GAINS IN PERFORMANCE OF DIESEL CYCLE ENGINE USING B10 COMPARED TO OTHER MIXTURES

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ABSTRACT

Studies to develop renewable fuels, such as biodiesel, as substitutes for petroleum diesel have a great environmental importance. However, in order to be effectively incorporated into the energy mix, a satisfactory performance of a diesel cycle engine under the effect of this biofuel must be ensured. The objective of this study was to evaluate the specific fuel consumption, effective power and torque of a diesel engine related to resistive loads under varying volumetric proportions of soybean biodiesel in mineral diesel oil (5% (B5), 10% (B10), 25% (B25) and 50% (B50)) under varying applied loads (1.5, 3.0, 4.5, 6.0, 7.5 and 9.0 kW). For the test, a 7.36 kW engine coupled to a 28.8 kW three-phase electric generator was used. The loads were elevated up to 9.0 kW via a three-phase resistive bench. In terms of power and torque, the performances of the B5 and B10 mixtures were not significantly different, whereas the B25 and B50 mixtures displayed lower performances. The B10 mixture showed better performance in terms of consumption because the remaining mixtures had similar results to those B5 mixture. For this reason, it can be a basis for encouraging anticipation of this mixture in diesel cycle engines use. Additionally, the reduction in power and torque for mixtures with higher concentration of biodiesel should not be considered significant front the environmental gains from the use of renewable fuels and the analyzed technical aspects.

GANHOS NO DESEMPENHO DE MOTOR CICLO DIESEL COM O USO DO B10 EM COMPARAÇÃO COM OUTRAS MISTURAS

RESUMO

Estudos voltados ao desenvolvimento de combustíveis com origem renovável, como o biodiesel, em substituição ao diesel de petróleo, são de grande importância ambiental. Entretanto, para serem inseridos, efetivamente, na matriz energética, é necessário garantir o desempenho satisfatório do motor ciclo diesel sob efeito desse biocombustível. Objetivou-se avaliar o consumo específico de combustível, a potência efetiva e o torque do motor diesel em função de cargas resistivas, sob as proporções volumétricas de biodiesel de soja no óleo diesel mineral: 5% (B5), 10% (B10), 25% (B25) e 50% (B50), e das cargas aplicadas (1,5, 3,0, 4,5, 6,0, 7,5 e 9,0 kW). Para o ensaio, utilizou-se motor de 7,36 kW acoplado a um gerador elétrico trifásico de 28,8 kW. As cargas utilizadas: 1,5, 3,0, 4,5, 6,0 e 7,5 foram elevadas até 9,0 kW, oriundas de uma bancada trifásica de cargas resistivas. O desempenho com as misturas B5 e B10 não diferiram significativamente em termos de potência e torque, ao passo que as misturas B25 e B50, em relação a estes parâmetros, tiveram desempenho inferior. O B10 apresentou melhor desempenho em termos de consumo, já as demais misturas tiveram resultados semelhantes ao do B5. Por esta razão, este resultado pode ser referência para antecipação do uso desta mistura em motores do ciclo diesel. Adicionalmente, a redução da potência e torque usando misturas com maiores concentrações de biodiesel não deve ser considerada significante diante dos ganhos ambientais resultantes do uso de combustíveis renováveis e dos aspectos técnicos analisados.

INTRODUCTION

Due to environmental concerns, the need for renewable energy and according to the need for eco-innovations, biodiesel presents itself as a potential substitute for mineral diesel oil. This biofuel can be obtained by the transesterification of oils and/or fats with a short-chain alcohol in the presence of a catalyst (LÔBO et al., 2009).

According to GALVÃO (2007), biodiesel has the characteristics required for a fossil diesel oil substitute, being free from sulfur and organic compounds that are harmful to humans, in addition to being renewable, biodegradable and non-toxic. In addition, ELA et al. (2016) emphasized the rapid evolution with which the diesel engine has proven to be one of the most effective energy conversion systems.

