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Tractor performance in function of storage period and different proportions of biodiesel and diesel

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Abstract

Biodiesel is a renewable and biodegradable fuel produced from vegetable oil or animal fat by transesterification. The viability of this product as an alternative source of energy depends on several factors such as blend proportion and stability during storage since the availability of raw materials is seasonal and varies according to the harvest of each crop. This study aimed to evaluate the operational performance and the smoke density of the tractor operating on biodiesel from castor oil. The factors studied were the storage period and biodiesel/diesel blend proportion. The fuel storage periods was zero, three and six months after the date of production and biodiesel/diesel blend proportions were 0% of biodiesel (B0), 5% of biodiesel (B5), 25% of biodiesel (B25), 50% of biodiesel (B50) and 100% of biodiesel (B100). The results showed an increase in the specific fuel consumption from the blend with 25% biodiesel, however, the storage period had no effect on consumption. Smoke density was reduced with the addition of 5% biodiesel, noting that the storage period influenced this variable.

Keywords: biofuel; bioenergy; farm tractors test; *ricinus communis* L; smoke density; specific fuel consumption.
Abbreviations: SFC_Specific Fuel Consumption (g kW h^{-1}); WHC_Weight Hourly Fuel Consumption (kg h^{-1}); Dp_Drawbar Power (kW); Sv_Supply Fuel Volume (mL); Dsf_Fuel Supply Density (kg m^{-3}); Rv_Return Fuel Volume (mL); Drf_Return Fuel Density (kg m^{-3}); t_travel time (s); HVC_Hourly Volumetric Fuel Consumption (L h^{-1}); BIOEM_Biocombustível e Ensaio de Máquinas; B0_0% of Biodiesel; B5_5% of Biodiesel; B25_25% of Biodiesel; B50_50% of Biodiesel; B100_100% of Biodiesel; UNESP_Universidade Estadual Paulista; LADETEL_Laboratório de Tecnologias Limpas; USP_Universidade de São Paulo; FWA_Front-Wheel Assist; FAPESP_Fundação de Amparo à Pesquisa do Estado de São Paulo; CNPq_Conselho Nacional de Desenvolvimento Cientifico e Tecnológico; COOPERCITRUS_Cooperativa de Produtores Rurais.

Introduction

Biodiesel has gradually become a popular alternative to replace fossil fuel due to the fact it is renewable and has low toxic emissions. Strategies have been adopted to ensure the continued growth of the biodiesel industry such as developing policy, reducing the incidence of tax on biodiesel and supporting research, and development of potential raw materials for biodiesel (Nasir et al., 2014). Biodiesel is biodegradable, renewable, non-toxic and environmental friendly. It has properties similar to diesel in terms of chemical structure and energy content. Thus it is compatible with diesel engines and does not require modifications (How et al., 2012). Biodiesel is seen as a possible solution to the uncertainties and doubts of energy security, especially in developing countries (Lam et al., 2009). Biodiesel is an alternative fuel that has a huge potential to reduce pollutant emissions in compression ignition engines (Mofijur et al., 2012; Rahman et al., 2013). Basha et al. (2009) showed that the use of biodiesel results in a significant reduction in the emission of greenhouse gases when compared to the burning of conventional diesel. Storage conditions strongly affect the stability of biodiesel but the production and purification can play an important role in long-term stability. Serrano et al. (2013) showed a significant increase in the stability of biodiesel by adding citric acid to the water used to purify biodiesel after esterification, possibly due to the low concentration of chelating metals. Christensen and McCormick (2014) studied the storage stability for biodiesel and biodiesel blends in the long-term and observed that the exposure to oxygen, contamination by metals and other radicals, exposure to water, light and heat can contribute to the degradation of fuel quality. The presence of water in biodiesel, for instance, can deteriorate the quality of the fuel by reducing the heat of combustion due to incomplete combustion and a decrease in the content of the fuel components. The presence of water will also cause corrosion of the engine and the development of microbial colonies that can clog the components of supply line and return line (Demirbas, 2009). The study by Biradar and Adeppa (2014) on the performance and emissions of diesel engine operating with biodiesel and blends, showed that blends with up to 20%

