

Physical Property Prediction for Waste Cooking Oil Biodiesel

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Abstract: This paper focuses on the physical property prediction of waste cooking oil biodiesel and examines the accuracy of different methods to estimate reliable basic physical properties, including density, viscosity and surface tension of waste cooking oil biodiesel in a wide range of temperature based on its fatty acid methyl ester component. A program for the physical property prediction of the biodiesel was developed and experimental measurements for the density, viscosity and surface tension of the biodiesel were performed to validate the chosen methods. The results show that the modified Rackett equation and the Orrick-Erbar method have the high estimation accuracy for the prediction of the density and the viscosity, respectively. The Sastri-Rao method and the Pizer method have the accuracy enough to predict the surface tension.

Keywords: Waste cooking oil biodiesel, fatty acid methyl ester, physical properties, estimation.

1. INTRODUCTION

Due to the world's energy shortage problem, it is more and more urgent to find alternative energy source as soon as possible. Plenty of fossil fuels have been consumed, which causes the depletion of these resources. On the other hand, the combustion of fossil fuels results in a serious environmental pollution and a serious greenhouse effect.

Biodiesel fuels derived from animal fats and vegetable oils are currently the most widely accepted fuels for engines due to their renewability, less particularly emissions and good lubrication properties. Besides, biodiesel is non-toxic, biodegradable and contains essentially no sulphur or aromatics [1-4]. Under steady operating conditions of an engine, CO and HC emissions decrease with the increase of the ratio of biodiesel in petroleum diesel [5-9]. Therefore, the research and development of biodiesel fuels have become a new hot field in recent years. Meanwhile, the USA government's plan to increase bioenergy production by threefold in ten years has added impetus to the research for viable biodiesel [10]. Biodiesel can be obtained from many oleaginous vegetable species such as soybean, sun-flower, peanut and so on. The choice of biodiesel source to be used mainly depends on availability. In China, waste cooking oil is a potential low cost biodiesel feedstock. It is estimated that about (0.8-1.0) million tonnes of waste cooking oil are collected each year, mainly from the catering industry. Its price is approximately half that of virgin oil [11] and the biodiesel fuels made from waste cooking oil have similar properties with the required fuels for diesel engines. However, the task of determining the fuel properties of the waste cooking oil biodiesel still remains a challenge for engine researchers [12]. The focus of this paper is to

determine the basic physical properties of the biodiesel such as density, viscosity and surface tension in a wide range of temperatures, which strongly influence spray properties, atomization and combustion processes, engine deposits formation, engine performances in cold weather conditions and are used as input data for predictive engine combustion models, while the wide range of temperatures required for these properties makes it difficult to experimentally measure them.

Up to now, there are several available methods in the literature to determine the density of the biodiesel. Blangino *et al.* [13] used the modified Rackett equation combining a mixing role to estimate the density of biodiesel fuels based on their fatty acid methyl ester composition. Tate *et al.* [14] measured the density of three different biodiesels, namely, canola-oil biodiesel, soya bean-oil biodiesel and fish-oil biodiesel and reported a regression line equation which was developed based on the data obtained from a capacitance type liquid level meter within temperature range of (293-573)K and has different regression coefficients corresponding to the three different biodiesel fuels. Tat *et al.* [15] also gave a temperature-dependant regression linear equation to predict the specific gravity of a soybean oil-based biodiesel with an experimental method. Tesfa *et al.* [16] obtained a linear regression equation for evaluating the densities of biodiesel fuels based on the measurements of corn oil biodiesel, rapeseed and waste oil biodiesel at the temperature range of 290 to 360 K.

As for the methods to predict the viscosity of biodiesel fuels, Allen *et al.* [17] measured the viscosities of several pure fatty acid esters commonly found in biodiesel fuels and then predicted the viscosities of six vegetable oil methyl ester biodiesels at 313K based on their pure fatty acid methyl ester compositions with the modified Grunberg-Nissan equation. Alpetekin and Canakci [18] investigated the variation of the viscosity as a function of different percentages of blends of bio-diesel at 313K for several biodiesels such as waste palm oil, sunflower, soybean oil,

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corn oil, cottonseed oil biodiesel fuels with an experimental method. They developed a second degree empirical equation to calculate the viscosity of blended biodiesel taking the fraction of biodiesel in the mixture as the main parameter. Tesfa *et al.* [16] gave an empirical correlation of the kinematic viscosity and temperature to estimate the viscosity of biodiesel fuels based on their measured results.