Among oilseeds, soybean has fulfilled the largest proportion of the current production of biodiesel in Brazil. Despite being susceptible to oxidation, mainly due to the presence of double bonds in the linoleic fatty acid (the main component of soybean oil) (BELTRÃO & OLIVEIRA, 2008), it is possible to obtain a biodiesel quality by controlling the production process, using antioxidants and adequately storing the biofuel.

Furthermore, the more complete biodiesel combustion, compared to diesel, can render the specific consumption equivalent to that fossil fuel while also reducing the emissions of particulate matter (PM), carbon monoxide (CO), and hydrocarbons (HC) (SHARMA et al., 2009); and reducing the increase net of the carbon dioxide level (CO_2) (CARVALHO, 2012; ZAHARIN et al., 2017; BEATRICE et al., 2017). Vehicle emissions have an important effect on global warming and climate changes (HAZAR, 2017), encouraging studies that minimize these emissions without significant losses to engine performance.

Due to the need for new alternatives that minimize reliance on oil products and the elucidation of biodiesel potential, in terms of the mechanical performance of the engine, this study aimed to evaluate the power, the torque, and specific consumption of a diesel engine with a 7.36 kW (10 hp) power, coupled to a 28.8 kW three-phase generator. It used different volumetric proportions of soybean biodiesel (B5, B10, B25 and B50) and resistive loads of 1.5, 3.0, 4.5, 6.0, 7.5 and 9.0 kW. In addition, research was conducted in the literature for to evidence environmental gains.

MATERIALS AND METHODS

The biodiesel was produced in the Laboratory of Chemical Processes (LCP) from Federal University of São Francisco Valley - via methyl transesterification of soybean oil, using sodium hydroxide (NaOH) as the catalyst, generating crude biodiesel and glycerin as products. We separated the glycerin from the crude biodiesel by decantation, and then proceeded to the purification process.

The purification of the biodiesel consisted of aqueous washing with the addition of distilled water, corresponding to 30% of the biodiesel/water mixture, to remove the alcohol, catalyst and glycerin excess by stirring and heating, followed by decantation. Next, the biodiesel was dried with the addition of Magnesol and vacuum filtration to remove the residual water that was retained in the filter with the Magnesol.

After production, the pure biodiesel (B100) was mixed with commercial diesel (B5), acquired in Juazeiro-BA, in order to obtain biodiesel/diesel mixtures with 10% (B10), 25% (B25), and 50% (B50) biodiesel. Samples of B5, B10, B25, B50, and B100 (reference sample) were subjected to the quality analyses described below.

The acid value was analyzed according to the methodology of the standard ABNT NBR 14448 by the potentiometric titration method (BORSATO et al., 2012), the National Agency of Petroleum, Natural Gas and Biofuels (ANP) requirement of which establishes a maximum limit of 0.5 mg KOH $g_{biodiesel}^{-1}$.

The kinematic viscosity at 40° C was obtained according to the standard ASTM D445, using a Cannon-Fenske viscometer number 75 for opaque liquids, which establishes limits within the range from 3 to 6 mm² s^{-1}.

The oxidative stability was determined using the standard method described in the EN 14112, commonly referred as Rancimat method, in which 3.0 grams of each sample were aged in an

airflow (10 L h^{-1} at 110 ºC) within a measurement cell supplied with deionized water. This method measures the induction time by conductivity (ZULETA et al., 2012), which should reach the minimum limit of 6 h.

The specific masses of the mixtures were established with the methods recommended by the standards ABNT NBR 14065 and ASTM D4052, which determine the specific mass and the relative density of oil distillates and viscous oils using a digital densitometer (LÔBO et al., 2009). The ANP regulation provides a limit from 820 to 850 kg m^{-3} for the commercial diesel (B5) and from 850 to 900 kg m^{-3} for B100.

The determination of the sulfur content of the mixtures is in agreement with the methodology recommended by the standards ABNT NBR 14533, ASTM D4294 and ASTM D5453 (LÔBO et al., 2009), using molecular fluorescence spectrometry. The ANP standards establish a maximum limit of 10 mg kg^{-1} sulfur for B100.