of biodiesel do not influence diesel engine performance, and it shows reduction of particulate matter emission, concluding that biodiesel is an alternative fuel that is suitable for diesel engines. The use of distilled biodiesel in agricultural tractors on chisel plowing resulted in a 15.5% increase in hourly volumetric fuel consumption, 18.1% in hourly fuel consumption by weight, 16% in operational consumption (ha/h), and 18% in specific fuel consumption compared to diesel (B0) (Soranso et al., 2008). In the same research line, Grotta et al. (2008) observed that the hourly fuel consumption increased 4.9%, weight hourly fuel consumption 13.0% and the specific fuel consumption 11.4% comparing B0 with B100. Castellanelli et al. (2008), using a dynamometer test over a range of engine speeds, observed that for blends above B50 there was a gradual decrease in performance and an increase in specific fuel consumption. It was observed that in certain range of engine speeds, there is incomplete combustion of blends due to poor atomization by the injection system. Lopes et al. (2009) evaluated the consumption of ethyl ester biodiesel from residual soybean oil. The results showed that the use of biodiesel blends up to B50 did not change the consumption. However, when the tractor worked with 100% of biodiesel, the fuel consumption increased by 11% with no abnormality in its operation. Koike et al. (2010) evaluated the emission of combustion gases from a compression ignition engine and found that when alcohol was injected with diesel, smoke density decreased by 17.4% due to higher combustion efficiency. Regarding biodiesel and biodiesel with ethanol, the smoke density was reduced and the measures were smaller than the limit of sensitivity of the equipment. It is assumed that storage for prolonged periods contributes to the aging of biodiesel and the addition of biodiesel to the proportions affect the performance of tractors and smoke density. In this scenario, the present study aimed to evaluate fuel consumption, smoke density and performance of farm tractors in function of storage period of biodiesel from castor oil and proportions of blend with diesel.

Results

Tractor performance

Table 1, in which the average results of the evaluated items are shown, data concerning the factors storage period and proportion of biodiesel represent averages of 6 and 15 observations, respectively. It is observed that the storage period did not affect the hourly volumetric fuel consumption; however, regarding the proportion of biodiesel, when comparing B0 and B100, consumption increased by 16.9%. This increase is due to the lower calorific value of biodiesel compared to diesel, which means a greater fuel supply was needed to accomplish the same work. The weight hourly fuel consumption was similar to the volumetric, except from B25 and B50 proportions that were statistically different. The difference is due to the density effect of biodiesel from castor oil compared to diesel, emphasizing that in this modality the tractor consumed equal mass of fuel. The relevance of this measurement is for professionals working on the distribution of fuels and verifying that fuel mass from the origin and at the destination are equal (Table 1).

The specific fuel consumption of biodiesel (Table 1) did not differ in function of storage period. Regarding biodiesel blends proportions in diesel, it is noted that up to the addition of 25% of biodiesel from castor oil (B25) there was no significant difference in the specific fuel consumption. However, when comparing B0 with B100, the consumption increased by 31.3%. Specific fuel consumption is the most commonly used metric when comparing treatments in the scientific field due to the fact that it takes into account the amount of fuel consumed, developed power, and density of the product. Figure 1 shows the average of specific fuel consumption for the three storage periods depending on blend proportion obtained linear behavior.

Smoke density of tractor engine

Table 2 shows the average results of smoke density. Data regarding the factors type of diesel and proportion of biodiesel represent averages of 6 and 15 observations, respectively. In this table, it is noteworthy that the interaction between the factors was significant, so the variable was analyzed using a complementary deployment table. According to Table 3, it can be seen that in the storage period (on the line) there was smoke density reduction as the blend proportion of biodiesel from castor oil in diesel increased. The non-stored, 3-month stored, and 6-month stored fuels showed a reduction of 48.76%, 35.78%, and 47.15% in smoke density, respectively, when comparing B0 and B100.

