PERFOMANCE EVALUATION OF A DIRECT INJECTION ENGINE USING DIFFERENT BLENDS OF SOYBEAN (*Glycine max*) METHYL BIODIESEL

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ABSTRACT: Diesel fuel is used widely in Brazil and worldwide. On the other hand, the growing environmental awareness leads to a greater demand for renewable energy resources. Thus, this study aimed to evaluate the use of different blends of soybean (*Glycine max*) methyl biodiesel and diesel in an ignition compression engine with direct injection fuel. The tests were performed on an electric eddy current dynamometer, using the blends B10, B50 and B100, with 10; 50 e 100% of biodiesel, respectively, in comparison to the commercial diesel B5, with 5% of biodiesel added to the fossil diesel. The engine performance was analyzed trough the tractor power take off (PTO) for each fuel, and the best results obtained for the power and the specific fuel consumption, respectively, were: B5 (44.62 kW; 234.87 g kW^{-1} h^{-1}); B10 (44.73 kW; 233.78 g kW^{-1} h^{-1}); B50 (44.11 kW; 250.40 g kW^{-1} h^{-1}) e B100 (43.40 kW; 263.63 g kW^{-1} h^{-1}). The best performance occurred with the use of B5 and B10 fuel, without significant differences between these blends. The B100 fuel showed significant differences compared to the other fuels.

KEYWORDS: dynamometer, power, specific consumption.

AVALIAÇÃO DO DESEMPENHO DE UM MOTOR DE INJEÇÃO DIRETA SOB DIFERENTES MISTURAS DE BIODIESEL METÍLICO DE SOJA (*Glycine max*)

RESUMO: O óleo diesel combustível é utilizado em grande escala no País e no mundo. Por outro lado, a crescente conscientização ambiental acarreta em maior demanda por recursos energéticos renováveis. Assim, o presente trabalho objetivou avaliar o uso de diferentes misturas de biodiesel metílico de soja (*Glycine max*) e diesel mineral em um motor de ignição por compressão e injeção direta de combustível. Os procedimentos de ensaio foram realizados em um dinamômetro elétrico de correntes parasitas, utilizando as proporções de mistura B10, B50 e B100, com 10; 50 e 100% de biodiesel, respectivamente, em comparação ao diesel comercial B5, com 5% de biodiesel adicionado ao diesel fóssil. O desempenho do motor foi analisado através da tomada de potência do trator (TDP) para cada mistura, sendo que os melhores resultados obtidos para potência e consumo específico de combustível, respectivamente, foram: B5 (44,62 kW; 234,87 g kW^{-1} h^{-1}); B10 (44,73 kW; 233,78 g kW^{-1} h^{-1}); B50 (44,11 kW; 250,40 g kW^{-1} h^{-1}) e B100 (43,40 kW; 263,63 g kW^{-1} h^{-1}). O melhor desempenho ocorreu sob o uso dos combustíveis B5 e B10, sem diferenças significativas entre essas misturas. Já o combustível B100 apresentou diferenças significativas em relação aos demais combustíveis.

PALAVRAS-CHAVE: dinamômetro, potência, consumo específico.

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INTRODUCTION

Diesel fuel is used widely in Brazil and worldwide and most agricultural machines currently in operation uses this fuel as a source of power. It is noteworthy that the use of vegetable oils in Diesel engines was initially considered by its own inventor, however, the increased supply of oil during the first half of the twentieth century created a very favorable situation to the use of mineral diesel. With the oil crisis triggered in the 1970s, the planet began the process of searching for alternative means of generating energy, among which we highlight fuels from plant biomass.

According to CORRÊA et al. (2008), the theme of replacing diesel with biofuels or diesel blends is currently more focused on filling the shortages of oil fuels and reducing emission levels of gas pollutants. Also GRANDO (2005) argues that international great concern on global warming further highlights the inherent benefits of biofuels. Brazil does not figure as an exception in the search for alternative energy sources, and the fact that this country has a huge range of raw materials for biodiesel production; more studies should be developed to generate parameters for use of biodiesel in compression ignition engines (CASTELLANELLI et al., 2008).

To VOLPATO (2009), biodiesel is defined as a renewable and biodegradable fuel made from a mixture of methyl or ethyl esters of fatty acids, usually obtained by the transesterification process, which takes place by removing the glycerin generated in this reaction. Thus, HOGAN (2005) points out that biodiesel is an alternative to diesel and ethanol is an alternative to gasoline, intended for use in diesel engines without requiring major changes. According to this author, biodiesel can be used pure or blended with petroleum diesel at various levels.

