Fuel 90 (2011) 1700–1702

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Short communication

Physical–chemical properties of waste cooking oil biodiesel and castor oil biodiesel blends

Osmano Souza Valente [a,1], Vanya Márcia Duarte Pasa [b,2], Carlos Rodrigues Pereira Belchior [c,3], José Ricardo Sodré [a,*]

[a] Pontifical Catholic University of Minas Gerais, Department of Mechanical Engineering, Av. Dom José Gaspar, 500, CEP 30535-610, Belo Horizonte, MG, Brazil
[b] Federal University of Minas Gerais, Department of Chemistry, Av. Antônio Carlos, 6627, CEP 31270-901, Belo Horizonte, MG, Brazil
[c] Federal University of Rio de Janeiro, Department of Mechanical Engineering, Cidade Universitária, P.O. Box 68503, CEP 22245-110, Rio de Janeiro, RJ, Brazil

ARTICLE INFO

Article history:
Received 6 August 2010
Accepted 22 October 2010
Available online 4 November 2010

Keywords:
Biodiesel
Waste cooking oil
Castor oil
Properties
Biofuels

ABSTRACT

This work presents the physical–chemical properties of fuel blends of waste cooking oil biodiesel or castor oil biodiesel with diesel oil. The properties evaluated were fuel density, kinematic viscosity, cetane index, distillation temperatures, and sulfur content, measured according to standard test methods. The results were analyzed based on present specifications for biodiesel fuel in Brazil, Europe, and USA. Fuel density and viscosity were increased with increasing biodiesel concentration, while fuel sulfur content was reduced. Cetane index is decreased with high biodiesel content in diesel oil. The biodiesel blends distillation temperatures T_{10} and T_{50} are higher than those of diesel oil, while the distillation temperature T_{90} is lower. A brief discussion on the possible effects of fuel property variation with biodiesel concentration on engine performance and exhaust emissions is presented. The maximum biodiesel concentration in diesel oil that meets the required characteristics for internal combustion engine application is evaluated, based on the results obtained.

1. Introduction

Biodiesel is a fuel made up by mono-alkyl-esters of long chain fatty acids, derived from vegetable oils or animal fat. It can be used in compression ignition engines for automotive propulsion or energy generation, as a partial or total substitute of fossil diesel fuel. Biodiesel can be processed from different mechanisms. Transesterification is the most common process, in which an ester compound is exchanged by an alcohol in the alkyl group. The alcohol used in the process is usually methanol or ethanol. These reactions are normally catalyzed by the addition of an acid or a base.

Biodiesel can be obtained from many oleaginous vegetable species. In Brazil, for instance, soybean, castor oil, palm tree, sunflower, babassu, peanut, physic nut, Ethiopian mustard, and others have been used to produce biodiesel. Besides, animal fat, and waste cooking oil have also been used as biodiesel sources. The choice of the biodiesel source to be used mainly depends on availability, price, and compliance with the required fuel specifications for diesel engine application. In this sense, the access to information on the physical–chemical properties of the many biodiesel sources available is a key issue to decide on investments for the development of crop production, processing, quality control, and engine adequacy.

Thus, the objectives of this work are to investigate the physical–chemical characteristics of waste cooking oil and castor oil biodiesel, to compare them with the required specifications for diesel engine operation and to discuss their possible effects on engine performance and emissions. The ideal diesel fuel characteristics include good fluidness in the engine operating temperature range, contamination-free and wax-free, easy ignition, clean, and efficient combustion.

2. Methodology

N. 2 diesel fuel (B0), waste cooking oil biodiesel (B100 W), castor oil biodiesel (B100C) and blends of 25%, 50%, and 75% of waste cooking oil biodiesel (B25W, B50W, and B75W) or castor oil biodiesel (B25C, B50C, and B75C) in N. 2 diesel fuel were analyzed. Waste cooking oil was collected from different restaurants, while castor oil was produced from a single harvest. Biodiesel was produced by a methanol based transesterification process at 60 °C, using the ratio of 6 mol of alcohol per mole of oil and 0.5% w/w of sodium hydroxide as a basic catalyst. The quality of the fuels produced was

* Corresponding author. Tel.: +55 31 3319 4911; fax: +55 31 3319 4910.
E-mail addresses: osmano.valente@gmail.com (O.S. Valente), vanya@ufmg.br (V.M.D. Pasa), belchior@peno.coppe.ufrj.br (C.R.P. Belchior), ricardo@pucminas.br (J.R. Sodré).
1 Tel.: +55 31 9951 5567; fax: +55 31 3319 4910.
2 Tel.: +55 31 3499 5724; fax: +55 31 3499 5700.
3 Tel.: +55 21 9963 5806; fax: +55 21 2562 8751.

