academicJournals

Vol. 11(40), pp. 4055-4061, 6 October, 2016
DOI: 10.5897/AJAR2016. 11582
Article Number: 02CF89E60991
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Smoke opacity of ethyl biodiesel from babassu and two types of diesel at different daytimes

Thyago Augusto Medeiros Lira*, Thaisa Calvo Fugineri Moreti, Afonso Lopes, Ariston Pinto Santos, Melina Cais Jejcic de Oliveira, Murilo Coelho Theodoro Neves, Priscila Sawasaki Iamaguti, Leomar Paulo de Lima, Gilberto Hirotsugu Azevedo Koike and Rogério de Abreu Silva

Laboratório Associado BIOEM/IPBEN, Departamento de Engenharia Rural, Universidade Estadual Paulista, Via de Acesso Prof. Paulo Donato Castellane s/n 14884-900 – Jaboticabal-SP, Brazil.

Received 19 August, 2016; Accepted 15 September, 2016

Renewable energy benefits and disadvantages have been subject of major discussions and studies. Thus, this study aimed at assessing the smoke opacity from a farming tractor running two types of diesel, B S1800 (B0) and B S10 (B0), and ethyl biodiesel from babassu oil at two rates (B50 and B100), at six day periods (2, 6, 10 am, 2, 6 and 10 pm). The study was conducted at the Department of Agricultural Engineering of the Faculty of Agricultural and Veterinary Sciences, UNESP, in Jaboticabal - SP, Brazil. The results showed a reduced smoke opacity during daytimes of lower ambient temperature and higher air relative humidity. In addition, smoke opacity was reduced as higher rates of babassu biodiesel were added to B S1800 diesel and B S10; thus, consisting of an efficient procedure of reducing smoke opacity in farming tractor engines.

Key words: Biofuel, emissions, pollutants, renewable energy, diesel engine cycle, *Orbinya martiana.*

INTRODUCTION

Biodiesel use in compression ignition engines has increased substantially in the recent decades, mainly because it is a sulphur-free fuel in contrast to fossil diesel. Moreover, it is a renewable vegetal source that may be a carbon cycle contributor (Silitonga et al., 2011; Mofijur et al., 2012; Zhou et al., 2012). It is worth mentioning, biodiesel production importance in raising farm income, enhancing environment by reducing greenhouse gas emissions, developing economy, optimizing and decentralizing investments, as well as promoting social development through job and income generations in rural areas (De Gorter and Just, 2010).

Fossil fuel is a scarce resource and, when burnt, releases harmful gases to the atmosphere. Thus, it is important to search for alternative energy sources replacing, even partially, such fossil fuels and face the

*Corresponding author. E-mail: thyagolira@hotmail.com. Tel: +551632097289.

challenge of growing demands for sustainable energy, thus reducing environmental impacts (Caland et al., 2009).

In Brazil, fossil fuels have been on agenda of government leaders, mainly because of environmental issues resulting from their increased demand. For the transportation industry of goods and people, three types of diesel are available, serving up to 46.4% of this sector. These products are B S500 (500 mg kg^{-1} of sulphur) and B S50 (50 mg kg^{-1} of sulphur), which were launched by Petrobras in 2009. Apart from these, B S10 diesel (10 mg kg^{-1} of sulphur) was introduced and regulated into domestic market in 2012, motivated by the implementation of increasingly stringent limits on pollutant emissions from circulating vehicles (ANP, 2013). Because of its great similarity with diesel, in terms of chemical structure and energy content, biodiesel is compatible with engines running on diesel and, therefore, no modifications are required (Lam et al., 2009). This fuel is featured by owning a mixture of alkyl esters of long chain fatty derived from different raw materials, including vegetable oils, animal fats and algae lipids by transesterification reaction with alcohols. The properties of biodiesel derivatives from different raw materials can vary according to the composition of fatty acids (Pehan et al., 2009; Hoekman et al., 2012; Oliveira et al., 2015). To ensure biodiesel quality, it is necessary to follow the national regulatory standards of biodiesel.