When the smoke density was evaluated according to blend proportion (Table 3) that in all blends proportions the fuel storage period of 3 months had low particulate emissions by the tractor engine, except for B50 proportions comparing with 6 months, and B100 compared with new fuels. It was not possible to identify the cause of this behavior.

Discussion

Tractor performance

The results of this study are consistent with those found by Monyem and Van Gerpen (2001) and Peterson et al. (1996), highlighting that the volumetric fuel consumption is the most used information by farmers due to the ease of measurement and that biodiesel combustion properties can be affected by oxidation after being stored for a period. This increase of specific fuel consumption is due to the combined effects of density, viscosity and lower calorific value of biodiesel compared to diesel, according to what was presented by Murugesan et al. (2009) and Chauhan et al. (2012). Working with biodiesel from castor oil in two types of diesel, Tabile et al. (2009) observed an increase of 38.3% of the specific fuel consumption, which was slightly higher than the value found in this study (31.3%), since the power required at drawbar was similar in both experiments. Gokalp et al. (2011) observed that the increase in the proportions of soybean oil methyl ester in diesel reduced the thermal efficiency and slightly increased the specific fuel consumption. Buyukkaya (2010) conducted an experimental study addressing the effect of biodiesel from rapeseed oil on the performance of diesel engine and concluded that the use of biodiesel increased the specific fuel consumption around 11%.

Smoke density of tractor engine

Lima et al. (2012) found that the smoke density reduced as the amount of biodiesel in the blend increased. Yoon et al. (2014) observed that the emission of particulate matter decreased by about 33%, on average, comparing B30 with diesel (B0).

Table 1. Average results for the variables hourly volumetric fuel consumption (HVC), weight hourly fuel consumption (WHC) and specific fuel consumption (SFC).

Factors	HVC	WHC	SFC
	L h^{-1}	kg h^{-1}	g kWh^{-1}
Storage period (Sp)			
0 month	13.9 a	12.0 a	353 a
3 month	13.9 a	12.0 a	361 a
6 month	13.8 a	11.9 a	358 a
Biodiesel proportion (Bp)			
B0	13.0 a	10.8 a	320 a
B5	13.4 a	11.2 a	337 a
B25	13.8 b	11.8 b	341 ab
B50	14.1 b	12.3 c	368 b
B100	15.2 c	13.7 d	421 c
F TEST			
Sp	0.45^{NS}	0.50^{NS}	0.6^{NS}
Bp	65.44^{**}	154.64^{**}	33.20^{**}
SpxBp	0.75^{NS}	0.75^{NS}	0.63^{NS}
C.V.%	2.25	2.29	5.73

Averages followed by the same lowercase letter in the column do not differ between themselves by Tukey's test at 1% of probability. ** Significant (p≤0.01); ^{NS}: not significant; C.V.: coefficient of variation.

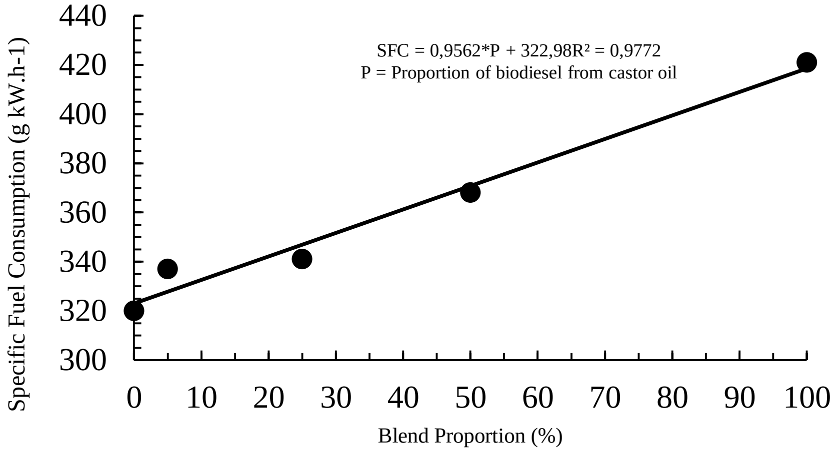

Fig 1. Specific fuel consumption according to the proportion of biodiesel from castor oil.

