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THERMOPHYSICAL PROPERTIES OF DIESEL/BIODIESEL BLENDS

Edson Rodrigues da Silva[1]
Ricardo Belchior Tôrres[1,2]
[1]Departamento de Engenharia Mecânica, Centro Universitário da FEI, Av. Humberto de Alencar Castelo Branco, 3972, 09850-901, São Bernardo do Campo, São Paulo, Brazil
[2]Departamento de Engenharia Química, Centro Universitário da FEI, Av. Humberto de Alencar Castelo Branco, 3972, 09850-901, São Bernardo do Campo, São Paulo, Brazil
belchior@fei.edu.br

Abstract. *Fuel quality is defined in terms of a range of values that certain properties, such as density, viscosity and heat of combustion can provide. The main motivation of this study is that these properties significantly affect the atomization process, which is the initial stage of combustion in a diesel engine. As a continuation of an experimental study and optimization of processes involving biofuels, in the present work, density, viscosity, speed of sound and heat of combustion of binary mixtures of biodiesel with different diesel (S10, S500 and S1800) were determined as a function of composition at different temperatures. Both pure liquid and mixture viscosity were measured using a Stabinger viscosimeter (Anton Paar SVM 3000M). Density and speed of sound were measured using a commercial density and speed of sound measurement apparatus (Anton Paar DSA 5000). The calorific value was measured using a IKA C2000 Calorimeter and the equipment was calibrated using benzoic acid. The experimental results showed that the heat of combustion of the blends decreases when the concentration of biodiesel and sulfur content in diesel fuel increases. For the others properties, the properties values increase with increasing biodiesel concentration.*

Keywords: *Thermophysical properties, biodiesel, diesel*

1. INTRODUCTION

Many efforts to develop clean fuels have been under way in many countries and among many possible sources, biodiesel fuel derived from vegetable and animal fat has attracted attention as a possible substitute for petrodiesel fuels (Balat and Balat, 2010; Enweremadu and Mbarawa, 2009; Murugesan, *et al.*, 2009; Pinto, *et al.*, 2005, Fangrui and Milford, 1999). Brazil is as an emerging power in the production of biodiesel, especially due to the following reasons. First, Brazil has climatic conditions to grow different kinds of crops. Soybean oil is already used for biodiesel production and other sources may be used in the future. Second, Brazil is the world's leader in ethanol production from sugar cane, and the production of biodiesel using ethanol may become economically viable.

Biodiesel has many advantages over petroleum-based diesel fuel. However, there are some drawbacks of using biodiesel in diesel engines such as higher cost and poor low temperature properties. Blending is one of the methods to overcome the performance deficiency of using pure biodiesel in combustion engines. Physical properties of biodiesel such as density, viscosity, and low temperature properties can be improved when it is mixed with diesel fuel.

Some studies have been carried out to investigate the variation of thermophysical properties of biodiesel/diesel blends (Baroutian, *et al.,* 2012; Santos, *et al.,* 2011; Kumar *et al.,* 2011; Parente, *et al.*, 2011; Baroutian, *et al.,* 2009; Alptekin and Canakci, 2008). However, to best our knowledge, no comprehensive study has been conducted to investigate the variations in density, viscosity, speed of sound and heat of combustion of biodiesel/diesel blends with diesel fuel containing different sulfur contents. In present study, density, viscosity, speed of sound and heat of combustion of binary mixtures of biodiesel with different diesel (S10, S500 and S1800) were determined as a function of composition at different temperatures.

2.1. EXPERIMENTAL SECTION

The samples of biodiesel and different diesel fuel were provided by Ipiranga Produtos de Petróleo S/A. All samples of the fuels used in this study were certified in accordance with current legislation and standards of the National Agency of Petroleum, Natural Gas and Biofuels (ANP). Mixtures were prepared at a volume fraction (%VV) from B2 (indicates 2% of biodiesel with 98% diesel) to B100 (100 % biodiesel).

Density and speed of sound were measured using a commercial density and speed of sound measurement apparatus (Anton Paar DSA 5000). The equipment was calibrated with air and water. The uncertainty in density and speed of sound was, respectively, $\pm$ 0.000005 $g{\cdot}cm^{-3}$ and 0.1 $m{\cdot}s^{-1}$. The viscosity of the blends was determined by using a Viscosimeter Stabinger manufactured by Anton Paar (Model SVM 3000). The uncertainty in viscosity was $\pm$ 0.35% of the measurement value. Heating values were determined using an IKA bomb calorimeter (Model C-2000) according to ASTM D240.