To estimate the variation of the surface tension of biodiesel fuels, Allen *et al.* [19] used the Sugden expression to estimate the surface tension of each pure fatty acid methyl ester component in biodiesel fuels and then calculated the mean surface tension of biodiesel fuels with a weighted function equation of the pure components.

In a word, there are two kinds of methods to determine the basic physical properties, density, viscosity and surface tension of biodiesel fuels at different temperatures. The first one was put forward by Blangino *et al.* [13], Allen *et al.* [17] and Allen *et al.* [19], in which the physical properties of biodiesel fuels are determined based on the pure fatty acid methyl ester components in biodiesel fuels, and the properties can be obtained once the pure fatty acid methyl ester compositions in biodiesel fuels are measured. General methods for pure liquids and their mixtures at different temperatures can be used to estimate the physical properties of the pure fatty acid methyl esters and biodiesel fuels. The second one is regression linear equations coming from experimental results. The experimental regression correlations for the estimation of the basic physical properties of biodiesel fuels at different temperatures are fairly complicated, depending on the number of input parameters. And this correlation is variation for the different biodiesel sources. The validity of these expressions depends on the experimental conditions, not on the molecular structure of their components and the characteristics of the mixtures. Moreover, the biodiesels which come from different raw materials may have different physical characteristics, due to the differences of fatty acid methyl ester components. Therefore, the second method has its application limits. The objective of this paper is to compare the prediction power of the first type of methods and propose the existing best correlations used for estimating the physical properties of waste cooking oil methyl esters biodiesel in terms of density, viscosity and surface tension.

2. METHODOLOGY FOR PREDICTING THE PHYSICAL PROPERTIES OF THE BIODIESEL

The available equations in literature for the prediction of the physical properties of pure liquids are used to estimate the density, viscosity and surface tension of each fatty acid methyl ester which is the main component of the biodiesel. Then the corresponding properties of the biodiesel are determined with some mixing rules in terms of the weight percent of each pure fatty acid methyl ester in the biodiesel fuel. This methodology can be used to infer the influence of the molecular structure on the physical properties. When the properties of pure liquids or biodiesel fuels are computed, the predictive accuracy of the used formulae should be evaluated and analyzed in comparison with other expressions and measured data for the same property in the same

conditions. Therefore, a computational program based on the Matlab software was developed. Finally, the methods with the best accuracy for the estimation of physical properties of the biodiesel are proposed.

2.1. Estimation of Normal Boiling Point, Critical Parameters and Acentric Factor

The existing methods of the property estimation for biodiesel fuels are proposed in terms of normal boiling point, critical parameters and acentric factor of methyl esters and molecular weight. Therefore, these parameters are estimated first based on the published methods which have been verified to have the best or better accuracy.

The normal boiling point T_b is estimated by Constantinou-Gani correlation which yields the smaller errors analyzed by Anand *et al.* [12].

$$T_b = 204.359 \ln(\sum \Delta_{1T_b} + W \sum \Delta_{2T_b}). \quad (1)$$

The critical parameters (T_C , P_C , V_C) of the fatty acid methyl esters are predicted by Joback method [20],

$$T_C = T_b / [0.584 + 0.965 \sum \Delta_T - (\sum \Delta_T)^2], \quad (2)$$

$$P_C = \left(0.113 + 0.0032N - \sum \Delta_P \right)^2, \quad (3)$$

$$V_C = 17.5 + \sum \Delta_V. \quad (4)$$

As recommended by Reid *et al.* [20], these equations yield the smaller error for the estimation of the critical parameters of pure components.