0016-2361
doi:10.1016/j.fuel.2010.10.045

certified by measurement of their physical–chemical properties, according to Brazilian regulatory agency ANP 07/2008 specifications. Fuel density and viscosity were determined using ASTM D 1298 standard and ASTM D 445 standard, respectively. Distillation temperatures were measured according to ASTM D 86 standard. Cetane index was here calculated by ASTM D 4737 standard, using the three distillation temperatures method [1]. Fuel sulfur content was measured according to ASTM D 4294 standard.

3. Results and discussion

Fig. 1 shows that waste cooking oil biodiesel and castor oil biodiesel blends have similar densities at a given concentration. Blends with up to approximately 70% waste cooking oil biodiesel or castor oil biodiesel can meet density specification for engine use according to Brazilian standard ANP 07/2008 (850–900 kg/m^3 at 20 °C) or European standard EN 14214:2008 (860–900 kg/m^3 at 15 °C). Higher fuel density can produce more power and soot emissions from diesel engines [1]. Considering a diesel engine with unmodified settings, with the fuel injection system displacing invariable fuel volume amounts, the use of biodiesel blends with higher density than diesel oil will enrich the fuel/air mixture. As a result, increasing fuel consumption, carbon monoxide (CO) and hydrocarbon (HC) emissions can be expected. The density of pure waste cooking oil biodiesel is higher than those values found by Refs. [2–4]. However, the density of pure castor oil biodiesel was close to the values reported by Ref. [5].

Fig. 1 also shows that all fuel blends with waste cooking oil biodiesel or castor oil biodiesel present higher viscosity than N. 2 diesel fuel. Waste cooking oil biodiesel blends with maximum concentration in N. 2 diesel fuel of 20% meet the maximum recommended viscosity for European biodiesel, of $5.0 \times 10^{-6}\ m^2/s$ (EN 14214:2008). The blends with castor oil biodiesel concentration up to 35% can meet the maximum recommended viscosity limit in Europe. For use in Brazil or USA, blends with waste cooking oil biodiesel concentration up to 25% or castor oil biodiesel concentration up to 40% would be acceptable. The kinematic viscosity affects injection system lubrication and fuel atomization, being an important parameter to determine fuel injection strategy. High fuel viscosity reduces the fuel amount vaporized prior to combustion [1]. The measured viscosity of pure waste cooking oil biodiesel at 40 °C is higher than those values reported by Refs. [2–4]. On the other hand, the viscosity of pure castor oil biodiesel at 40 °C coincides with those values described by Ref. [5].

In general, the distillation temperatures T_{10} and T_{50} for all biodiesel blends were higher than those of N. 2 diesel fuel (Fig. 2). In opposition, the distillation temperature T_{90} for all biodiesel blends was lower than that of N. 2 diesel fuel. This indicates that the addition of waste cooking oil biodiesel or castor oil biodiesel to N. 2 diesel fuel can cause difficult engine start. On the other hand, the use of biodiesel can help to burn the heavy HC fractions in the fuel, thus decreasing unburned HC and soot emissions and deposit formation. The fuel blends with waste cooking oil biodiesel concentration over 25% present the distillation temperature T_{50} above the maximum recommended value for N. 2 diesel fuel, of 310 °C, while the fuel blends with castor oil biodiesel concentration up to 75% meet that limit. All biodiesel blends showed the distillation temperature T_{90} below the maximum recommended value for biodiesel use in USA of 360 °C (ASTM D6751-09).