Among the sources of raw material for biodiesel production, it can be mentioned that the babassu (*Orbinya martiana*), a Brazilian native palm is widely distributed in the northeastern (largest producer), northern, central and western of the country (About 196.000 km² at Brazilian territory), although it can also be found in Mexico and Bolivia (Silva et al., 2014). The crude oil, babassu is easily obtained by way of crushing the fruit kernel, which constitute about 65% by almond weight, been used for biodiesel production since its composition increase the lauric fatty acid (about 44%)(Oliveira et al., 2013).

Many studies, such as those assessing smoke opacity in farm tractors running several raw materials, have enabled biodiesel use in diesel engines. These studies have shown decrease in smoke opacity levels as the rate of biofuels increases (Zhu et al., 2010). Comparing B0 with B100, Chauhan et al. (2013) tested a diesel engine cycle with karanja-oil biodiesel and found lower smoke opacity as amounts of biodiesel for the diesel increased. Likewise, Tabile et al. (2009) evaluated rates of castor-oil biodiesel versus B S2000 and B S500 diesels, and observed that by increasing the amount of biodiesel up to a B75 rate, opacity was reduced; yet when they compared B0 and B75, reduction reached 22.0 and 10.6% for B S2000 and B S500, respectively.

It is assumed that air relative humidity and ambient temperature changes, as well as varied rates of biodiesel blends in diesel, may influence smoke opacity response in the tractor engine. Given the above-mentioned, this study aimed to assess the smoke opacity emitted from a farm tractor running B S1800 diesel (B0) and B S10 (B0) mixed with babassu biodiesel at two distinct rates, 50 and 100% (B50 and B100, respectively) at six periods of the day (2, 6, 10 am, 2, 6 and 10 pm).

MATERIALS AND METHODS

This study was conducted at the Laboratory of Biofuel and Machines Tests (BIOEM) of the Bioenergy Research Institute (IPBEN, FCAV/UNESP), Jaboticabal, SP, Brazil. This laboratory is located at the geographic coordinates of 21° 14' 26.25" S and 48° 17' 13.22" W, and at average altitude of 570 m. The region has an average annual temperature of 22.2°C, average air relative humidity of 71% and atmospheric pressure of 94.3 kPa. According to the Köppen's classification, local climate is rated as an *Aw* type, which stands for a tropical humid with rainy summers and dry winters.

Diesel types used in this experiment were B S1800 (B0) and B S10 (B0), which had been regulated in the domestic market by the Program of Air Pollution Control by Motor Vehicles (PROCONVE). According to the ANP resolution no. 42/ 2009 (ANP, 2009) and ANP resolution no. 46/ 2012 (ANP, 2012), these fuels have total sulphur amounts of 1800 and 10 mg kg^{-1}, respectively. Both of them were purchased in Jaboticabal City, SP, Brazil.

In addition to these diesels, ethyl biodiesel distilled from babassu (B100) was used, being manufactured by our partner, the Laboratory of Clean Technology Development (LADEL), which is in Ribeirão Preto city, SP, Brazil. As blend rate B50, 50% of B S10 diesel and 50% of ethyl babassu biodiesel were used, being mixture by measuring cylinders of 500 and 250 mL, funnel and containers.

Measurements were carried out in a Valtra tractor, model BM 125i, 4 × 2 with front wheel assist (FWA), working at a maximum engine power of 91.9 kW (125 hp) at 2300 rpm (ISO1585). The machine was equipped with turbocharger and intercooler, reaching a total mass of 7000 kg distributed as 40 and 60% in the front and rear axles, respectively, and a mass/power ratio of 76 kg kW^{-1} (56 kg hp^{-1}).

Two experiments were conducted in a completely randomized design, arranged in a 6 × 3 factorial scheme with 18 treatments and 3 repetitions, totaling 54 results for each experiment. It is noteworthy that, in compliant with the smoke opacity testing, each repetition consisted of seven replications, which is based on a principle that the difference between the highest and lowest readings of each replication could not exceed 0.25 m^{-1}.

In this test, the number of samples may vary between seven and ten, being set at the testing time, since the equipment itself manage the process in order to achieve result homogeneity. Such uniformity might be influenced by engine and fuel conservation state, besides environmental conditions (temperature, pressure and air humidity), among others.