The acentric factor ω is predicted by the following equation which yields the higher accuracy [21].

$$\omega = \frac{-[\ln(P_C / 1.01325) + f^{(0)}]}{f^{(1)}}. \quad (5)$$

where, $f^{(0)}$ and $f^{(1)}$ can be expressed as the functions of reduced normal boiling point temperature $T_{br}(=T_b/T_C)$ as follows:

$$f^{(0)} = \frac{-5.97616(1-T_{br}) + 1.29847(1-T_{br})^{1.5} - 0.60394(1-T_{br})^{2.5} - 1.06841(1-T_{br})^5}{T_{br}},$$

$$f^{(1)} = \frac{-5.03365(1-T_{br}) + 1.11505(1-T_{br})^{1.5} - 5.41217(1-T_{br})^{2.5} - 7.46628(1-T_{br})^5}{T_{br}}.$$

The estimated results of the normal boiling point temperature, critical parameters and acentric factors are shown in Table 1.

2.2. Physical Property Estimation of the Biodiesel

2.2.1. Density

There are a number of techniques for estimating pure liquid density. Compared with other techniques, the following three methods are simpler and appear to be highly accurate [20], so they are chosen to predict the densities of the fatty acid methyl esters in a wide range of temperature.

Table 1. Predicted Normal Boiling Point, Critical Parameters and Acentric Factor of Fatty Acid Methyl Ester

Symbol	Name	T_b (K)	T_c (K)	P_c (MPa)	$V_c \times 10^{-3}$ ($m^3 \cdot mol^{-1}$)	ω
C12:0	Methyl laurate	536.0	695.1	1.6511	0.7895	0.8864
C14:0	Methyl myristate	569.7	723.9	1.4208	0.9015	0.9833
C16:0	Methyl palmitate	611.5	766.9	1.2355	1.0135	1.0559
C18:0	Methyl stearate	624.5	775.4	1.0842	1.1255	1.0941
C18:1	Methyl oleate	624.4	774.2	1.1223	1.1055	0.9784
C18:2	Methyl linoleate	624.4	798.3	1.1625	1.0855	0.9056
C18:3	Methyl linolenate	624.4	801.7	1.2048	1.0655	0.8243
C20:0	Methyl arachidate	643.7	797.1	0.9591	1.2375	1.0108
C22:0	Methyl behenate	660.3	819.1	0.8545	1.3495	0.9390
C22:1	Methyl erucate	660.3	819.1	0.8811	1.3295	0.9287
C24:0	Methyl lignocerate	679.4	841.7	0.7661	1.3295	0.8065

2.2.1.1. The Modified Rackett Equation [20, 21]

$$\rho = \rho_R / (0.29056 - 0.08775\omega)^\phi. \quad (6)$$

where, the reference density ρ_R is given from published values [22, 23] and ϕ is a fugacity coefficient.

$$\phi = (1 - T_r)^{2/7} - (1 - T_r^R)^{2/7}.$$

2.2.1.2 Hankinson-Brost-Thomson (HBT) Method [20]

$$\frac{M}{\rho V_c} = V_R^{(0)} [1 - \omega V_R^{(\delta)}]. \quad (7)$$

In this equation, $V_R^{(0)}$ and $V_R^{(\delta)}$ are expressed as

$$V_R^{(0)} = 1 + a(1 - T_r)^{1/3} + b(1 - T_r)^{2/3} + c(1 - T_r) + d(1 - T_r)^{4/3} \quad (0.25 < T_r < 0.95)$$

$$V_R^{(\delta)} = [e + fT_r + gT_r^2 + hT_r^3] / (T_r - 1.00001) \quad (0.25 < T_r < 1.0)$$

where, a, b, c, d, e, f, g and h are constants.

2.2.1.3. Bhirud Method [20]:

$$\ln \frac{P_c M}{\rho R T} = \ln V^{(0)} + \omega \ln V^{(1)}. \quad (8)$$

where,

$$\ln V^{(0)} = 1.39644 - 24.076T_r + 102.615T_r^2 - 255.719T_r^3 + 355.805T_r^4 - 256.617T_r^5 + 75.1088T_r^6.$$

$$\ln V^{(1)} = 13.4412 - 135.7437T_r + 533.380T_r^2 - 1091.453T_r^3 + 1231.43T_r^4 - 728.227T_r^5 + 176.737T_r^6.$$

The density of biodiesel fuels is predicted by weighting the density of each fatty acid methyl ester estimated by the aforementioned equations as follows:

$$\rho_m = \sum y_i \rho_i. \quad (9)$$

2.2.2. Viscosity

In the present work, the following methods are used to predict the viscosity of each fatty acid methyl ester.