2.2. RESULTS AND DISCUSSIONS

Figures 1and 2 show the variation in densities and speed of sound of diesel/biodiesel blends as a function of volume fraction at different temperatures. The density and speed of sound of biodiesel are higher than all diesel studied. The results show that the density and speed of sound the blends increase with increasing biodiesel composition.

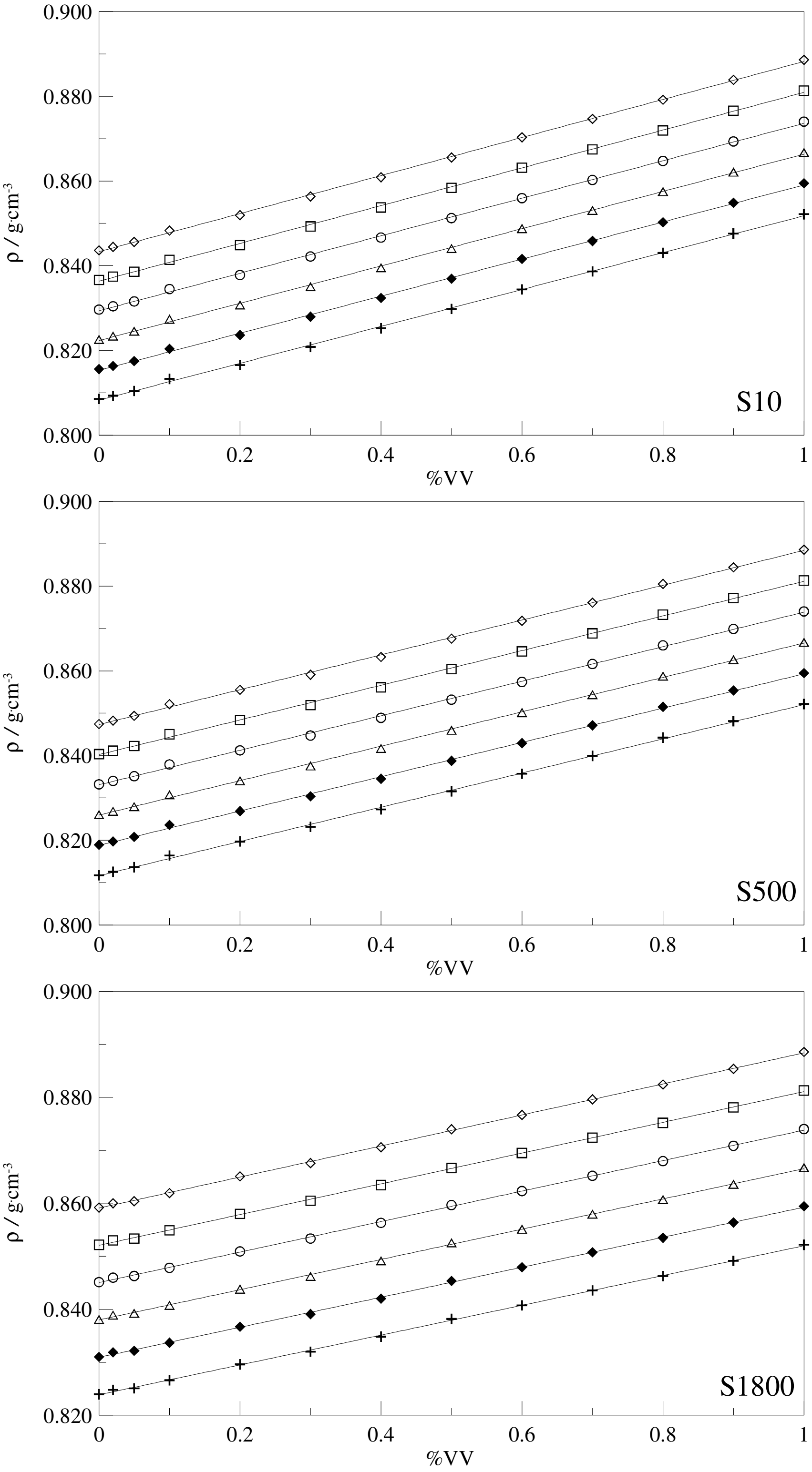

Figure 1. Density values, ρ, as a function volume fraction of biodiesel, for biodiesel/diesel blends as different temperatures: ◇, 10 °C; □, 20 °C; ○, 30 °C; △, 40 °C; ◆, 50 °C; ✚, 60 °C. (——) Eq. (1).