The three biodiesel/diesel blends were assessed at six distinct daytimes (2, 6, 10, 2, 6 and 10 pm). The first experiment was composed of B S1800 diesel (B0), 50% B S1800 diesel + 50% biodiesel (B50) and 100% babassu biodiesel (B100). Yet, the second was composed of B S10 diesel (B0), 50% B S10 diesel + 50% biodiesel (B50) and 100% babassu biodiesel (B100).

Local temperature and air relative humidity were obtained from a meteorological station located at UNESP (Jaboticabal, SP), which is near the experimental area. The records of these variables for all daytimes assessed are shown in Table 1.

Table 1. The records of these variables for all daytimes assessed.

Times of trial (h)	Room temperature (ºC)	Relative humidity (%)
2	14,7	72
6	13,9	95
10	22,4	60
14	28,4	27
18	25,2	42
22	18,0	63
Standart deviation	10.20	23.63

Engine smoke opacity was measured by a partial flow opacimeter (Tecnomotor, model TM 133), which measures light absorption and follows the standards proposed by the NBR 13037 of INMETRO and CEE 72/306. A serial controller was also used for the communication of the vehicle inspection equipment through a serial port to the microcomputer and a software of vehicle inspection called IGOR®.

Tests were performed according to the snap idle test, which consists of submit engine to a full-throttle acceleration for 3 to 5 s, with the power developed absorbed only by the inertia of the mechanical engine components (clutch, gearbox primary shaft), since the tractor was static, as described in the NBR 13037 (ABNT, 2001). Opacity measurement results were given in K, which is the light absorption coefficient in m^{-1} (TECNOMOTOR, 2012).

Biodiesel was mixed to the diesel by the time of the test. From one test to the other, all unconsumed fuel was removed out of tanks, filters and pipes avoiding next test contamination. For test standardization, after refueling, engine was operated for ten minutes prior to each test start.

Data underwent variance analysis and means were compared by the Tukey's test at 5% probability, and the Kolmogorov normality test - Smirnov and ANOVA.

Table 2. Summary of the values of analysis of variance and mean test for smoke opacity.

Factors	Smoke opacity (m^{-1})
Fuel type (FT)	
B S10 diesel B0	2.12
Biodiesel B50	1.62
Biodiesel B100	1.11
Time (T)	
2:00 am	1.57
6:00 am	1.47
10:00 am	1.73
02:00 pm	1.85
06:00 pm	1.59
10:00 pm	1.49
F-test	
FT	3964.0309 **
T	162.9397 **
FT x T	31.0043 **
CV (%)	4.18
Standart deviation	0.068

*Significant at 5% (P<0.05); **significant at 1% (P<0.01); CV: coefficient of variation.

RESULTS

According to the Tables 2 and 3, concerning smoke opacity, there was a significant interaction between fuel type and daytime. As a result, those variables underwent an interaction breakdown analysis, which are shown in Tables 4 and 5.

It can be observed that B S10 diesel (B0) showed higher opacity values when compared with B50 and B100 mixture for all times (Table 4), differing from the other fuel types. Smoke opacity decreased as the amount of biodiesel in the mixture increased, within which babassu biodiesel (B100) stood out, presenting a significant reduction of 51.82 and 54.21%, as compared to B S10 at 6 am and 2 pm, respectively.

It can be stated that running biodiesel in diesel engines instead promotes significant reduction in particulate emissions (Ong et al., 2011; Xue et al., 2011; Bora and Baruah, 2012). Moreover, Table 4 shows that opacity levels would be within the limit of 2.5 m^{-1} defined by the CONAMA resolution number 251/1999 (CONAMA, 1999). This outcome can be explained by the fact that biodiesel have no sulphur within its composition, aside from presenting free oxygen in its molecule (reduced fuel-rich zones inside combustion chamber and increased yield during diffusive combustion). Therefore, combustion efficiency is increased and particulate matter production is reduced substantially (Sahoo et al., 2009; Chauhan et al., 2012).

Investigating emissions from diesel engine running on rapeseed oil (B100) and mixtures B5, B20 and B70 and comparing them with those from diesel-run ones, Buyukkaya (2010) emphasized that biodiesel has less opacity (up to 60%) as compared to the diesel. When biodiesel is added to diesel, fuel oxygen contents are increased, thus, less oxygen is demanded for combustion.