2.2.2.1. Krisnangkura Method

Krisnangkura *et al.* [24] presented different expressions for the short-chain saturated fatty acid esters with low carbon number (from C8:0 to C12:0) and the long-chain saturated fatty acid esters with high carbon number (from C14:0 to C24:0). These expressions relate the natural logarithm of the kinematic viscosity with the temperature and the carbon number of the compound, starting from Andrade's formula [20] and through thermodynamic considerations.

For short-chain methyl esters C6:0-C12:0, viscosity is expressed as

$$\ln \mu = -2.915 - 0.158z + \frac{492.12}{T} + \frac{108.35}{T} z. \quad (10)$$

For long-chain methyl esters C12:0-C18:0, it becomes

$$\ln \mu = -2.177 - 0.202z + \frac{403.66}{T} + \frac{109.77}{T} z. \quad (11)$$

The following expressions are used for unsaturated fatty acid methyl esters C18:1, C18:2, C18:3, and C22:1, respectively.

$$\ln \mu_{18:1} = -5.03 + \frac{2051.5}{T}, \quad (12)$$

$$\ln \mu_{18:2} = -4.51 + \frac{1822.5}{T}, \quad (13)$$

$$\ln \mu_{18:3} = -4.18 + \frac{1685.5}{T}, \quad (14)$$

$$\ln \mu_{22:1} = -5.42 + \frac{2326.2}{T}. \quad (15)$$

2.2.2.2. Orrick-Erbar Method [20-21]

$$\ln \frac{\eta}{\rho_{20} M} = A + \frac{B}{T} \cdot (T < 0.75T_r) \quad (16)$$

The values of the parameters A and B are computed from the contribution of the function group listed in table 9.9 in Reid *et al.* [20].

2.2.2.3. Sastri-Rao Method [21]

$$\eta = \eta_B p_{vp}^{-N} \quad (17)$$

where, η_B , p_{vp} and N are determined by the following expressions,

$$\eta_B = \sum \Delta \eta_B + \sum \Delta \eta_{Bcor}$$

$$\ln p_{vp} = (4.5398 + 1.0309 \ln T_b) \times \left[1 - \frac{(3 - 2T/T_b)^{0.19}}{T/T_b} - 0.38(3 - 2)T/T_b^{0.19} \ln(T/T_b) \right] \quad (T < T_b)$$

$$N = 0.2 + \sum \Delta N + \sum \Delta N_{cor}$$

2.2.2.4. (d) Velzen, Vardoza, and Langenkamp (VVL) Method [20]

$$\log \eta = B(T^{-1} + T_0^{-1}) \quad (18)$$

where,

$$B = B_A + \sum \Delta B$$

$$B_A = \begin{cases} 530.59 + 13.740N^* & N^* > 20 \\ 24.79 + 66.885N^* + 1.3173(N^*)^2 - 0.00377(N^*)^3 & N^* < 20 \end{cases}$$

$$T_0 = \begin{cases} 238.59 + 8.164N^* & N^* > 20 \\ 28.86 + 37.439N^* - 1.3547(N^*)^2 + 0.02076(N^*)^3 & N^* < 20 \end{cases}$$

$$N^* = z + \sum \Delta N^*$$

2.2.2.5. Vogel Equation [25]

$$\ln \eta = C + \frac{D}{T + E} \quad (19)$$

The viscosity of biodiesel fuels is calculated by Grunberg-Nissan mixing rule:

$$\ln \eta_m = \sum_i y_i \ln \eta_i + \frac{1}{2} \sum_{i=1}^n \sum_{j=1, j \neq i}^n y_i y_j G_{ij}(T) \quad (20)$$

where,

$$G_{ij} = \sum \Delta_i - \sum \Delta_j + K$$

$$K = \frac{0.3161 \times (z_i - z_j)^2}{z_i + z_j} - 0.1188(z_i - z_j)$$

2.2.3. Surface Tension

Essentially all existing useful estimation techniques for the surface tension of a pure liquid are empirical and

correlated with critical property. The following four methods are used to predict surface tension of fatty acid methyl esters.

