor predictions were obtained for the biodiesel vapor pressures. Consequently, a new set of CPA pure-compound parameters for the FAMES composing the biodiesels studied is proposed here for applications at high temperatures. The recent density data by Pratas et al.⁷ and vapor pressures by Yuan et al.¹² were used in a simultaneous regression for parameter estimation. Critical properties to be applied in eq 6 were generated by the Wilson and Jasperson²⁶ group-contribution model for the saturated FAMES and by Ambrose²⁷ for the unsaturated FAMES. These group-contribution models were shown previously to be the best models to calculate critical properties for the correspondent family of compounds.²⁸ Parameter values are presented in Table 5, as well as critical temperature values and deviations in vapor pressures and liquid densities.

Higher density errors for C10 and C12 were obtained, which can be related to the extrapolation for high temperatures of the density–temperature relations proposed in ref 7, which seem to provide poorer density descriptions at high temperatures for

Table 3. Experimental Boiling Point for (a) Biodiesel Fuels and (b) Biodiesel Fuels from Oil Mixtures^a

(a) Biodiesel Fuels									
Sf		soy A		S		R		P	
T_b (K)	P^v (kPa)	T_b (K)	P^v (kPa)	T_b (K)	P^v (kPa)	T_b (K)	P^v (kPa)	T_b (K)	P^v (kPa)
490.98	2.74	497.15	3.85	491.10	2.74	493.51	2.74	490.65	3.85
500.56	3.85	505.55	5.17	499.74	3.85	502.65	3.85	499.79	5.17
505.51	4.56	512.30	6.59	505.80	4.56	507.73	4.56	506.05	6.48
510.44	5.37	518.90	8.11	509.20	5.27	511.19	5.27	512.65	8.21
515.29	6.28	523.15	9.22	515.47	6.28	516.50	6.28	516.73	9.32
520.49	7.40	527.15	10.64	520.40	7.60	522.29	7.60	520.20	10.44
525.48	8.61	534.60	13.27	523.95	8.61	525.94	8.61	527.01	13.37
528.12	9.32	539.37	15.40	524.15	9.32	528.31	9.32	531.33	15.30
532.63	10.64			531.00	10.64	531.90	10.54	537.65	18.34
538.16	12.46			533.35	11.65	535.01	11.65		
545.83	15.40					537.65	12.46		
556.42	20.37					540.40	13.17		
561.21	23.00					543.32	15.20		
565.25	25.43					552.15	18.34		
569.89	28.47								
572.76	30.50								
575.36	32.42								
579.21	35.46								
582.92	38.60								
585.08	40.53								
590.39	45.60								
595.24	50.66								

(b) Biodiesel Fuels from Oil Mixtures									
SP		GP		SRP		RP		SR	
T_b (K)	P^v (kPa)	T_b (K)	P^v (kPa)	T_b (K)	P^v (kPa)	T_b (K)	P^v (kPa)	T_b (K)	P^v (kPa)
486.15	2.74	490.95	2.84	488.40	2.74	487.15	2.74	492.40	2.74
496.15	3.85	499.45	3.85	497.98	3.85	495.75	3.85	501.60	3.85
500.90	4.56	503.85	4.56	502.80	4.56	498.45	4.56	506.59	4.56
505.65	5.27	507.90	5.27	506.24	5.27	502.93	5.27	510.90	5.27
510.40	6.28	513.15	6.28	512.04	6.28	508.35	6.38	516.15	6.28
516.15	7.60	518.65	7.60	517.54	7.60	515.90	7.60	521.65	7.60
520.65	8.61	523.15	8.71	521.80	8.71	519.65	8.61	525.30	8.61
522.65	9.32	524.90	9.32	523.90	9.32	521.90	9.32	527.80	9.32
527.15	10.64	529.40	10.64	528.19	10.64	525.95	10.64	531.65	10.64
530.15	11.65	531.90	11.65	535.01	11.65	529.36	11.65	534.60	11.65
532.27	12.46	534.40	12.46	537.65	12.46	531.51	12.46		
534.15	13.27	536.65	13.37	534.89	13.17	533.83	13.37		
538.50	15.20			538.74	15.20	536.17	14.19		
544.90	18.34			545.40	18.24	538.37	15.30		
548.55	20.37					543.45	18.24		
552.30	22.70								
556.25	25.33								
560.33	28.37								
563.15	30.40								
568.15	35.46								
571.25	40.53								