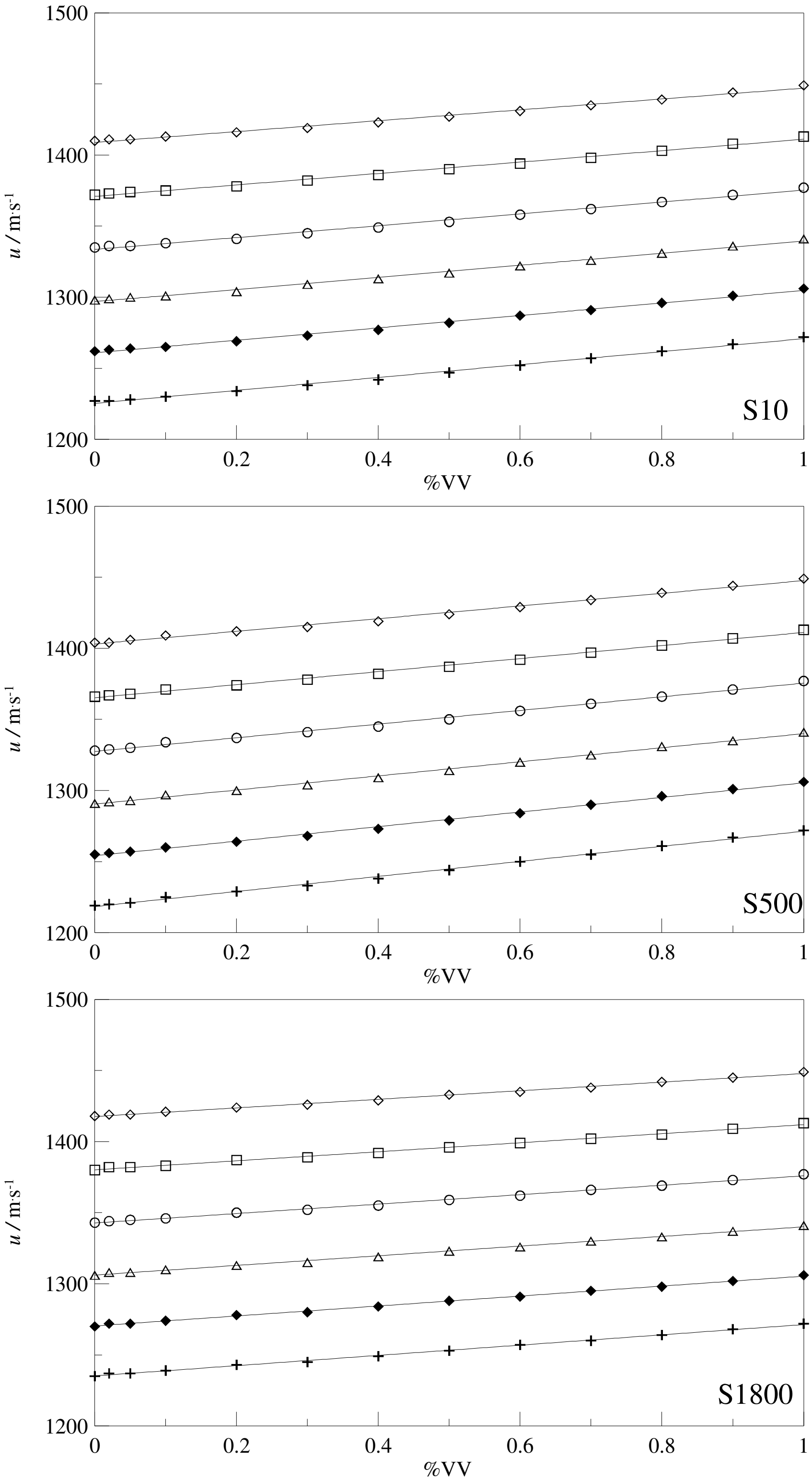

Figure 2. Speed of sound values, u, as a function volume fraction of biodiesel, for biodiesel-diesel blends as different temperatures: ◇, 10 °C; □, 20 °C; ○, 30 °C; △, 40 °C; ◆, 50 °C; ✚, 60 °C. (——) Eq. (2).