Once the quality of the mixtures had been established, the dynamometer test of the 7.36 kW (10 hp) Branco diesel engine was performed at Mechanical Engineering Laboratory from UNIVASF in 2014, using the B5, B10, B25, and B50 mixtures.

In this dynamometer, the diesel engine was coupled to a three-phase 28.8 kW generator with an output voltage of 220 V, which supplied a three-phase resistive bench with 30 light bulbs of 100 W each per phase.

After the initial heating and stabilization, the engine was subjected to the maximum rotational speed (3600 rpm) and the resistive loads were activated, applying 1.5 kW per stage, which enabled the measurement of current, voltage and rotational speed using an ammeter, a multimeter and a tachometer, respectively. Thus, it was possible to determine the power under the test conditions related to the applied load. This procedure was followed until all of the resistive loads of the bench (9.0 kW) were applied. The power was calculated using Eq. 1 (Kosov, 1982):

$$P_{effective\ observed} = \sqrt{3} * V * I \qquad (1)$$

Where: $P_{effective\ observed}$ – Produced power, Watts; V – Output voltage, Volts; and I – Output current, Ampere.

After measuring the power for each stage of the load application, the fuel supply from the tank was switched off, the fuel supplied from the burette connected to the engine was switched on, and the volumetric consumption (volume/time) was measured with the help of a stopwatch. According to MIALHE (1996), from the consumed fuel mass values and the measurement of power and time, the specific fuel consumption (SPF) can be calculated, as shown in Eq. 2:

$$SFC = \frac{3.6 * 10^3 * C * \mu}{P_{effective\_observed}} \qquad (2)$$

Where: SFC – Specific fuel consumption, g kW^{-1} h^{-1}; C – Fuel consumption, mL s^{-1}; μ –Specific mass, kg m^{-3}; and $P_{effective\_observed}$ – Power produced during the test, W.

With the values of power and rotational speed, the values of torque can be obtained using Eq. 3:

$$T = \frac{P_{effective\_observed} * \mu}{rpm} \qquad (3)$$

Where: T- Torque of the engine, kgf.m; $P_{effective\_observed}$- Power produced during the test, W; and rpm - Rotational speed of the engine in revolutions per minute.

The dynamometer test of the engine was repeated three times for each mixture, using the same system and test conditions, according to the ABNT NBR 6398 method.

To determine the differences and the possible gains from the use of different biodiesel / diesel mixture, the obtained results of power, torque and consumption were statistically analyzed by a two-way analysis of variance (ANOVA), in which two factors were simultaneously evaluated. Thus, the influence of the type of fuel (B5, B10, B25 and B50), the applied loads (1.5, 3.0, 4.5, 6.0, 7.5 and 9.0 kW), and the interaction of these two factors were analyzed for the results of the observed effective power, specific consumption and engine torque at the significance level $\alpha = 0.05$.

After concluding that there are significant differences between treatments, the magnitude of these differences was evaluated using Tukey's test, which tests any contrast between two treatment

126

means at the significance level α = 0.05.

Finally, extensive research in the literature was done to evidence environmental gains.