Considering the numerous options of vegetable oil in Brazil (soybean, rapeseed, sunflower, palm etc.) for biodiesel production, it is important to known the physical and chemical characteristics and their effect on greenhouse gas emissions (MAZIERO et al., 2006). However, whatever the raw material used, one should evaluate the effects of its use in mechanical performance of the engine.

Studies using twelve alternative fuels produced by blending vegetable oils with diesel fuel in a dynamometer diesel engine performed by ALI et al. (1996) showed that motor performance was similar to that obtained with diesel oil, indicating that there would be no effect on performance parameters after 200 hours of the dynamometer operation. EJIM et al. (2007) argue that binary mixtures with higher proportions of diesel oil can still provide adequate atomization characteristics of the mixture formation in a diesel engine. In turn, CASTELLANELLI et al. (2008) report that in studies using different blends of soybean ethyl biodiesel in a direct injection engine, the B2, B5 and B10 biodiesel blends showed similar performance to diesel. From these proportions, there was a gradual decline of performance as the percentage of biodiesel in the blend increased, and pure biodiesel (B100) showed the worst performance.

It becomes relevant to conduct research on this issue, since such contributions may support the use of appropriate proportions of biofuels, pure or binary mixtures with mineral diesel, according to technical, economic and environmental viability relative to biofuel production from different raw materials currently available. Thus, this work aimed to evaluate the effect of different mixtures of methyl soybean biodiesel and mineral diesel in a compression ignition engines and direct fuel injection, through performance tests in an eddy current dynamometer.

MATERIAL AND METHODS

Mixtures B10, B50 and B100 with soybean methyl ester were evaluated in comparison with commercial diesel, which currently consists of a mixture containing 5% biodiesel added to mineral diesel (B5). These four fuels were tested in a Perkins 4000 engine model with direct fuel injection, with approximately 3000 working hours, with a rated power of 45 kW at 1,900 revolutions per minute (rpm). Table 1 lists the treatments and the related description of them.

TABLE 1. Treatments for evaluation of power, volumetric and specific fuel consumption.

Treatment	Description
1	5% soybean methyl biodiesel and 95% mineral diesel (B5)
2	10% soybean methyl biodiesel and 90% mineral diesel (B10)
3	50% soybean methyl biodiesel and 50% mineral diesel (B50)
4	100% soybean methyl biodiesel (B100)

The tests were conducted at the Laboratory of Agrotechnology, which is part of the Center for Testing of Agricultural Machinery, Universidade Federal de Santa Maria - RS. This laboratory has an electric eddy current dynamometer, also known as eddy current dynamometer; model MWD NL 480 with braking capacity of up to 500 kW. The information was collected by computer with software enabling automatic data acquisition. We also used a, Oval MIII LSF 41 flow meter interconnected to a central data acquisition to verify the volume of fuel consumed (consumption volume in L h^{-1}), later serving for the calculation of specific fuel consumption (g kW^{-1} h^{-1}), and a set of sensors to monitor parameters such as engine oil pressure and weather conditions in real time.

The diesel fuel used was purchased at a local gas station. The biodiesel used was purchased from the company BS BIOS Indústria e Comércio de Biodiesel Sul Brasil S/A, which presented a detailed report of the fuel produced. Results of the analysis of physicochemical parameters of these samples were in accordance with the Resolution ANP n. 7 (2009) (Table 2). For the calculation of specific fuel consumption, it was required to determine the density of each fuel used. The procedure for obtaining density values was the average of three weighing measurements of one-liter volume of each fuel used. The mixtures were homogenized in appropriate containers with a maximum capacity of seven liters. The proportions were measured with the aid of two measuring cylinders with capacity of 200 ml each and a beaker with capacity of one liter. It was also accounted for the initial ratio contained in the commercial diesel, which contained 5% biodiesel, during the rest of the mixture, ensuring the proper balance between biodiesel and diesel business generated for each mixture.

TABLE 2. Physicochemical parameters of soybean methyl biodiesel used.

Analytic Item	Unity	Result	Specification	Methods (Regulation)
Specific Mass at 20ºC	kg m^{-3}	881.3	850-900	ASTM D 4052
Cinematic Viscosity at 40ºC	mm^2 s^{-1}	4.083	3.0-6.0	ASTM D 445
Cetane Index	-	44.0	-	-
Water Content	mg kg^{-1}	96.4	Max 500	ASTM D 6304
Total Contamination	mg kg^{-1}	1.37	Max 24	EN 12662
Flash Point	ºC	128	Min 100.0	ASTM D 93
Esther Content	% mass	97.2	Min 96.5	EN 14103
Total Sulfur	mg kg^{-1}	0.4	Max 50	ASTM D 5453
Sodium + Potassium	mg kg^{-1}	0.507	Max 5	EN 14538
Calcium + Magnesium	mg kg^{-1}	0.011	Max 5	EN 14538
Acidity Index	mg KOH/g	0.354	Max 0.50	ASTM D 664
Total Glycerin	% mass	0.208	Max 0.25	ASTM D 6584
Methanol	% mass	< 0.05	Max 0.20	EN 14110