Table 3. Summary of the values of analysis of variance and mean test for smoke opacity.

Factors	Smoke opacity (m^{-1})
Fuel type (FT)	
B S1800 diesel	2.21
Biodiesel B50	1.79
Biodiesel B100	1.11
Time (T)	
2:00 am	1.66
6:00 am	1.51
10:00 am	1.82
02:00 pm	1.93
06:00 pm	1.68
10:00 pm	1.64
F-test	
FT	6630.2308 **
T	208.4222 **
FT x T	27.3399 **
CV (%)	3.38
Standart deviation	0.058

*Significant at 5% (P<0.05); **significant at 1% (P<0.01); CV: coefficient of variation.

Table 4. Summary of interaction breakdown analysis of fuel type (B0 = 100% diesel B S10 + 0% babassu biodiesel; B50 = 50% diesel B S10 + 50% babassu biodiesel; B100 = 0% diesel B S10 + 100% babassu biodiesel) against daytime for smoke opacity (m^{-1}).

Fuel type	Daytime (h)					
	2 am	6 am	10 am	2 pm	6 pm	10 pm
B S10 diesel (B0)	2.00^{Aa}	1.93^{Aa}	2.23^{Ac}	2.49^{Ad}	2.08^{Ab}	1.99^{Aa}
Biodiesel B50	1.54^{Bb}	1.56^{Bb}	1.74^{Bc}	1.91^{Bd}	1.56^{Bb}	1.41^{Ba}
Biodiesel B100	1.19^{Ccd}	0.93^{Ca}	1.21^{Cd}	1.14^{Cbcd}	1.13^{Cbc}	1.08^{Cb}

Means followed by the same uppercase letter in the columns and lowercase letter in the lines do not differ from each other by the Tukey's test at 5% probability.

Table 5. Summary of interaction breakdown analysis of fuel type (B0 = 100% diesel B S1800 + 0% babassu biodiesel; B50 = 50% diesel B S1800 + 50% babassu biodiesel; B100 = 0% diesel B S1800 + 100% babassu biodiesel) against daytime for smoke opacity (m^{-1}).

Fuel type	Daytime (h)					
	2 am	6 am	10 am	2 pm	6 pm	10 pm
B S1800 diesel	2.10^{Aab}	2.04^{Aa}	2.31^{Ad}	2.48^{Ae}	2.17^{Ac}	2.15^{Abc}
Biodiesel B50	1.71^{Bb}	1.59^{Ba}	1.89^{Bc}	2.12^{Bd}	1.75^{Bb}	1.69^{Bb}
Biodiesel B100	1.19^{Ccd}	0.91^{Ca}	1.23^{Cd}	1.14^{Cbc}	1.13^{Cbc}	1.08^{Cb}

Means followed by the same uppercase letter in the columns and lowercase letter in the lines do not differ from each other by the Tukey's test at 5% probability.

However, the ratio oxygen/fuel is the main reason for a fullest combustion and, therefore, resulting in reduced amounts of pollutant emitted (Ghobadian et al., 2009; Reis et al., 2013). Biodiesel properties are influenced by inherent characteristics of fatty esters composed of the fuel (Lôbo et al., 2009).

Table 4 shows smoke opacity increases of 29.01 and 22.43% for B0 and B50 between the time at which was observed the lowest value (6 am, 13.9°C and 95%) and the time at which the highest one (2 pm, 28.4°C and 27%) was registered. Data recorded at 2 pm showed difference when compared with the other times. For B100, opacity increased (22.58%) at a different time (10 am, 22.4°C and 60%) from that recorded for B0 and B50, differing from 6 am, 6 and 10 pm records. Furthermore, it was observed that the opacity values of B0, B50 and B100 were low at low temperature and high air humidity. According to Lopes et al. (2009), milder ambient temperature and high humidity may improve engine combustion.

The higher opacity registered for babassu biodiesel (B100), at a different time from that recorded for B0 and B50, might have been related to physicochemical properties, which are influenced by inherent characteristics of fatty esters composed of the fuel (Lôbo et al., 2009; Dabdoub et al., 2009).