RESULTS AND DISCUSSION

The mixtures B5, B10, B25, and B50 used in the dynamometer tests, as well as the B100 reference sample, showed quality parameters, as described in the Materials and Methods section, consistent with the limits established by the resolution number 45 of the ANP, published in 2014.
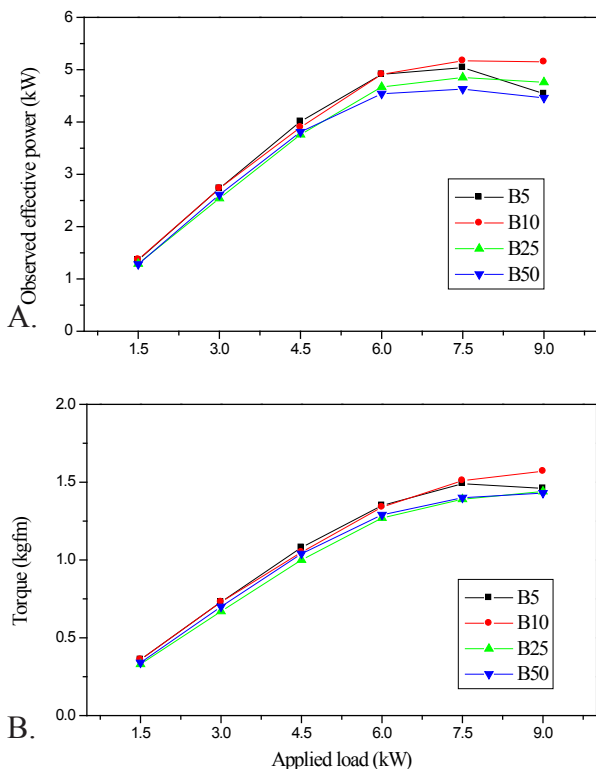
The engine behavior with the use of B5, B10, B25, and B50 mixtures in terms of power and torque is shown in Figure 1; these two parameters increase with the applied load. With the applied load increase (from 6 kW - Figure 1), it was identified a detachment between the effective power and torque curves for the analyzed mixtures that can be attributed to the inefficient atomization of the fuel, due to the higher viscosity of the mixtures with larger proportions of biodiesel. The inefficient atomization can result in losses during the fuel burn (NIETIEDT, et al., 2011).

Through the ANOVA analysis, a significant difference was observed in the results of the mean effective power as well as in the results of the torque and specific consumption for the mixtures (Table 1), the applied loads and the interaction between these two variables.

Table 1. Means of the observed effective power, the torque and the specific consumption related to the tested mixtures

Mixtures	Power (kW)	Torque (kgf.m)	Specific consumption (g kW^{-1} h^{-1})
B5	3.77 a	1.08 a	622 ab
B10	3.87 a	1.09 a	534 c
B25	3.64 b	1.02 b	617 a
B50	3.55 b	1.04 b	664 b
F-test	18.60**	18.00**	19,70**
CV	5.24	4.72	12.07

In each column and for each factor, the means followed by the same lowercase letters do not differ from Tukey's test at 5% probability: ** Significant at the 1% probability level (P<0.01); * Significant at the 5% probability level (P <.05)

The results of power and torque related to the types of fuel (mixtures) (Table 1) indicate that the highest mean power and the highest mean torque achieved by the engine occurred under the influence of B10, whose results are statistically similar to those of B5. The mixtures B25 and B50 showed a performance decrease regarding power and torque. However, these two mixtures had similar results to each other. This decrease can be attributed to the lower calorific value of biodiesel.

The reduction in power and torque, obtained in the study, for mixtures with higher concentration of biodiesel, should not be considered significant front the environmental gains from the use of renewable fuels. YILMAZ et al. (2017) confirm the reduction of carbon monoxide (CO) and unburned hydrocarbons (HC) emissions to mixtures with high percentages of biodiesel (90% and 80%) compared to mixtures of fossil origin. Results such as these should be developed to anticipate the increase of biodiesel percentage in diesel to 10%, which was only predicted for 2019 and, in November 2017, it was anticipated for March 2018 (VENTURA, 2017).

Figure 1. Curves of the B5, B10, B25, and B50 mixtures related to (A) the mean reduced power and (B) the mean torque.

Additionally, UYUMAZ et al. (2018) pointed that the usage of biodiesel/diesel mixtures, with mustard biodiesel oil, provides reasonable and effective approach in order to reduce exhaust emission and close thermal efficiency with diesel fuel. ZAREH et al. (2017) and HUANG et al. (2017) also identified environmental gains from the use of the biodiesel/diesel mixtures, such as the reduction of particulate matter, carbon monoxide and dioxide in the engine exhaust. This latter studied properties of castor, coconut and waste cooking based biodiesel as fuel.
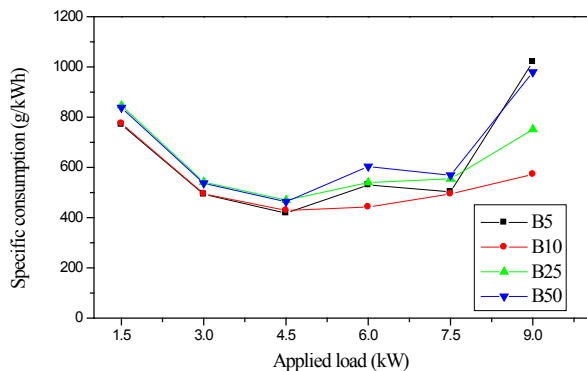
Figure 2. Consumption trend curves for B5, B10, B25, and B50 mixtures.