2.2.3.1. Miller Method [20]

$$\sigma = P_C^{2/3} T_C^{1/3} Q (1 - T_r)^{11/9} \quad (21)$$

$$Q = 0.1196 \left[1 + \frac{T_{br} \ln(P_C/1.01325)}{1 - T_{br}} \right] - 0.297$$

2.2.3.2. Pizer Method [21]

$$\sigma = P_C^{2/3} T_C^{1/3} \frac{1.86 + 1.8\omega}{19.05} \left(\frac{3.75 + 0.91\omega}{0.291 - 0.08\omega} \right)^{2/3} (1 - T_r)^{11/9} \quad (22)$$

2.2.3.3. Sastri-Rao Method [21]

$$\sigma = 0.158 P_C^{0.50} T_b^{-1.5} T_C^{1.85} \left(\frac{1 - T_r}{1 - T_{br}} \right)^{11/9} \quad (23)$$

2.2.3.4. (d) Zuo-Sternby Method [21]

$$\sigma_r = \ln \left(1 + \frac{\sigma}{T_C^{1/3} P_C^{2/3}} \right) \quad (24)$$

where, σ_r of the target liquid is related with the $\sigma_r^{(1)}$ and $\sigma_r^{(2)}$ of methane and octane.

$$\sigma_r = \sigma_r^{(1)} + \frac{\omega - \omega^{(1)}}{\omega^{(2)} - \omega^{(1)}} (\sigma_r^{(2)} - \sigma_r^{(1)})$$

For methane

$$\sigma_r^{(1)} = 40.520(1 - T_r)^{1.287}$$

For octane

$$\sigma_r^{(2)} = 52.095(1 - T_r)^{1.21548}$$

Use the following mixture rule [17] to predict the surface tension of biodiesel fuels

$$\sigma_m = \sum_{i=1}^n w_i y_i \sigma_i \quad (25)$$

3. EXAMINED FUEL AND EXPERIMENTAL MEASUREMENTS

The waste cooking oil biodiesel chosen as the examined fuel was produced locally in Chongqing municipality. The mass percent of the fatty acid methyl esters comprising this biodiesel are tested with the gas chromatography analysis method which adopts polyethylene glycol with polarity capillary column and can separate each components of fatty acid methyl ester of the biodiesel well by Research Institute of Petroleum Processing of China. The tested results are shown in Table 2.

The density was measured with a glass hydrometer. The HS-4(B) thermostatic bath (range 258K to 368K, precision $\pm 0.02K$) is used to maintain the temperature of the biodiesel sample constant. The density data of the biodiesel fuel were collected in every 10K from 293K to 353K and the same experimental process was repeated four times. The final result at each temperature was obtained by averaging the

experimental data obtained by repeating the experiment four times.

Table 2. Mass Percent of Fatty Acid Methyl Ester in the Examined Biodiesel

Fatty Acid Methyl Ester	Mass Percent
C12:0	0.0074
C14:0	0.0148
C16:0	0.1961
C18: 0	0.0674
C18:1	0.3244
C18: 2	0.2667
C18: 3	0.0333
C20: 0	0.0212
C22: 0	0.0024
C 22:1	0.0289
C24: 0	0.0024

The viscosity was tested with an HB-YND glass viscometer maintaining the biodiesel sample at constant temperature in a thermostatic bath (range 293K to 393K, precision ± 0.01 K). The measurement was conducted between 293K and 353K. The surface tension has been tested with a MiniLab ILMS interfacial tensiometer (Interfacial tension range: 0.005-2000 N/m depending on the selected sensor, precision 0.1mN/m). A thermostatic bath was used to control the temperature of the biodiesel sample which was changed in every 10K from 303K to 353K. The testing process was carried out four times. The average value of the four different experimental data at same temperature is the final result corresponding to the specific temperature. The tested results of the density, viscosity and surface tension are shown in Table 3.