Through a daytime assessment in Table 5, values of smoke opacity were higher for B0 related to B50 and B100 for all assessed hours, standing out from all the other fuel types. Additionally, smoke opacity decreased as the amount of biodiesel increased, especially for B100, which presented a significant reduction mainly at 6 am and 2 pm, displaying reduction rates of 55.4 and 54.0%, respectively, as compared to B S1800.

DISCUSSION

These results reinforce those reported by Louzeiro (2012), who observed a decrease in CO, NOx and opacity using micro-emulsion formed by oxygenated substances (babassu oil), brandy and isobutyl alcohol, comparing them with the diesel. This behavior was also observed by Lima et al. (2013), who obtained a reduction of 36.25 and 60% in smoke opacity for a farm tractor engine running on blends of palm and tucuman biodiesels, respectively.

Similar results were also obtained by Neves et al. (2013), who observed a reduction of 26.1 and 53.5% when useing increasing proportions of soybean and murumuru biodiesel, respectively, in an agricultural tractor equipped with turbo intercooler.

Concerning the fuel type, B S1800 diesel (B0) and the mixture (B50) promoted the highest smoke opacity values at 2 pm (28.4 °C and 27%), which increased by 17.7 and 25%, respectively, when compared with the lowest values registered at 6 am (13.9°C and 95%). On the other hand, when evaluating biodiesel (B100), opacity increased (26%) under different conditions, that is, at 10 am(22.4°C and 60%) as compared to those recorded for B0 and B50, differing from 6 am, 6 and 10 pm readings. Furthermore, the values of smoke opacity emitted from engines were reduced as temperatures decreased and humidity increased. According to Janaun and Ellis (2010), the use of biodiesel as fuel in diesel engine cycle reduces the emissions of particulate matter as compared to the diesel use.

Yoon et al. (2014) observed that particulate emissions diminished on average (about 33%) changing diesel for B30. These results are similar to those reported by Gonçalves et al. (2013), in which opacity index was lower in the early hours of the day (6:30, 9:30 and 10:30 am), at a maximum ambient temperature of 25.4°C and air relative humidity of above 50%. From 12 pm, and under opposite conditions (temperature higher than 25°C and humidity lower than 50%), higher opacity values was obtained. Liotti et al. (2010), when assessing diesel (B0), as a function of weather conditions (humidity from 91.4 to 69% and temperature from 20 to 25°C), observed higher opacity indexes at 12 and 3 pm and lower at 6 and 12 am.

The literature tends to corroborate that in internal-combustion engine compression, combustion thermodynamics has most influence from air excess, calculated as the ratio between actual air mass/fuel and the stoichiometric air mass (kg)/fuel (kg); mixture richness or equivalence ratio, which indicates the arbitrary ratio of oxidant and fuel relatively to a stoichiometric mixture; lower fuel calorific power; lower mixture calorific power; and temperature variation. For lower temperatures (about 1250 K) and lean mixtures (high air/ fuel ratio), stable chemical species (mainly CO_2, H_2O, N_2 and O_2) are produced by exothermic combustion; while for higher temperatures (above 1500 K), stable chemical species are dissociated, forming many others, such as CO, H_2, OH, H, O, NO and unburned hydrocarbons, among others (Coelho and Costa, 2007).

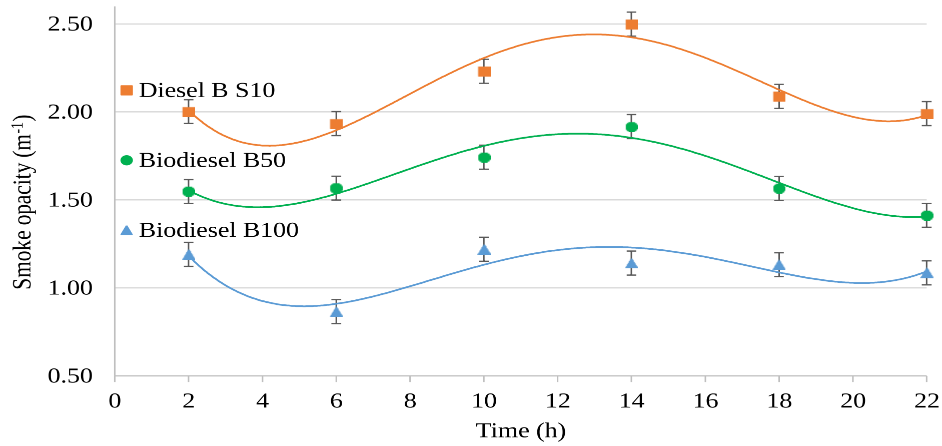
Figures 1 and 2 show smoke opacity behavior as a function of testing and weather conditions.