The data acquisition methodology used in the short-term tests consisted of a continuous process where the lever drive of the engine injection pump of the tractor was placed in a position to provide maximum engine speed, causing it to operate at full force, i.e. full throttle of the fuel injection pump. Then, increasing loads were applied, which resulted in subsequent breaking the driveshaft connected to the dynamometer to the tractor power take-off (PTO). Such loads cause a steady fall in the rotation, providing data to feed the engine performance curves. The tests consisted of three repetitions, lasting about 12 minutes each, for each of the fuels under study. During fuel type changes for the continuity of the tests, the engine was run for a period not less than 45 minutes to burn the residues of the mixture previously tested, and to maintain the temperature range of engine operation. The tests and calculation of the performance parameters have been adapted to the methodology anticipated by the regulations ABNT NBR 13400 (1995) and ABNT NBR 5484 (1985).

The experimental design applied was completely randomized for the evaluations performed in the laboratory under conditions of constant temperature and relative humidity, using three replicates for each fuel evaluated. Each variable was processed in a spreadsheet and analyzed by the statistical program SOFTWARE CIENTÍFICO SOC - NTIA/EMBRAPA, which initially proceeded with the analysis of variance (ANOVA), and the means were then compared by Tukey's test at 5% error probability.

RESULTS AND DISCUSSION

The largest power values in the range of rated speed (1,900 rpm) were obtained with the use of B5 and B10 fuels, with no significant differences between them. The B100 proportion showed statistically significant differences compared to other fuels evaluated with power values less than 3.0%, 2.8% and 1.6%, respectively, in relation to the fuels B10, B5 and B50. These values are slightly greater than those obtained by CORRÊA et al. (2008) to engine power with different fuels, and the percentage differences were up to 2.2% between the B100 and the fuel with best performance. Also, BARBOSA et al. (2008) evaluated the performance of an engine fueled with mineral diesel, biodiesel and mixtures of equal proportions equivalent to B2, B5, B20 and B100, and concluded that engine power increased gradually from B100 to mineral diesel.

Power reductions at higher biodiesel proportions added to commercial diesel can be attributed to the lower calorific value of the biodiesel. CASTELLANELLI et al. (2008) explain that the differences in values of torque, specific power and consumption are constant along the curves; which can be explained due to the inferiority of calorific value of biodiesel compared to mineral diesel. However, when a greater distance is noticed between the curves from certain rotation ranges, there is also inefficient fuel atomization, due to higher viscosity attributed to higher levels of biodiesel in the blend. This leads to poor atomization losses inherent to fuel burning. EJIM et al. (2007) explain that binary mixtures with higher proportions of biodiesel can still provide adequate atomization characteristics of mixture formation in a diesel engine. Combining this factor to increases cetane number values of the mixtures containing higher biodiesel levels, there may be improvements in fuel burning in the combustion chamber.

Figure 1 shows the performance analysis of the engine and the power under use of different fuels.

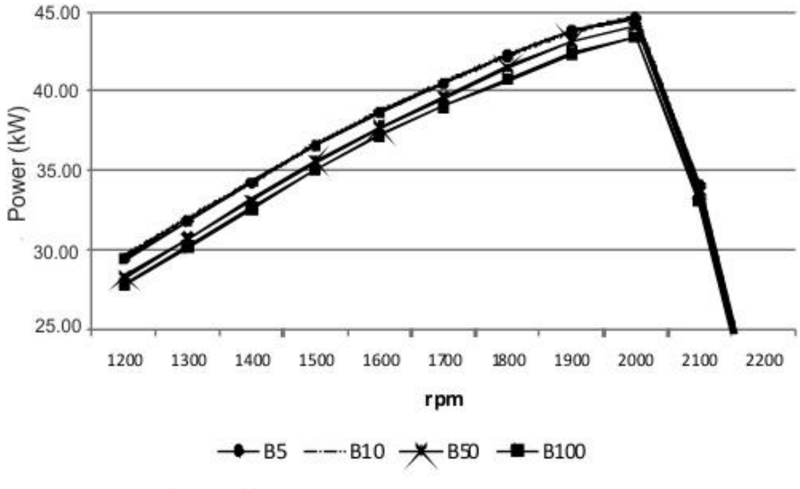

FIGURE 1. Power curves for different blends evaluated, in the whole rotation band analyzed.