4. RESULTS AND DISCUSSION

The predicted results of the physical properties of the biodiesel are shown in Figs. (1-3). Fig. (1) gives a comparison between the predicted densities by three methods and the experimental results. At low temperatures, the density of the biodiesel decreases linearly with

temperature. It is found that the results of modified Rackett method are the closest to the experimental results, and the average relative error is 0.19%. Both the HBT and Birud methods overestimate the values of density and the average relative errors are 17.49% and 4.68%, respectively. Therefore, it is suggested that the modified Rackett equation should be used to predict the density of the biodiesel when the reliable values of the reference densities for the fatty acid methyl esters are available. Otherwise, Birud method is recommended because it yields a smaller error and has a similar computational complication compared with HBT method.

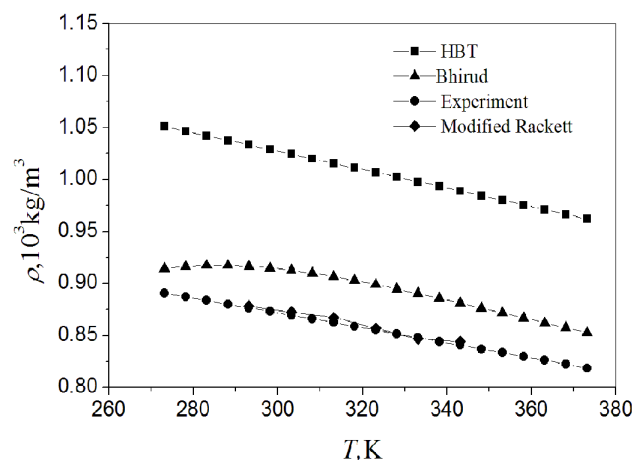


Fig. (1). Density.

Fig. (2) shows the comparison of the estimated viscosity results and the experimental results. The prediction values by the Orrick-Erbar method are the closest to the experimental results, and the average relative error is 7.82%. The average relative errors of the Sastri-Rao and VVL methods are 57.17% and 23.88%, respectively. The Krisnangkura and Vogel methods have middle class of accuracies and their average relative errors are 11.26% and 12.34%, respectively. But the difference between the estimated results from the above five methods and the experimental results are decreased with the increase of temperature. Although the Sastri-Rao and VVL methods consider the influence of molecular structure, the Sastri-Rao method assumes that viscosity and pressure have similar relationships with temperature and VVL assumes that $\log \eta$ is linear in T^{-1} . Both the Krisnangkura and Vogel methods come from the experimental data-fitting of the temperature dependent

Table 3. Experimental Results of Biodiesel Physical Properties

Temperature (K)	Density $\times 10^3$ (kg/m ³)	Viscosity $\times 10^{-3}$ (Pa.s)	Surface Tension $\times 10^{-3}$ (N/m)
293	0.8782	6.56	
303	0.8728	5.22	32.32
313	0.8675	4.22	29.60
323	0.8571	3.51	29.19
333	0.8469	3.00	28.56
343	0.8441	2.55	28.07
353	0.8322	2.28	27.59

viscosity of each fatty acid methyl esters, so they also relate the viscosity to the molecular structure of biodiesel fuels. Compared with the previous four methods, the Orrick-Erbar method is modified to include the density, so it has the highest prediction accuracy in predicting the viscosity of biodiesel fuels.

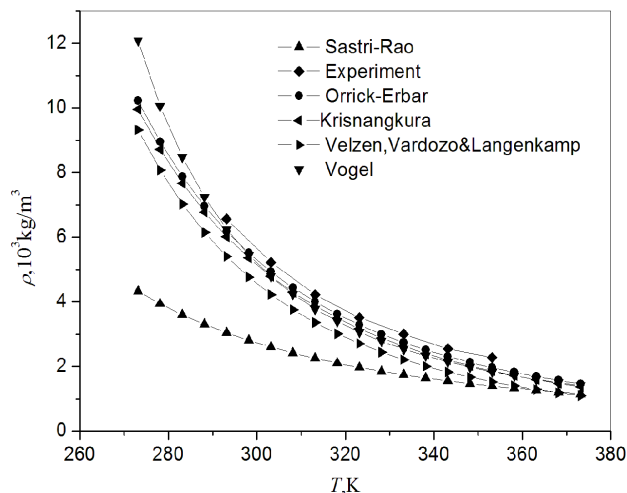


Fig. (2). Viscosity.