In the present study, increases above 10% of soybean biodiesel in the mixture resulted in a power reduction of the engine. However, the fuels with higher concentrations of biodiesel (B25 and B50) showed equivalent power values.

Regarding to the specific consumption (Figure 2), the engine had a lower consumption when using B10, followed by B25, B5, and B50 (Table 1).

The consumption with the use of B25 and B50 was similar to B5, which is in agreement with the results presented by SORANSO et al. (2008), who obtained similar specific consumptions for the B5, B25 and B50 mixtures.

The consumption results show that the use of a fuel with proportions of biodiesel up to 50% does not cause consumption losses compared to commercial diesel and it can even contribute to its reduction via the use of diesel with an addition of 10% biodiesel (B10).

The reduction of fuel consumption for mixtures with 10% of biodiesel can be associated with thermal efficiency of the engine. According to

MOREIRA et al. (2013), the thermal efficiency compensated the lower calorific value of biodiesel.

These results correlate with those of NIETIEDT et al. (2011), who evaluated the use of methyl biodiesel mixtures of soybean with diesel (B5, B10, B20 and B100) in a compression ignition engine with direct fuel injection and obtained better performance with the use of B10, showing higher power and lower consumption.

SILVA et al. (2012), when evaluating a small generator set (single cylinder) using various proportions of chicken tallow biodiesel, reported that the use of mixtures with proportions of 20% biodiesel does not significantly affect engine performance in terms of specific fuel consumption.

In a study by VOLPATO et al. (2009), the use of soybean biodiesel (B100) was considered feasible related to the lower specific and energetic consumption of this biofuel compared to diesel, even identifying losses up to 10.7% in torque and a 6.1% decrease in the reduced power with the use of B100. In that study, it was not used the mixtures investigated in this study.

The results of the mean observed power, torque and specific consumption related to the applied loads are described in Table 2. The values of power increase with increased applied load, achieving the highest magnitudes at the load of 7.5 kW. The same behavior is observed for the mean torque, with the loads of 9.0 kW and 7.5 kW, providing the highest torque and displaying similar results.

The highest consumptions were obtained with load applications of 1.5 and 9.0 kW, and these results were statistically equivalent (Table 2). The lowest mean consumption was obtained with a load application of 4.5 kW. This result is shown in the graph of the specific consumption mean curves in Figure 2, which indicates that when applying a load of 9.0 kW, there was a higher consumption of the B5 and B50 mixtures (equivalent), followed by the B25 and B10 mixtures; these results are also shown in Table 5.

The results of the interactions between the applied loads and the mixtures for the mean observed power, mean torque and consumption are described in Tables 3, 4 and 5, respectively.

With the use of B10 (Table 3), the engine showed better performance in terms of power compared to other mixtures for loads of 7.5 and 9.0 kW. Regarding other loads, significant performance differences were not observed between the fuels, i.e., *the powers provided by the mixtures are similar*

when applying loads of 1.5, 3.0, 4.5 and 6.0 kW.

The best observed effective power of B10 in relation to B5 (Table 3) can be related to the increase in the cetane number and higher oxygen concentration in mixtures with higher amounts of biodiesel, which improves the fuel burn inside the combustion chamber (TEIXEIRA, 2010). In contrast, the blends with higher amounts of biodiesel may have been affected by the lower calorific value and larger viscosity of biodiesel

that compromise fuel burn and reduces engine performance.