Table 2. Summary of variance analysis and mean test for the variable smoke density.

Factors	Density
Storage period (Sp)	(m^{-1})
0 month	0.95
3 month	0.81
6 month	0.95
Biodiesel proportion (Bp)	
B0	1.13
B5	1.08
B25	0.85
B50	0.84
B100	0.63
F TEST	
Sp	188.6534 **
Bp	711.3146 **
SpxBp	28.7174 **
C.V.%	5.02

Averages followed by the same lowercase letter in the column do not differ between themselves by Tukey's test at 1% of probability. ** Significant (p≤0.01); ^{NS}: not significant; C.V.: coefficient of variation.

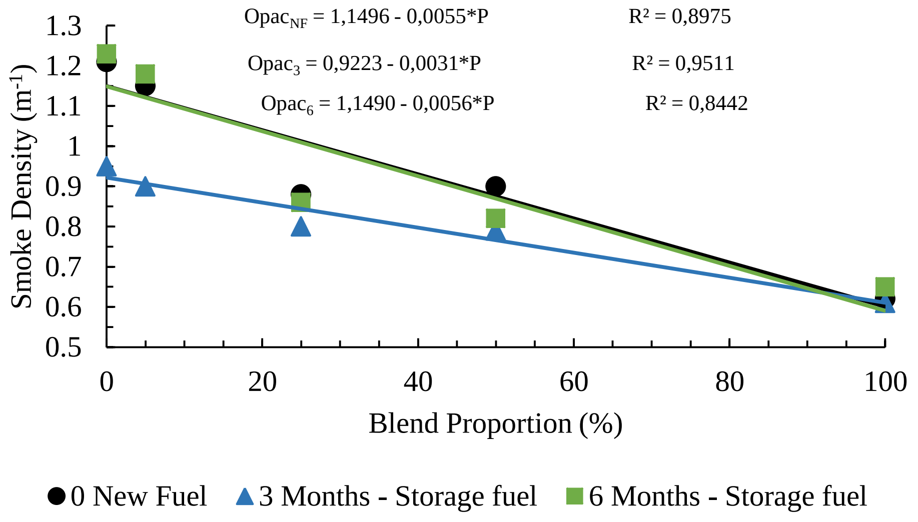

Fig 2. Graphical representation of the smoke density in function of the proportion distilled castor oil ethyl esters mixed with diesel in the three storage period.

According to Khalid et al. (2013) a longer storage period for B5 and B45 blends resulted in greater density of the fuel, and increased viscosity, especially under high temperature storage conditions (300°C). Also combustion of the B45 blend had a high variation in CO emissions. This behavior can be attributed to the combustion process due to the amount of oxygen in the B45 blend. Figure 2 shows the smoke density variation, showing similar behavior between new fuel and 6 months storage. Based on the analysis and the consulted literature, it was not possible to explain this behavior.