^aS and soy A, soybean; Sf, sunflower, R, rapeseed, P, palm; SR, soybean + rapeseed; RP, rapeseed + palm; SP, soybean + palm; and SRP, soybean + rapeseed + palm.

these smaller compounds. However, an excellent vapor pressure description, of relevance for this work, is assured, as seen in Table 5. Subsequently, the good vapor pressure description of biodiesels rich in C10 or C12 is guaranteed.

Because there were no data of the vapor pressure for methyl palmitoleate (C16:1), the parameters of the CPA EoS used for this compound were the same as those of methyl palmitate (C16:0). In terms of ARDs on the vapor pressures, Yuan's and

CPA EoS models were shown to be better than Ceriani's model by presenting an OARD of only 3.41 and 0.79%, respectively, compared to 9.85% of the latter, as shown in Table 6. Even for the pure FAME, Ceriani's model shows large deviations in the range of pressures studied.

Similar results are observed for the boiling points when estimating the average temperature deviations (ΔT_m) or its overall value ($O\Delta T_m$). Yuan's and CPA EoS models describe

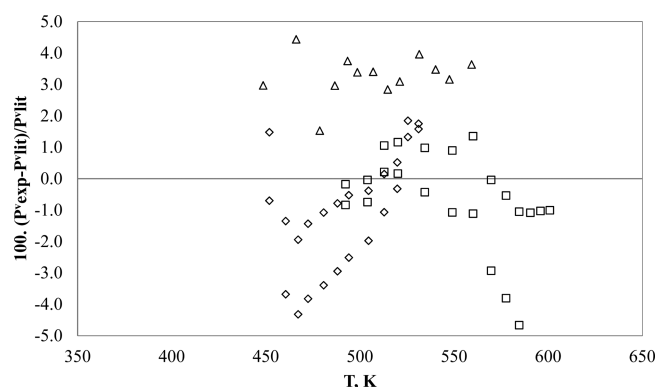


Figure 1. RDs between the experimental and literature data of the vapor pressure for three methyl esters: (◇) methyl laurate (C12:0), (△) methyl myristate (C14:0), and (□) methyl palmitate (C16:0).^{11,16}

Table 4. Antoine Equation ($\text{Log}_{10} = A - B(T + C)$, with P in mmHg and T in °C) Constants for Fatty Acid Esters

	A	B	C
C12:0	9.122	3677.486	322.394
C14:0	7.429	2036.858	153.707
C16:0	7.164	2037.26	147.818

the experimental data of the boiling points in the range of pressures studied with only 1.12 and 1.25 K of overall average temperature deviation ($\text{O}\Delta T_m$), respectively, compared to 4.01 K of Ceriani's model, as shown in Table 7. The predicted boiling points of biodiesel fuels were plotted against the experimental data in Figure 2, where Yuan's and CPA EoS models show a very good agreement with the experimental data, while Ceriani's model presents larger deviations at high temperatures in the range of pressures studied, overpredicting boiling points.

Table 5. FAME Critical Temperatures, CPA Pure-Compound Parameters, and Modeling Results

FAME	T_c (K)	a_0 ($\text{J m}^3 \text{ mol}^{-2}$)	c_1	b ($\times 10^4, \text{m}^3 \text{ mol}^{-1}$)	ARD ^a (%)	
					P^v	ρ
C10	671.66	15.6091	2.53578	9.12143	3.05	10.16
C12	710.41	19.5572	2.38142	10.1706	1.47	4.34
C14	740.97	22.4382	2.37557	10.7970	1.58	1.99
C16	765.92	25.2426	2.35711	11.2031	1.05	0.93
C16:1	749.63	25.2426	2.35711	11.2031	1.05	0.93
C18	788.63	29.2890	2.23414	11.5228	0.65	0.45
C18:1	772.34	29.0970	2.17406	11.3055	1.52	0.41
C18:2	786.37	26.9235	2.29569	11.1373	4.87	0.42
C18:3	797.26	25.0167	2.44113	10.9424	5.60	0.44
C20	803.28	32.2317	2.14492	11.7254	2.01	0.73
C20:1	786.99	31.5768	2.13976	11.5255	2.23	0.66
C22	817.47	36.1734	2.03297	11.8412	2.48	1.01
C22:1	801.18	36.9556	1.97865	11.7285	2.65	1.00
C24	830.41	40.0294	1.94411	11.9713	2.85	1.27