In view of the interaction between applied loads and the mixtures (Table 4), the B10 mixture showed better performance than the remaining mixtures in terms of torque, with loads of 9.0 and 7.5 kW. The B5, B25 and B50 mixtures displayed performances that were statistically similar to those loads. For the remaining loads (1.5, 3.0, 4.5 and 6.0 kW), the torque was statistically similar among all the mixtures.

Table 2. Means of the observed effective power, the torque and the specific consumption related to the applied loads

Load (kW)	Power (kW)	Torque (kgf.m)	Specific consumption (g kW^{-1} h^{-1})
9.0	4.73 b	1.48 a	830.80 a
7.5	4.92 a	1.45 a	530.12 b
6.0	4.76 b	1.31 b	528.90 b
4.5	3.87 c	1.05 c	444.95 c
3.0	2.65 d	0.71 d	516.72 b
1.5	1.33 e	0.35 e	807.22 a
F-test	1328.71**	1988.63**	120.95**
CV	5.24	4.72	12.07

In each column and for each factor, the means followed by the same lowercase letters do not differ from Tukey's test at 5% probability: ** Significant at the 1% probability level (P<0.01); * Significant at the 5% probability level (P <.05)

Table 3. Means of the observed effective power related to the interaction of the loads with the mixtures

Load (kW)	B5 (kW)	B10 (kW)	B25 (kW)	B50 (kW)
9.0	4.54 bBC	5.15 aA	4.76 aB	4.46 aC
7.5	5.04 bAB	5.17 aA	4.85 aBC	4.63 aC
6.0	4.91 aA	4.91 aA	4.59 aAB	4.54 aB
4.5	4.01 cA	3.90 bA	3.76 bA	3.81 bA
3.0	2.73 dA	2.73 cA	2.54 cA	2.61 cA
1.5	1.36 eA	1.39 dA	1.29 dA	1.28 dA
F-test	2.94**		CV	5.24

In each row the means followed by the same upper case letters and in each column the means followed by the same lowercase letter do not differ from Tukey test at 5% probability. ** Significant at the 1% probability level (P<0.01); * Significant at the 5% probability level (P <.05)

Table 4. Means of torque related to the interaction of the loads with the mixtures

Load (kW)	B5 (kgf.m)	B10 (kgf.m)	B25 (kgf.m)	B50 (kgf.m)
9.0	1.46 aB	1.57 aA	1.44 aB	1.43 aB
7.5	1.49 aA	1.51 aA	1.39 aB	1.40 aB
6.0	1.35 bA	1.34 bAB	1.27 bB	1.29 bAB
4.5	1.08 cA	1.05 cA	1.00 cA	1.04 cA
3.0	0.73 dA	0.73 dA	0.67 dA	0.70 dA
1.5	0.36 eA	0.36 eA	0.33 eA	0.34 eA
F-test	1.83*		CV	4.72

In each row the means followed by the same upper case letters and in each column the means followed by the same lowercase letter do not differ from Tukey test at 5% probability. ** Significant at the 1% probability level (P<0.01); * Significant at the 5% probability level (P <0.05)

Table 5. Means of the specific consumption related to the interaction between loads and mixtures

Load (kW)	B5 (g kW^{-1} h^{-1})	B10 (g kW^{-1} h^{-1})	B25 (g kW^{-1} h^{-1})	B50 (g kW^{-1} h^{-1})
9.0	1020.02 aA	572.59 bC	751.64 aB	978.94 aA
7.5	502.87 cA	494.20 bcA	554.73 bA	568.70 cdA
6.0	529.93 cAB	442.52 cB	539.67 bAB	603.47 cA
4.5	417.87 cA	428.86 cA	469.59 bA	463.49 dA
3.0	493.33 cA	494.87 bcA	541.58 bA	536.70 cdA
1.5	770.45 bA	774.62 aA	846.14 aA	837.65 bA
F-test	7,63**		CV	12.07

In each row the means followed by the same upper case letters and in each column the means followed by the same lowercase letter do not differ from Tukey test at 5% probability. ** Significant at the 1% probability level (P<0.01); * Significant at the 5% probability level (P <.05)

The consumption results (Table 5) showed that with the application of a 6.0 kW load, the consumption with the B10 mixture was lower than the remaining mixtures. The highest consumption was observed with the use of B50, with a magnitude similar to the B5 and B25 mixtures.