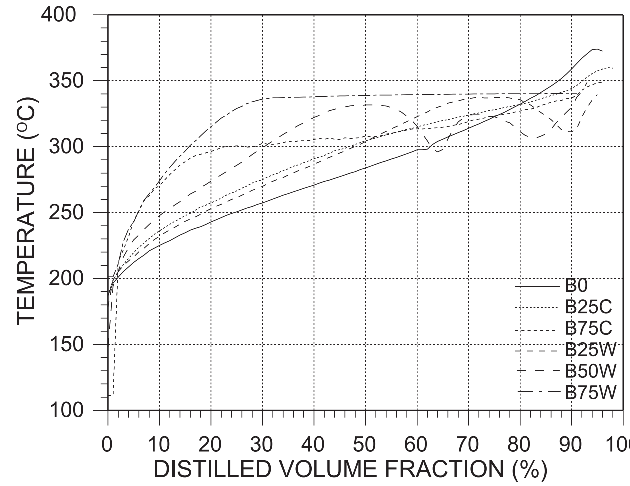

Fig. 2. Distillation curves of castor oil biodiesel and waste cooking oil biodiesel blends.

Fig. 3 shows reducing cetane index with increasing waste cooking oil biodiesel and castor oil biodiesel concentration in N. 2 diesel fuel. In order to meet the USA limit for biodiesel cetane number of 47 (ASTM D6751-09), the maximum biodiesel concentration in the fuel should be 3% for waste cooking oil and 5% castor oil. For Europe, none of the blends tested would meet the cetane number limit required.

The results found for waste cooking oil biodiesel cetane index (Fig. 3) project a value for B100W that is below the cetane index and cetane number levels reported by Refs. [2–4,6,7]. One possible reason is that the oil source and the cooking process have an important effect on the waste cooking oil molecular structure, with impacts on cetane number and on other properties. In fact, the cetane number and cetane index reported by Refs. [4,6] for biodiesel produced specifically from waste cooking palm oil are higher

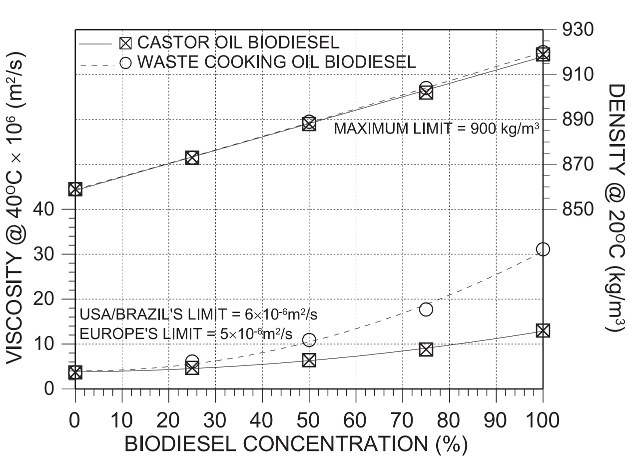

Fig. 1. Variation of fuel density and viscosity with biodiesel concentration.

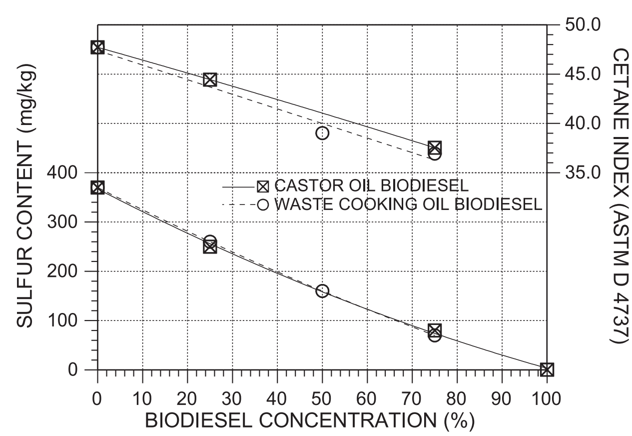

Fig. 3. Variation of cetane index and sulfur content with biodiesel concentration.

than those described by Refs. [2,4,7] for biodiesel produced from waste cooking oil collected from different restaurants. The biodiesel purification process is a second possible reason for the differences found for cetane number and cetane index [7]. It should be further investigated if the cetane index calculation method originally developed for mineral diesel oil (ASTM D 4737) adequately represents the cetane number of biodiesel blends.