Conclusions

The use of babassu biodiesel and daytime influence smoke opacity emissions from a farming tractor engine. Reduced values of smoke opacity were recorded at 6 am, when a lower ambient temperature (13.92°C) and higher air relative humidity (95%) were measured, decreasing by 55.4 and 51.82% when compared with B S1800 and B S10 with B100, among which babassu biodiesel stood out. The blends of babassu biodiesel with B S1800 diesel and B S10 proved to be efficient in reducing smoke opacity from a farming tractor engine.

Conflict of Interests

The authors have not declared any conflict of interests.

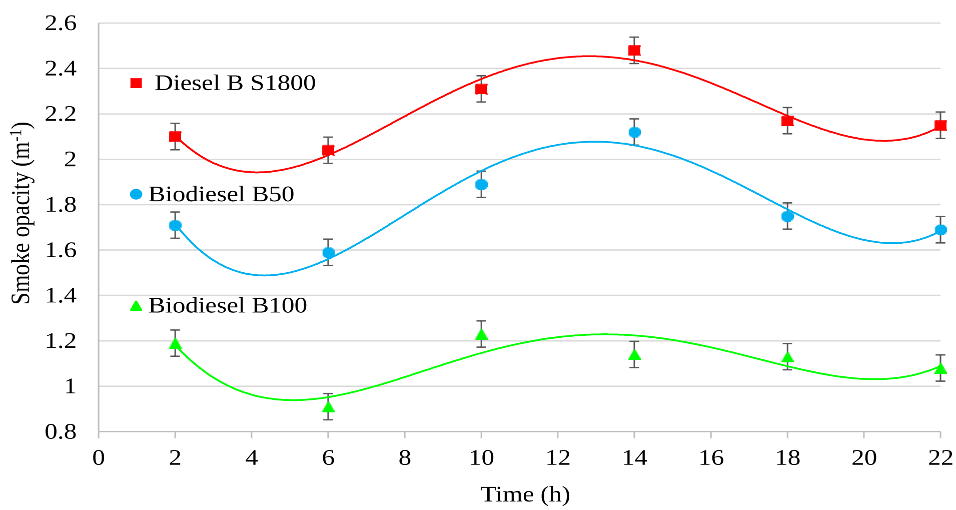


Opacity diesel B S10= $0.0001x^4 - 0.0057x^3 + 0.0935x^2 - 0.5138^x + 2.7071$
$R^2 = 0.9359$

Opacity biodiesel B50 = 7E-05x4 - 0.0036x3 + 0.058x2 - 0.3026x + 1.955
$R^2 = 0.9343$

Opacity biodiesel B100= 8E-05x4 - 0.0042x3 + 0.0725x2 - 0.4547x + 1.833
$R^2 = 0.7559$

Figure 1. Graphical representation of smoke opacity as a function of testing time for B0, B50 and B100.



Opacity diesel B S1800 = $1E\text{-}04x^4 - 0.0049x^3 + 0.0784x^2 - 0.426x + 2.6804$
$R^2 = 0.9628$

Opacity biodiesel B50 = $0.0001x^4 - 0.0058x^3 + 0.0946x^2 - 0.5313x + 2.4446$
$R^2 = 0.9509$

Opacity biodiesel B100 = $7E\text{-}05x^4 - 0.0037x^3 + 0.0635x^2 - 0.3951x + 1.7463$
$R^2 = 0.7193$

Figure 2. Graphical representation of smoke opacity as a function of testing time for B0, B50 and B100.

ACKNOWLEDGEMENTS

The authors thank the FAPESP (process number 01/09972-8), CNPq, CAPES and associated laboratory BIOEM/IPBEN/UNESP government agencies, for the financial support to purchase the tractor instrumentation, and the Coopercitrus and Valtra companies, is providing the testing tractors.