With the application of 9.0 kW, lower consumption was observed using the B10 mixture, followed by the B25 mixture and subsequently by the B50 and B5 mixtures, which showed similar results (Table 5). Finally, for the 1.5, 3.0, 4.5 and 7.5 kW loads, the consumptions of the mixtures were all similar.

The use of larger proportions of biodiesel up to 50% does not compromise the engine performance compared to commercial diesel. Mixtures with 10% biodiesel present a reduction in consumption and a better performance in terms of power and torque.

As perspective, non-linear regression studies can be performed. For this, new dynamometric tests for new mixtures should be carried out, generating new additional results. From these, it can be possible to predict differences in engine performance using different soybean biodiesel mixtures in mineral diesel oil through the interpolation.

CONCLUSIONS

- The power and torque produced by the engine with B10 were equivalent to the results obtained with B5, which suggests the feasibility of increasing the mandatory percentage of biodiesel to B10.

- The specific consumption of B10 mixture was lower than that for the other mixtures. However, the B25 and B50 mixtures had similar results to those for B5 mixture. There was a difference in consumption related to the loads; for the 1.5 and 9.0 kW loads, there was a higher consumption, while at 4.5 kW, there was a lower consumption.

- The engine performance was lower in terms of torque and power as the proportion of biodiesel in the mixture increased above 10%. The results for B25 and B50 were similar.

- The reduction in power and torque for mixtures with higher concentration of biodiesel was not considered significant front of environmental gains from the use of renewable fuels and analyzed technical aspects.

BIBLIOGRAPHIC REFERENCES

BEATRICE, C.; DI BLASIO, G.; BELGIORNO, G. Experimental analysis of functional requirements to exceed the 100kW/l in high-speed light-duty diesel engines. Fuel, v.207, p.591-601, 2017.

BELTRÃO, N.E.M.; OLIVEIRA, M.I.P. Oleaginosas e seus óleos: vantagens e desvantagens para produção de biodiesel. 1.ed. Campina Grande: Embrapa Algodão, 2008. 28p.

BORSATO, D.; MAIA, E.C.R.; DALL'ANTONIA, L.H.; SILVA, H.C.; PEREIRA, J.L. Cinética da oxidação de biodiesel de óleo de soja em mistura com TBHQ: determinação do tempo de estocagem. Química Nova, v.35, n.4, p.733-737, 2012.

CARVALHO, P.T. Balanço de emissões de gases de efeito estufa de biodiesel produzido a partir de soja e dendê no brasil. 153f. Dissertação (Mestrado em Ciências em Planejamento Energético) – Universidade Federal do Rio de Janeiro, Rio de Janeiro, 2012.

ELA, A.M.A.E.; ELDRAINY, Y.A.; ELKASABY, M.M.; NOUR, A.M. Effect of replacing nitrogen with helium on a closed cycle diesel engine performance. Alexandria Engineering Journal, v.55, Issue 3, p.2251-2256, 2016.

GALVÃO, L.P.F.C. Avaliação termoanalítica da eficiência de antioxidantes na estabilidade oxidativa de mamona. 159f. Dissertação (Mestrado em Físico-Química) – Universidade Federal do Rio Grande do Norte, Natal, 2007.

HAZAR, H. Investigation of the effects of tripropylene glycol addition to diesel fuel on combustion and exhaust emissions at an isolated diesel engine. Energy Conversion and Management, v.142, p.62-68, 2017.

HUANG, H.; LIU, Q.; TENG, W.; PAN, M.; LIU, C.; WANG, Q. Improvement of combustion performance and emissions in diesel engines by fueling n-butanol/diesel/PODE3–4 mixtures. Applied Energy, 2017.