The experimental data were correlated as a function of composition at different temperatures by means of the following empirical linear equations:

$$\rho / \mathrm{g \cdot cm^{-3}} = aw + b \quad (1)$$

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and

$$c / \mathrm{m \cdot s^{-1}} = aw + b \,, \qquad (2)$$

where ρ is density, c is speed of sound, a and b are coefficients and w is volume fraction. Tables 1 and 2 show the values of a and b and the coefficients of determination, R^2. It is possible to observe that there is a good agreement between the measured and estimated values.

Table 1 - Linear regression parameters and R^2 for densities according to Eq. (1).

Temperature / °C	Linear regression: $\rho / \mathrm{g \cdot cm^{-3}} = aw + b$		
	a / g·cm^{-3}	b / g·cm^{-3}	R^2
		Biodiesel + diesel S10	
10 °C	0.0448678778	0.8433316093	0.999617
20 °C	0.0445470031	0.8363585533	0.999563
30 °C	0.0442403540	0.8293734022	0.999494
40 °C	0.0439943287	0.8223411222	0.999509
50 °C	0.0437395110	0.8153214557	0.999476
60 °C	0.0435148378	0.8082790272	0.999492
		Biodiesel + diesel S500	
10 °C	0.0410814560	0.8473233300	0.999454
20 °C	0.0408960478	0.8402229241	0.999435
30 °C	0.0407301210	0.8331040174	0.999428
40 °C	0.0405878984	0.8259664158	0.999418
50 °C	0.0404617973	0.8188219068	0.999409
60 °C	0.0403454991	0.8116634285	0.999419
		Biodiesel + diesel S1800	
10 °C	0.0292937931	0.8591035825	0.999669
20 °C	0.0290212109	0.8520680658	0.999687
30 °C	0.0287824669	0.8450375123	0.999623
40 °C	0.0285536621	0.8379869309	0.999591
50 °C	0.0283332302	0.8309321468	0.999576
60 °C	0.0281249103	0.8238687115	0.999590

Table 2 - Linear regression parameters and R^2 for speed of sound according to Eq. (2).

Temperature / °C	Regressão linear: $c / \mathrm{m \cdot s^{-1}} = aw + b$		
	a / m·s^{-1}	b / m·s^{-1}	R^2
		Biodiesel + diesel S10	
10 °C	38.39458527	1408.716320	0.993501
20 °C	39.88653818	1371.014768	0.994373
30 °C	41.34712634	1333.702039	0.994996
40 °C	42.95655937	1296.768613	0.995657
50 °C	44.19279959	1260.698162	0.996004
60 °C	45.51477747	1225.437130	0.996329
		Biodiesel + diesel S500	
10 °C	44.51277882	1403.006448	0.996041
20 °C	46.26149884	1365.075650	0.996626
30 °C	48.00062950	1327.495884	0.996879
40 °C	49.82074512	1290.289112	0.996418
50 °C	51.39186269	1253.962871	0.997396
60 °C	53.02726777	1218.397548	0.997671
		Biodiesel + diesel S1800	
10 °C	30.04688189	1417.742221	0.997076
20 °C	31.44273664	1380.151074	0.997645
30 °C	32.70990620	1342.975063	0.997714
40 °C	33.97182471	1306.181303	0.996697
50 °C	35.23625071	1270.260314	0.998067
60 °C	36.44169272	1235.109982	0.998310

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Figure 3 shows the variation in viscosities of binary blends of biodiesel + diesel fuel as a function of volume fraction at different temperatures. The biodiesel viscosity is higher than of diesel. The results indicate that viscosity blend increases nonlinearly with increasing biodiesel composition.