Fig. 3 shows reduced sulfur content with increased biodiesel concentration. For pure biodiesel fuels (B100W and B100C) the presence of sulfur is negligible, meeting the specifications in Brazil (50 ppm), Europe (10 ppm) and USA (15 ppm). All fuel blends presented sulfur concentration below the Brazilian metropolitan limit for diesel fuels of 500 mg/kg. Fuel blends with biodiesel concentration over 83% reduce sulfur content below 50 mg/kg, complying with the present European specification for diesel fuels. Sulfur reduction in diesel fuel is one of the major tasks for oil companies, as low-sulfur fuels are required to reduce exhaust emissions. Thus, the use of biodiesel can help to obtain low-sulfur diesel fuels.

Engine fuel injection system must be optimized to account for the higher biodiesel density in comparison with N. 2 diesel fuel. With this action and considering that waste cooking oil biodiesel and castor oil biodiesel blends showed lower distillation temperature T_{90} than N. 2 diesel fuel, HC, CO, and smoke emissions can be reduced with the use of waste cooking oil or castor oil biodiesel, as well as deposit formation. Fuel injector orifice and injection pressure must probably be modified to compensate the higher biodiesel viscosity in comparison with N. 2 diesel fuel, to guarantee adequate fuel atomization. Cetane index is still an issue to be further investigated, as the reduced values found with the use of biodiesel do not agree with the results reported elsewhere. Finally, biodiesel low-sulfur content will help to reduce engine wear and the use of catalytic converters to reduce overall exhaust emissions.

4. Conclusions

Fuel blends with up to 20% waste cooking oil biodiesel or 35% castor oil biodiesel concentration in N. 2 diesel fuel will meet present specifications for biodiesel density, kinematic viscosity, and distillation temperature T_{90} in Brazil, Europe, and USA. With regard to cetane index calculated from the distillation temperatures T_{10}, T_{50}, and T_{90}, the fuel blends with waste cooking oil biodiesel or castor oil biodiesel concentration up to 3% or 5% in N. 2 diesel fuel, respectively, will meet the specification in the USA, but will not comply with the European specification for biodiesel. However, the calculation of the cetane index for biodiesel using a standard method for diesel fuels should be further investigated, being the measurement of the cetane number the safer procedure at present. Finally, the use of waste cooking oil biodiesel or castor oil biodiesel blended to N. 2 diesel fuel can substantially reduce the fuel sulfur content at an equivalent rate for a given concentration. The fuel blends containing over 83% waste cooking oil biodiesel or soybean biodiesel in N. 2 diesel fuel reduced the fuel sulfur content below 50 ppm.

Acknowledgements

The authors thank CNPq for the financial support to this project.

References

[1] Owen K, Coley T. Automotive fuels reference book. 2nd ed. USA: SAE, Inc.; 1995.
[2] Lin Y, Wu YG, Chang C. Combustion characteristics of waste-oil produced biodiesel/diesel fuel blends. Fuel 2007;86:1772–80.
[3] Utlu Z, Koçak MS. The effect of biodiesel fuel obtained from waste frying oil on direct injection diesel engine performance and exhaust emissions. Renew Energy 2008;33:1936–41.
[4] Alptekin E, Canakci M. Determination of the density and the viscosities of biodiesel–diesel fuel blends. Renew Energy 2008;33:2623–30.
[5] Canoira L, Galeán JG, Alcántara R, Lapuerta M, Contreras RG. Fatty acid methyl esters (FAMEs) from castor oil: production process assessment and synergistic effects in its properties. Renew Energy 2010;35:208–17.
[6] Ozsezen AN, Canakci M, Sayin C. Effects of biodiesel from used frying palm oil on the performance, injection and combustion characteristics of an indirect injection diesel engine. Energy Fuels 2008;22:1297–305.
[7] Predojević ZJ. The production of biodiesel from waste frying oils: a comparison of different purification steps. Fuel 2008;87:3522–8.