REFERENCES

ANP (Agência Nacional de Petróleo) (2009). Gás Natural e Biocombustíveis. Resolução nº 42/2009.

ANP (Agência Nacional de Petróleo) (2012). Gás Natural e Biocombustíveis. Resolução nº 46/2012.

ANP (Agência Nacional de Petróleo) (2013). Gás Natural e Biocombustíveis. Resolução nº 50/2013.

ABNT (Associação Brasileira de Normas Técnicas) (2001). NBR nº 13037: Veículos rodoviários automotores – Gás de escapamento emitido por motor em aceleração livre – Determinação da opacidade. Rio de Janeiro.

Bora DK, Baruah DC (2012). Assessment of tree seed oil biodiesel: a comparative review based on biodiesel of a locally available tree seed. Renew. Sustain. Energy Rev. 16(3):1616-1629.

Buyukkaya E (2010). Effects of biodiesel on a DI diesel engine performance, emission and combustion characteristics. Fuel 89(10):3099-3105.

Caland IB, Santos LSS, Moura CVR, Moura EM (2009). Preparation and study of bimetallic compounds efficiency in the synthesis of biodiesel fuel. Catal Lett. 128(3-4):392-400.

Chauhan BS, Kumar N, Cho HM (2012). A study on the performance and emission of a diesel engine fueled with jatropha biodiesel oil and its blends. Energy 37(1):616-622.

Chauhan BS, Kumar N, Cho HM, Lim HC (2013). A study on the performance and emission of a diesel engine fueled with karanja biodiesel and its blends. Energy 56(1):1–7.

Coelho P, Costa M (2007). Combustão. 1. ed.. Edições Orion, Lisboa, Portugal.

Conselho Nacional do Meio Ambiente (CONAMA) (1999). Resoluções que estabelecem o “programa de controle da poluição do ar por veículos automotores – Proconve”. nº 251.

Dabdoub MJ, Bronzel JL, Rampin MA (2009). Biodiesel: a critical overview on the current status and perspectives at the academy and industry. Quim. Nova 32(3):776-792.

De Gorter H, Just DR (2010). The Social Costs and Benefits of Biofuels: The Intersection of Environmental, Energy and Agricultural Policy. Appl. Econ. Perspect. Policy 32(1):4-32.

Ghobadian B, Rahimi H, Nikbakht AM, Najafi G, Yusaf TF (2009). Diesel engine performance and exhaust emission analysis using waste cooking biodiesel fuel with an artificial neural network. Renew Energy 34(4):976-982.

Gonçalves SS, Cortez JW, Arcoverde SNS, Machado NS, Nagahamas HJ (2013). Smoke opacity and noise level testing of a tractor. Eng. Agric. 21(3):244-252.

Hoekman SK, Broch A, Robbins C, Ceniceros E, Natarajan M (2012). Review of biodiesel composition, properties, and specifications. Renew. Sustain. Energy Rev. 16(1):143-169.

Janaun J, Ellis N (2010). Perspectives on biodiesel as a sustainable fuel. Renew Sust Energ Rev 14(4):1312-1320.

Lam MK, Tan KT, Lee KT, Mohamed AR (2009). Malaysian palm oil: surviving the food versus fuel dispute for a sustainable future. Renew. Sustain. Energy Rev. 13(6-7):1456-1464.

Lima LP, Lopes A, Oliveira MCJ, Neves MCT, Iamaguti PS (2013). Biodiesel in an agricultural tractor: operational behavior as a function of the type and proportions blended in diesel. Eng. Agric. 21(5):447-455.

Liotti CG, Lopes A, Lima LP, Camara FT, Guiotto FA, Koike GHA (2010). Opacidade da fumaça de trator agrícola em função do uso de biodiesel de dendê e das condições climáticas. In: Congresso de Iniciação Científica 22:1-4.

Lôbo IP, Ferreira SIC, Cruz RS (2009). Biodiesel: quality parameters and analytical methods. Quim. Nova 32(6):1596-1608.

Lopes A, Câmara FT, Oliveira MCJ, Furlani CEF, Silva RP, Mello Júnior JGS (2009). Opacidade da fumaça de trator agrícola utilizando biodiesel em função das condições climáticas no horário de execução do ensaio. In: Congr. Bras. Eng. Agríc. 38:1-4.