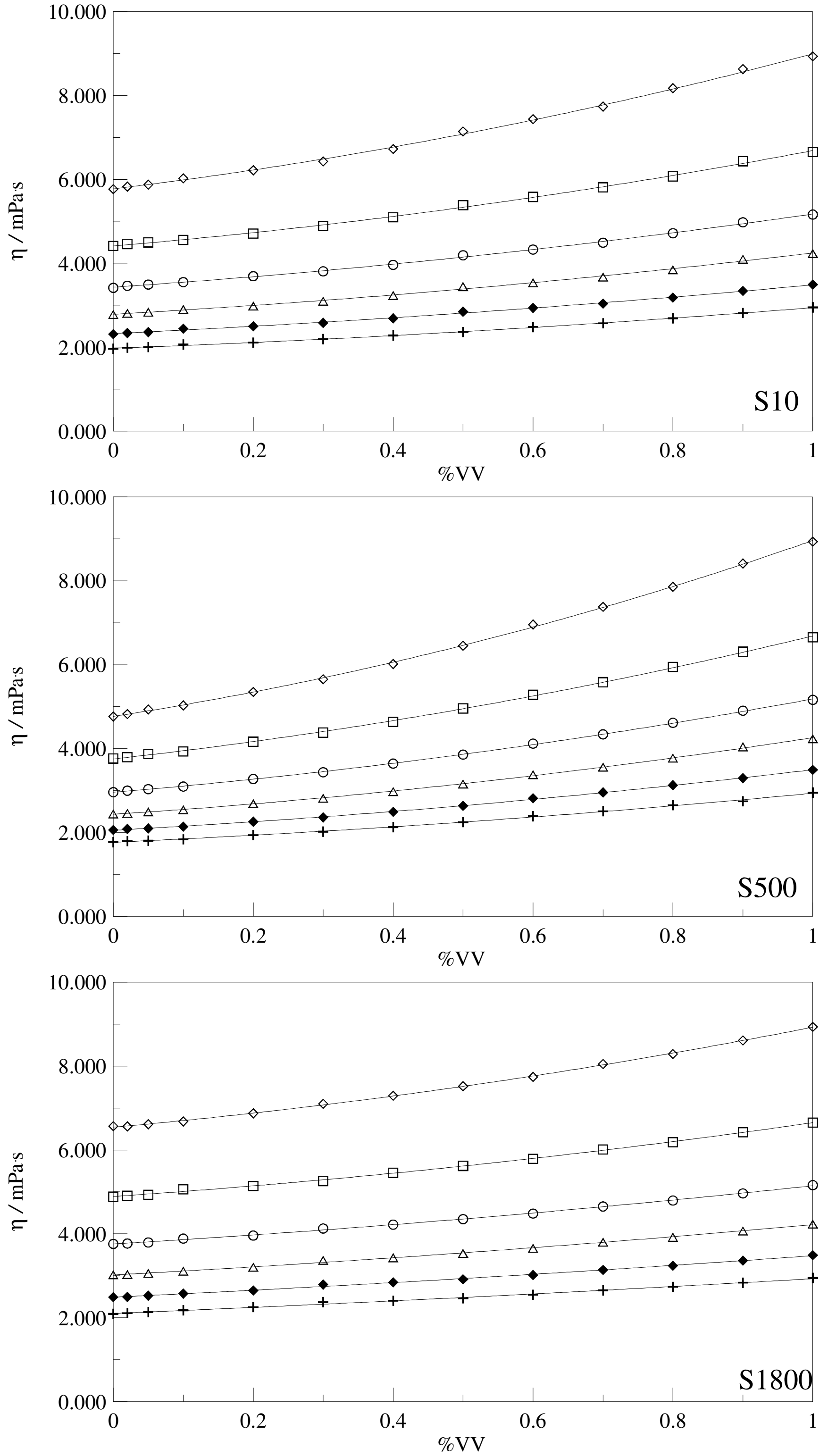

Figure 3. Viscosity values, η, as a function volume fraction of biodiesel, for biodiesel-diesel blends as different temperatures: ◇, 10 ºC; □, 20 ºC; ○, 30 ºC; △, 40 ºC; ◆, 50 ºC; ✚, 60 ºC. (–––) Eq. (3).

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The experimental data were correlated as a function of composition at different temperature by means of the following empirical equation:

$$\eta/\text{mPa}\cdot\text{s} = a\ln w + b\ , \qquad (3)$$

where η is viscosity, a and b are coefficients and w is volume fraction. Table 3 shows the values of a and b and the coefficients of determination, R^2. It is possible to observe that there is a good agreement between the measured and estimated values.

Table 3 - Regression parameters and R^2 for viscosity according to Eq. (3).