Fig. (3) shows the comparison between the predicted surface tensions by four methods and the experimental results. The prediction values by Sastri-Rao method and the Pitzer method are closer to the experimental results, and the average relative errors are 0.48% and 1.35%, respectively. Whereas the Zuo-Sternby method has the lowest accuracy, and the average relative error is 11.99%. The average relative error of the Miller method is 9.03%. Although all of the above methods are empirical, the Sastri-Rao method or Pitzer method has the higher estimation accuracy in predicting the surface tension of biodiesel fuels compared with other methods, the reason may be that the Pitzer method considers the influence of acentric factor and Sastri-Rao method relates the surface tension to the normal boiling point directly.

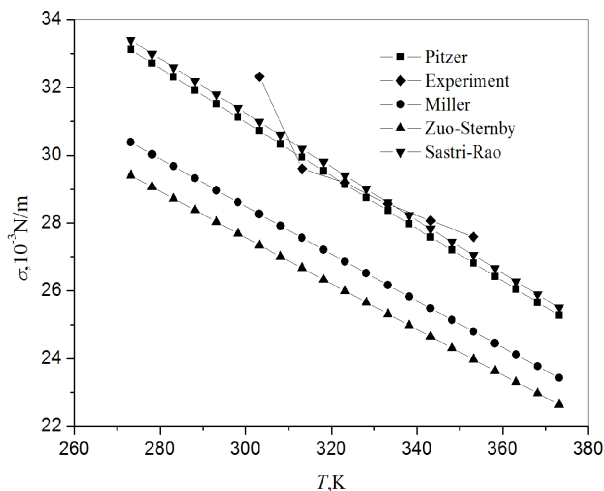


Fig. (3). Surface tensions.

5. CONCLUSION

The density, viscosity and surface tension of the waste cooking oil biodiesel are predicted with several methods, and the precision of each method has been obtained and compared. The analysis results show that the modified Rackett equation has the highest estimation accuracy to predict the density and the average relative error is 0.19%; the Orrick-Erbar method has the highest estimation accuracy to predict the viscosity and the average relative error is 7.82%; Sastri-Rao method and Pizer method have the higher estimation accuracy to predict the surface tension. The predictive errors of Sastri-Rao method and Pizer method are very small and the average relative errors are 0.48% and 1.35%, respectively.

NOMENCLATURE

- A, B = Constant determined by the contribution values of molecular groups
- C, D, E = Correlation parameters
- G = Interaction coefficient
- M = Molecular weight
- N = Total group contribution
- N^* = Equivalent chain length
- $\Delta N, \Delta N_{cor}$ = Group contribution of function groups to N
- ΔN^* = Group contribution of function groups to N^*
- P = Pressure
- R = Gas constant
- T = Temperature
- T_b = Normal boiling point temperature
- T_{br} = Reduced normal boiling point temperature, $T_{br} = T_b / T_C$
- T_r = Reduced temperature, $T_r = T / T_C$
- V = Molar volume
- w = Weight coefficient
- W = Constant
- a, b, c, d, e, f, g = Constant
- y = Mole fraction
- z = Number of carbon atom in molecule
- n_A = The number of atoms in molecule

Greek Symbols

- Δ = Atom or group contribution. When subscripted by T for T_C , by P for P_C , by V for V_C and by B for η
- $\Delta \eta_B, \Delta \eta_{Bcor}$ = Group contribution of function groups to η_B
- η = Dynamic viscosity
- μ = Kinematic viscosity

ρ	=	Density
ρ_{20}	=	Density at 293K
σ	=	Surface tension
ω	=	Acentric factor

Subscripts

1	=	First order function group
2	=	Second order function group
b	=	Boiling point
C	=	Critical
i	=	Fatty acid ester component
j	=	Fatty acid ester component
m	=	Biodiesel
R	=	Reference fluid or reference state

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

This work is supported by Natural Science Foundation Project of CQ CSTC (Project No. 2008BB7050)

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Received: November 11, 2013

Revised: March 30, 2014

Accepted: April 3, 2014

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