Louzeiro HC (2012). Microemulsões combustíveis a partir do óleo de babaçu para substituir o diesel em motores estacionários. 82f. Tese (Doutorado em Química) – Universidade Federal da Paraíba, João Pessoa, Brasil.

Mofijur M, Masjuki HH, Kalam MA, Shahabuddin M (2012). Experimental study of additive added palm biodiesel in a compression ignition engine. Energ Educ Sci Techn, Part a: Energy Sci. Res. 30(2):737-748.

Neves MCT, Lopes A, Lima LP, Oliveira MCJ, Koike GHA (2013). Performance of an agricultural tractor in function of biodiesel type (soybean x murumuru) in soil preparation. Eng. Agric. 21(4):351-360.

Oliveira LE, Giordani DS, Paiva EM, Castro HF, Silva MLCP (2013). Kinetic and thermodynamic parameters of volatilization of biodiesel from babassu, palm oil and mineral diesel by thermogravimetric analysis (tg). J. Therm. Anal. Calorim 111(1):155-160.

Oliveira MCJ, Lopes A, Lima LP, Neves MCT, Yamaguti PS, Lira TAM, Moreti TCF, Koike GHA (2015). Tractor performance in function of storage period and different proportions of biodiesel and diesel. Aust. J. Crop Sci. 9(10):909-914.

Ong HC, Mahlia TMI, Masjuki HH, Norhasyima RS (2011). Comparison of palm oil, jatropha curcas and *Calophyllum inophyllum* for biodiesel: a review. Renew. Sustain. Energy Rev. 15(8):3501-3515.

Pehan S, Jerman MS, Kegl M, Kegl B (2009). Biodiesel influence on tribology characteristics of a diesel engine. Fuel 88(6):976-979.

Reis EF, Cunha JPB, Mateus DLS, Delmond JG, Couto RF (2013). Performance and emissions of a diesel engine-generator cycle under different concentrations of soybean biodiesel. Rev. Bras. Eng. Agric. Ambient. 17(5):565-571.

Sahoo PK, Das LM, Babu MKG, Arora P, Singh VP, Kumar NR, Varyani TS (2009). Comparative evaluation of performance and emission characteristics of jatropha, karanja and polanga based biodiesel as fuel in a tractor engine. Fuel 88(9):1698-1707.

Silitonga AS, Atabani AE, Mahlia TMI, Masjuki HH, Badruddin IA, Mekhilef S (2011). A review on prospect of jatropha curcas for biodiesel in Indonesia. Renew. Sustain. Energy Rev. 15(8):3733-3756.

Silva MCD, Silva LM, Brandão KS, Souza AG, Cardoso LP, Santos AO (2014). Low temperature properties of winterized methyl babassu biodiesel. J. Therm. Anal. Calorim 115(1):635-640.

Tabile RA, Lopes A, Dabdoub MJ, Camara FT, Furlani CEA, Silva RP (2009). Mamona biodiesel in interior and metropolitan diesel in agricultural tractor. Eng. Agr-Jabot. 29(3):412-423.

Tecnomotor Eletrônica do Brasil Ltda (TECNOMOTOR) (2012). Opacer TM 133 – opacímetro de amostragem. Manual de Operação. Ed. 07/01:26.

Xue J, Grift TE, Hansen AC (2011). Effect of biodiesel on engine performances and emissions. Renew. Sustain. Energy Rev. 15(2):1098-1116.

Yoon SK, Kim MS, Kim HJ, Choi NJ (2014). Effects of canola oil biodiesel fuel blends on combustion, performance, and emissions reduction in a common rail diesel engine. Energies 7(12):8132-8149.

Zhou W, Li Y, Zhang Y, Zhao Z (2012). Energy efficiency evaluation of lipid production by oleaginous yeast rhodosporidium toruloides. J. Therm. Anal. Calorim 108(1):119-126.

Zhu L, Zhang W, Liu W, Huang Z (2010). Experimental study on particulate and NOx emission of a diesel engine fueled with ultralow sulfur diesel, rme-diesel blends and pme-diesel blends. Sci. Total Environ. 408(5):1050-1058.