^a

$$\text{ARD} (\%) = \frac{1}{N_p} \sum_{i=1}^{N_s} \left| \frac{\text{exp}_i - \text{calc}_i}{\text{exp}_i} \right| \times 100$$

Table 6. ARDs in the Vapor Pressure for Biodiesels and Methyl Esters Obtained with Yuan's, Ceriani's, and CPA EoS Models

compound	ARD ^a (%)		
	Yuan	Ceriani	CPA EoS
soy A	5.95	12.80	0.43
S	2.93	4.88	0.41
R	2.47	9.29	0.69
P	5.10	15.08	0.51
Sf	0.00	7.60	2.21
GP	5.14	10.91	0.43
SR	2.78	4.08	0.38
SP	2.75	13.24	1.62
PR	3.72	13.08	0.61
SRP	3.29	7.58	0.68
OARD (%)	3.41	9.85	0.80

^a

$$\text{ARD} (\%) = \frac{1}{N_p} \sum_{i=1}^{N_s} \left| \frac{\text{exp}_i - \text{calc}_i}{\text{exp}_i} \right| \times 100$$

5. CONCLUSION

The normal boiling points of 10 biodiesel fuels, 3 methyl esters, and 1 binary mixture of methyl esters were measured and predicted by three different approaches: Yuan's, Ceriani's, and CPA EoS models. It is shown that Yuan's and CPA EoS models provide a good description of the experimental data with only 1.12 and 1.25 K of overall average temperature difference ($\text{O}\Delta T_m$) in boiling temperatures and 3.41 and 0.80% of overall average deviations (OARDs) in vapor pressures, respectively. In addition, a new set of CPA EoS pure-compound parameters for FAMES for applications at high temperatures is proposed.

Table 7. Temperature Difference Obtained with Yuan's, Ceriani's, and CPA EoS Models for the Selected Biodiesels in the Pressure Range Studied

biodiesel fuel	ΔT_m (K)		
	Yuan	Ceriani	CPA EoS
soy A	2.02	4.84	1.87
S	0.93	1.73	0.70
R	0.70	3.61	0.66
P	1.72	6.35	2.08
Sf	0.30	3.51	1.52
GP	1.72	4.00	1.49
SR	0.82	1.46	0.85
SP	1.06	6.36	1.05
PR	1.21	5.24	1.27
SRP	0.74	3.00	1.04
$O\Delta T_m$ (K)	1.12	4.01	1.25

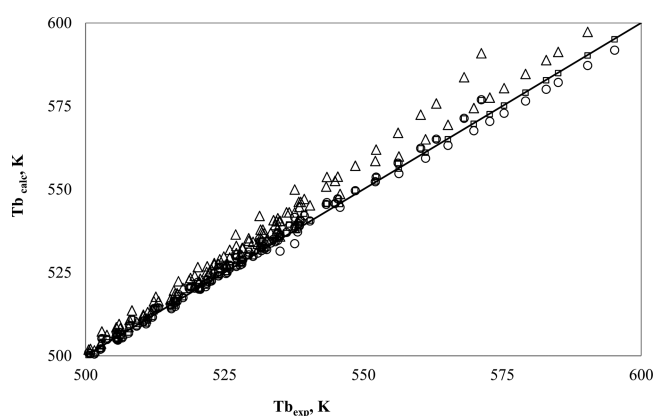


Figure 2. Linear relationship between the predicted and measured normal boiling points for 10 biodiesel fuels: (—) ideal, (□) Yuan's, (△) Ceriani's, and (○) CPA EoS models.

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Notes

The authors declare no competing financial interest.

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