Materials and Methods

Experimental area

The experiment was carried out on August 20, 2013, in the Biofuel and Engine Test – BIOEM of the Rural Engineering Department, in the State University of São Paulo – UNESP – Jaboticabal – SP, Brazil. The area is located lateral to the Acess Road Prof. Paulo Donato Castellane, km 5, geodesic coordinates 21°15' south and 48°18' east, 570 meters above the sea level. The annual average temperature is 22,2 ºC, annual average precipitation is 1.425 mm, average relative humidity of 71% and an atmospheric pressure of 94,3 kPa (Unesp, 2011). The regional weather is classified by Köeppen as Cwa, defined as subtropical with dry winter in transition to Aw, tropical-wet with defined rain period in summer and drought winter. The soil of the area was classified as Eutrustox, with gently rolling topography and average slope of 3% (Andreoli and Centurion, 1999). The average water content by gravimetric method on the experiment day was 11,2 and 13,4 % for 0-15 and 15-30 cm deep, respectively. The soil particle size at 0-20 cm layer to clay, silt, fine and coarse sand was 51, 29, 10 and 10%, respectively, being classified as clayey.

Fuels and Storage period

The biodiesel used was distilled castor oil ethyl esters. The production process and the supply of biofuel were made by the Laboratory for the Development of Clean Technologies-LADETEL at the University of São Paulo - USP, Campus Ribeirão Preto – SP, Brazil. The Diesel, classified in accordance with the resolution of the ANP Nº. 42, of December 16, 2009 (ANP, 2009), with at maximum 1.800 mg kg^{-1} of sulfur and a density of 860 $kg.m^{-}$
The fuel was stored in plastic gallons and refrigerated for 3 and 6 months. Blending of the Biodiesel and diesel was performed at the moment of each test.

Machinery

A BM 100 model Valtra tractor was used in the tests, , 4x2 front-wheel assist (FWA), power of 73.6 kW (100 hp) at 2350 rpm, total mass of 5400 kg distributed in 40% and 60 % on the front and rear axles, respectively, equipped with 14.9-24 tires on the front axle and 23.1-26 tires on the rear axle. In the tests, the tractor operated at 2000 rpm with operating speed achieved with the combination of the 3rd gear, range L.
A second Valtra Tractor was also used: model BH140, 4x2 front-wheel assist (FWA), power of 103 kW (140 hp) at 2400 rpm, total mass of 7400 kg distributed in 40% and 60% on the front and rear axles, respectively, equipped with 14.9-24 tires on the front axle and 23.1-26 tires on the rear axle. The second tractor, which had the function to provide load on the traction bar in order to simulate the work with chisel plow, was coupled to the first tractor by means of a steel cable. A preliminary test was conducted, also called pilot experiment, in order to set the load corresponding to maximum effort, technically feasible, that the first tractor could pull. It is noteworthy that the load was achieved through a combination of the gears of the second tractor with 23 kN. The second tractor was turned off and geared, since the only function was to provide the most possible uniform load on the tractor traction bar, with operating speed achieved with the combination of the 4th gear, range L.

Data Collect

Upon receipt the fuels (diesel and biodiesel) 0-month tests were performed. The fuels were stored for 3 months and another test was performed. And finally, after more 3 months of storage the 6-month test was performed. For the performance test, each experimental plot area had 30 m in length and in the longitudinal direction, it was reserved an area of 15 m for the realization of landmarks, machinery

Table 3. Deployment of the interaction storage period and biodiesel proportion for the variable smoke density (m^{-1}).

Storage Period	Biodiesel Proportion				
	B0	B5	B25	B50	B100
0 month	1.21 Aa	1.15 Ab	0.88 Ac	0.90 Ac	0.62 ABd
3 month	0.95 Ba	0.90 Ba	0.80 Bb	0.79 Bb	0.61 Bc
6 month	1.23 Aa	1.18 Aa	0.86 Ab	0.82 Bb	0.65 Ac

Averages followed by the same lowercase letter in the column do not differ between themselves by Tukey's test at 5% of probability

traffic and stabilization of machines in each treatment. In all plots, aiming to stabilize the measurements, the tractor started movement in an area of 15 m before the first landmark, which marked the beginning of the measurement. When the center of the rear wheel coincided with the first landmark, the data acquisition system was activated. The procedure was stopped at the end of 30 m length of plot, at which the center of the rear wheel coincided with the second landmark.