KOSOV, I. L. Máquinas elétricas e transformadores. 4.ed. Rio de Janeiro: Editora Globo, 1982. 689p.

LÔBO, I.P.; FERREIRA, S.L.C.; CRUZ, R.S. Biodiesel: parâmetros de qualidade e métodos analíticos. Química Nova, v.32, n.6, p.1596-1608, 2009.

MIALHE, L.G. Máquinas agrícolas: ensaio e certificação. Piracicaba: FEALQ, 1996, 772p.

MONTEIRO, L.A.; PIANOVSKI JÚNIOR, G.; VELÁSQUEZ, J.A.; ROCHA, D.S.; BUENO, A.V. Performance impact of the application of castor oil biodiesel in diesel engines. Engenharia Agrícola, Jaboticabal, v.33, n.6, 2013.

NIETIEDT, G.H.; SCHLOSSER, J.F.; RIBAS, R.L.; FRANTZ, U.G.; RUSSINI, A. Desempenho de motor de injeção direta sob misturas de biodiesel metílico de soja. Ciência Rural, Santa Maria, v.41, n.7, p.1177-1182, 2011.

SILVA, M.J.; SOUZA, S.N.M.; SOUZA, A.A.; MARTINS, G.I.; SECCO, D. Motor gerador ciclo diesel sob cinco proporções de biodiesel com óleo diesel. Revista Brasileira de Engenharia Agrícola e Ambiental, Campina Grande, v.16, n.3, p.320-326, 2012.

SHARMA, Y.C.; SINGH, B. Development of Biodiesel: Current Scenario. Renewable and Sustainable Energy Reviews, v.13, p.1646-1651, 2009.

SORANSO, A.M.; GABRIEL FILHO, A.; LOPES, A.; SOUZA, E.G.; DABDOUB, M.J.; FURLANI, C.E.A.; CAMARA, F.T. Desempenho dinâmico de um trator agrícola utilizando biodiesel destilado etílico e metílico de óleo residual. Revista Brasileira de Engenharia Agrícola e Ambiental, Campina Grande, v.12, p.63-69, 2008.

TEIXEIRA, C.V. Análise de emissões e desempenho de motores diesel utilizando óleo diesel comercial, biodiesel de palma (B100) e misturas (BX). 88f. Dissertação (Mestrado em Engenharia Mecânica) – Instituto Militar de Engenharia, Rio de Janeiro, 2010.

UYUMAZ, A. Combustion, performance and emission characteristics of a DI diesel engine fueled with mustard oil biodiesel fuel blends at different engine loads. Fuel, v.212, p.256-267, 2018.

VENTURA, M. O Globo – On line, 09 nov. 2017. Disponível em: https://extra.globo.com/noticias/economia/governo-antecipa-maior-mistura-de-biodiesel-no-diesel-para-2018-22050935.html. Acesso em: 22 dez. 2017.

VOLPATO, C.E.S.; CONDE, A.P.; BARBOSA, J.A.; SALVADOR, N. Desempenho de motor diesel quatro tempos alimentado com biodiesel de óleo de soja (B 100). Ciência e Agrotecnologia,

Lavras, v.33, p.1125-1130, 2009.

ZAREH P.; ZARE, A.A.; GHOBADIAN, B. Comparative assessment of performance and emission characteristics of castor, coconut and waste cooking based biodiesel as fuel in a diesel engine. Energy, v.139, p.883-894, 2017.

ZAHARIN, M.S.M.; ABDULLAH, N.R.; NAJAFI, G.; SHARUDIN, H.; YUSAF, T. Effects of physicochemical properties of biodiesel fuel blends with alcohol on diesel engine performance and exhaust emissions: A review. Renewable and Sustainable Energy Reviews, v.79, p.475-493, 2017.

ZULETA, E.C.; BAENA, L.; RIOSA, L.A.; CALDERÓN, J.A. A estabilidade oxidativa de biodiesel e seu impacto sobre a deterioração metálicas e de materiais poliméricos: a avaliação. Journal of the Brazilian Chemical Society, Campinas, v.23, n.12, p.2159-2175, 2012.