Temperatura / °C	Regression: η / mPa · s = $a\ln w + b$		
	a / mPa·s	b / mPa·s	R^2
		Biodiesel + diesel S10	
10 °C	0.4413290600	1.7445604104	0.996466
20 °C	0.4134141921	1.4756975081	0.996262
30 °C	0.4090607462	1.2251470895	0.997130
40 °C	0.4203129913	1.0168301685	0.996011
50 °C	0.4032840733	0.8381880608	0.997074
60 °C	0.3968600497	0.6724954491	0.997076
		Biodiesel + diesel S500	
10 °C	0.6326799255	1.5543997640	0.998927
20 °C	0.5777869277	1.3157131453	0.998706
30 °C	0.5611449126	1.0770641752	0.998781
40 °C	0.5596037142	0.8797988554	0.997892
50 °C	0.5318318497	0.7117944771	0.998083
60 °C	0.5070381579	0.5626230841	0.997833
		Biodiesel + diesel S1800	
10 °C	0.3082788530	1.8703063035	0.996188
20 °C	0.3049924941	1.5800683609	0.995872
30 °C	0.3125859003	1.3194974006	0.997750
40 °C	0.3335886032	1.1022056083	0.997903
50 °C	0.3338186450	0.9113089404	0.997620
60 °C	0.3324813990	0.7435821900	0.996040

Figure 4 shows the heating values for the studied systems as a function of composition at 25 °C. It is also possible to observe that biodiesel heating values are lower than diesel S10, S500 and S1800, meaning that for same amount of energy it will be necessary a greater amount of biodiesel.

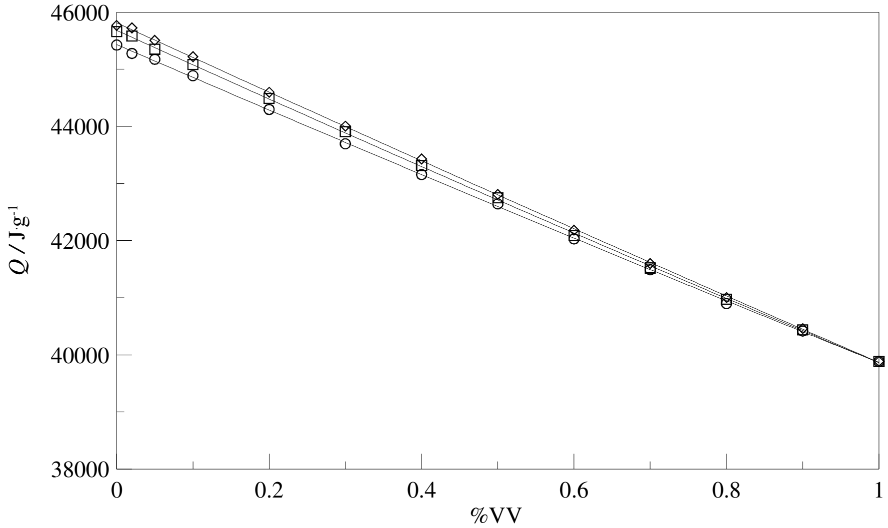

Figure 4. Heating values, Q, as a function volume fraction of biodiesel, for biodiesel-diesel blends: ◇, S10; □, S500; ○, S1800. (——) Eq. (4).

The heating values were correlated with the composition using the following empirical equation:

$$Q / \mathrm{J} \cdot \mathrm{g}^{-1} = \sum_{j=0}^{2} A_j w^j \, , \tag{4}$$

where Q is heating , A_j are coefficients and w is volume fraction. Table 4 shows the values of A_j and coefficients of determination, R^2. It has been found good agreement between the measured and estimated values.

Table 4 - Regression parameters and R^2 for heating at 25 ºC according to Eq. (4).

System	Regression: $Q / \mathrm{J} \cdot \mathrm{g}^{-1} = \sum_{j=0}^{2} A_j w^j$			
	A_0 / J·g^{-1}	A_1 / J·g^{-1}	A_2 / J·g^{-1}	R^2
Biodiesel + diesel S10	45816.12547	-6109.928748	162.5924875	0.999948
Biodiesel + diesel S500	45682.21357	-6060.199388	243.8610469	0.999877
Biodiesel + diesel S1800	45434.19768	-5774.876341	207.9980758	0.999902

2.3. CONCLUSIONS

An investigation was performed on the effect of composition and temperature on thermophysical properties when diesel and biodiesel were blended. By reducing temperature and increasing the biodiesel volume fraction, the density, speed of sound and viscosity of blend are increased. Density and speed of sound increased linearly with composition, whereas viscosity increased nonlinearly. Heating values decreases with increasing biodiesel concentration and sulfur contents. In this study, experimental data of the studied properties were correlated with empirical linear and polynomial equations and the results presented excellent agreement between the measured and the estimated values. The constants of these correlations are independent of the type of diesels.

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