At each plot, fuel consumption was measured as the difference between total volume supplied to the input of the injection pump and total volume returned. With this data, the hourly consumption (volumetric, weight) and the specific fuel consumption were determined.

Based on the volume consumed and the trajectory time from each plot, was determined hourly volumetric fuel consumption, according to equation (1):

$$HVC = \left(\frac{Sv - Rv}{t} \right) * 3,6 \qquad (1)$$

where,
HVC = hourly volumetric fuel consumption ($L\ h^{-1}$);
Sv = supply fuel volume (mL);
Rv = return fuel volume (mL);
t = travel time (s), and
3,6 = conversion factor.

To calculate the weight hourly fuel consumption, was considered the influence of density of the supplied and returned fuel during the test, according to equation (2):

$$WHC = \left(\frac{Sv * Dsf - Rv * Drf}{t} \right) * 0,0036 \qquad (2)$$

where,
WHC = weight hourly fuel consumption ($kg\ h^{-1}$);
Sv = supply fuel volume (mL);
Dsf = fuel supply density ($kg\ m^{-3}$);
Rv = return fuel volume (mL);
Drf = return fuel density ($kg\ m^{-3}$);
t = travel time (s), and
0,0036 = conversion factor.

Specific fuel consumption is the consumption of fuel expressed in units of mass per unit of power required in the drawbar, according to equation (3):

$$SFC = \left(\frac{WHC}{Dp} \right) * 1000 \qquad (3)$$

where,
SFC = Specific Fuel Consumption ($g\ kW\ h^{-1}$);
WHC = weight hourly fuel consumption ($kg\ h^{-1}$);
Dp = Drawbar power (kW), and
1000 = conversion factor.

For smoke density, the test was performed according to the method of free acceleration, which is the rotation speed at which the engine is submitted with the accelerator at its maximum, and the power developed is absorbed only by the inertia of the mechanical components of the engine (clutch, primary tree of gears) when the vehicle is parked. Smoke density measurements are made in K, which is the coefficient of light absorption, and has unit m-1 as stated in the manufacturer's manual (Tecnomotor).

The smoke density was determined using Valtra tractor, model BM100. At the end of each determination, there was a complete draining of the supply system, avoiding contamination of the following test. In addition, after the fuel was changed, the engine was in operation around ten minutes before the beginning of each test.

Statistical analysis

The study was divided into two stages: the first was dynamic, which was carried out under field conditions in order to assess the tractor performance. The second one was static, performed with the tractor parked in order to evaluate the smoke density of tractor engine. Both were carried out in a completely randomized experimental design and 5x3 factorial scheme with three replications, totaling 45 observations. The combinations of factors were five proportions of biodiesel/diesel blend (B0, B5, B25, B50 and B100, which the number indicates the percentage of biodiesel in diesel) and three storage periods (0, 3 and 6 months) in ambient condition, as diesel is usually kept in the properties.

Data were tabulated and submitted to variance analysis and Tukey's comparison test at 1% ($p \leq 0.01$) of probability, as recommended by Banzatto and Kronka (2006). In this study, variance analysis was used (F-test) to select the equation model with the most significant exponent.

For the specific fuel consumption and the smoke opacity, it was studied the regression adjustment model that could better explain the behavior of these variables in function of biodiesel proportion. In the case of fuel density, a response surface model to explain this variable also depending on the temperature and the proportion of biodiesel was adjusted.

Conclusion

The proportion of diesel/ biodiesel from castor oil did not compromise the operation of the tractor engine. Biodiesel increment of castor oil from B25, compared with B0, caused a significant increase in the specific fuel consumption of the tractor. Regarding B0 (diesel), when biodiesel in the proportion of B100 was used, the specific fuel consumption increased by 31.6%, and the smoke density was reduced by 44%. The six-month storage period did not influence the operational performance of the tractor; however, 3-month storage period resulted in 14.5% of smoke density reduction.

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