Regarding specific fuel consumption, in the speed range where the lowest values typically occur for the engine tested (1,500 rpm), B100 fuel values were about 10.9% higher when compared to results provided by the B5 fuel (Figure 2). These results demonstrate greater increases compared to the values obtained by CORRÊA et al. (2008) who reported an average increase of 7.3% in specific fuel consumption with the use of B100 biodiesel compared to mineral diesel. The fuel that showed the lowest specific fuel consumption along the entire curve was the B10 blend, which in the rotation of lower specific consumption for the engine tested, was about 0.5% lower compared to the B5 fuel, without statistically significant differences between these fuels.

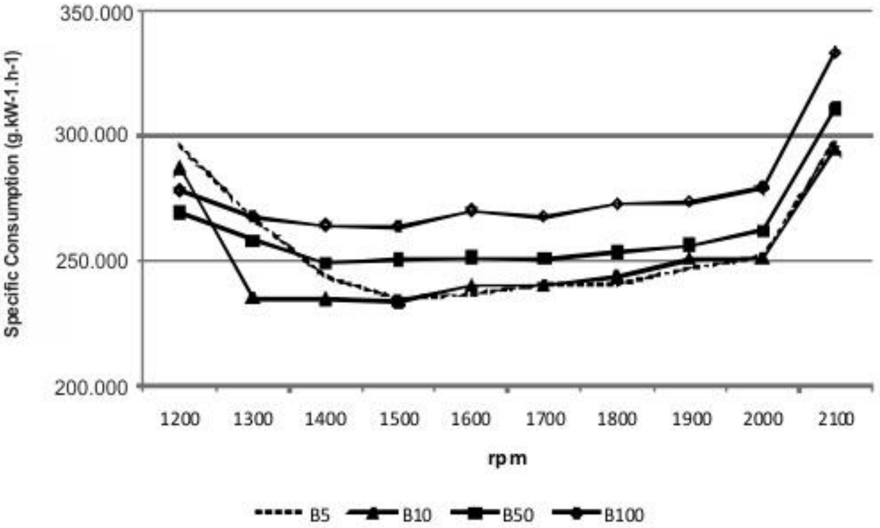

FIGURE 2. Specific consumption curves for different blends evaluated, in the entire rotation range analyzed.

KAUFMAN & ZIEJEWSKI (1984) found, for a diesel engine with 74.6 kW, four-cylinder direct injection power, values 5.8% lower than those obtained under the use of mineral diesel, with an increase of 8.6% in specific fuel consumption using B100 fuel. On the other hand, MAZIERO et al. (2005), in tests conducted with a 92 kW engine, found an increase in specific fuel consumption of 9.8% with B100. Table 3 highlights the values of corrected power (kW) and specific fuel consumption (g kW^{-1} h^{-1}) obtained for the different fuels evaluated.

TABLE 3. Engine performance related to the power and the specific consumption under different fuels evaluated.

Fuel	Adjusted Power (kW)(1)	Specific Consumption (g kW^{-1} h^{-1})
B10	44.73 a (2)	233.78 c (2)
B5	44.62 a	234.87 c
B50	44.11 b	250.40 b
B100	43.40 c	263.63 a
Mean	44.21	245.67
CV (%)	0.98	5.0

[1] Values corrected for the regulation ABNT NBR-5484 (1985). Accounting of losses by coupling to the tractor PTO is required. An increase of 8 to 10% in power values can be estimated as a function of losses.[2] Values followed by the same letter do not differ by Tukey's test at 5% probability of error. The statistical analysis compares values in the same column.

Regarding the hourly consumption of fuel, differences for all blends evaluated were not significant. This can be explained, since the hourly fuel consumption does not take into account power (kW) produced per mass of fuel consumed (g). Thus, as biodiesel has higher density compared to conventional diesel, a given volume of diesel has lower mass than that shown by the same volume of biodiesel. Consequently, the differences when comparing values only amount of fuel consumed are lower than when comparing mass quantities consumed for different fuels.

CONCLUSIONS

B50 and B100 fuels provided the worst results of engine performance in relation to B5 and B10. As for the specific fuel consumption, major differences were not identified for B10. B100 fuel expressed the lowest power, 2.8% lower than B5, and the highest values of specific consumption, 10.9% higher than B5. Thus, we concluded that there is technical feasibility in the use of binary mixtures of biodiesel and commercial diesel; however, the optimal proportions of the blend must be taken into account to sustain the best engine performance and greater economy regarding fuel consumption.

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