Acta Scientiarum
http://periodicos.uem.br/ojs
ISSN on-line: 1807-8664
Doi: 10.4025/actascitechnol.v44i1.56059

Change in injection angle as alternative for diesel engine fueled with biodiesel blends

Paulo Henrique Paiva*, Flávio Gurgacz, Jonas Gralick, Doglas Bassegio, Samuel Nelson Melegari de Souza and Deonir Secco

Programa de Pós-Graduação em Engenharia de Energia na Agricultura, Universidade Estadual do Oeste do Paraná, Rua Universitária, 1619, 85819-110, Cascavel, Paraná, Brazil. *Author for correspondence. E-mail: paulopaivah@gmail.com

ABSTRACT. Biodiesel properties have a significant impact on engine performance. The disadvantages of biodiesel include poor atomization. To overcome this problem, engine parameters such as the injection angle can be changed. The objective of this study was to evaluate the effect of changes in the injection angle of an injector pump on the performance of a diesel engine fueled with various biodiesel blends. The experimental design involved testing three injection angles: 26°, 28°, and 30°; and four biodiesel blends: B0, B8, B15, and B20. The effects of variations in these factors were evaluated in terms of the maximum power, rotation at maximum power, torque at maximum power, maximum torque, rotation at maximum torque, specific fuel consumption, engine elasticity index, torque reserve, and rotation reserve. The engine fueled with the biodiesel blends showed a lower specific consumption without losing power or torque, when the crank angle of the injector pump was changed from its original configuration of 26° to 28°.

Keywords: Diesel engine; biodiesel; performance; dynamometer.

Received on October 1, 2020.
Accepted on December 8, 2021.

Introduction

Currently, transportation and agriculture sectors in developing countries such as Brazil rely heavily on petroleum-based diesel for automotive and stationary applications. However, various factors, such as an increase in petroleum-based fuel consumption, rising prices due to increased demand, and growing environmental concerns, have led to a greater need for alternative and renewable energy sources (Kumar, Dinesha, & Rosen, 2019). Biodiesel, derived from vegetable oil or animal fats, is one such alternative (Silva et al., 2013; Leite et al., 2019). Current laws in Brazil require diesel oil to contain at least 8% biodiesel. Some Brazilian bus fleets are already using the B20 mixture as fuel (Miranda et al., 2018).

Biodiesel is an oxygenated, renewable, biodegradable, and ecological fuel (Hwang, Qi, Jung, & Bae, 2014). It has properties similar to those of mineral diesel but with additional advantages, such as a higher cetane number and the presence of oxygen, which enhance combustion and reduce the resulting greenhouse gas emissions (Hossain & Davies, 2010; Yusuf, Kamarudin, & Yaakub, 2011). Nevertheless, biodiesel also has various disadvantages, including its high viscosity, high density, and low calorific value, along with a slight increase in nitrogen oxide emission resulting from its combustion when compared to petroleum-based diesel (Yusuf et al., 2011; Kannan & Anand, 2012). The high viscosity of biodiesel leads to larger droplets of fuel (poor atomization), which can result in carbon deposits in the injector nozzle and cylinder liner, and the formation of fuel-air blends, resulting in minimal and slower combustion and lower thermal efficiency (Reddy & Ramesh, 2006; Kumar et al., 2019).

These different physical and chemical properties of biodiesel present technical challenges in the operation of diesel engines that run on blended diesel oil. The current design and operating parameters of engines are standardized only for petroleum-based diesel (Kannan & Anand, 2012). Therefore, modifications of the engine parameters are required to optimize their viability for using biodiesel. Thus, it is important to study the effects of altering of engine parameters that are directly related to the fuel injection system (Deep, Sandhu, & Chander, 2017). Such injection parameters include injection time, injected mass, injection mass ratio, number of injections, and injection pressure (Teoh et al., 2018).

Several studies on engines using biodiesel have shown that the injection time and crank angle affect engine performance. Agarwal et al. (2015) observed that the specific fuel consumption decreased as the injection angle started decreasing from 24° to 18°. Deep et al. (2017) observed that an engine powered with a blend of diesel and 20% castor oil-based biodiesel performed better in its original configuration, and required no change in the injection angle. Teoh et al. (2018) found that crank angles of 15° and 18° caused a slight decrease in thermal efficiency of the engine compared to a crank angle of 12°. As the injection angles were changed, the characteristics of the combustion and air-fuel mixing processes became different (Fang, Coverdill, Chia-fon, & White, 2008).

While there have been some studies investigating the isolated impacts of biodiesel blends and the crank angle degree on the efficiency of a diesel engine, studies on the combined effects of biodiesel blends and changes in the crank angle have been scarce. Most studies have been conducted on a mono-cylindrical research engine, which is not a practical representation of the multi-cylinder engine used in commercial vehicles. This is a critical drawback, given the fundamental differences between mono-cylindrical and multi-cylindrical engines in terms of rotational dynamics, gas intake dynamics, heat transfer dynamics, dynamic coupling between cylinders (Teoh et al., 2018). Therefore, this study was aimed at evaluating the effect of using various biodiesel blends at different injection angles of the injector pump, on the performance characteristics of a diesel engine.

Material and methods

The engine-run tests were conducted at the Laboratory of Agricultural Machinery, Tractors and Engines (Lama), *Universidade Estadual do Oeste do Paraná* (Unioeste), located in Cascavel, Paraná State, Brazil. The tractor used in the test was a Massey Ferguson MF 265 (AGCO, Duluth, GA, USA), manufactured in 1984 and with 1076 h of total use. It was equipped with a Perkins AD4.203 (Perkins Engines Company Limited, Peterborough, UK), which is a four-cylinder diesel engine having a total displacement of 3327 cm^3. According to the manufacturer, the engine delivers 44.8 kW (61 hp) of maximum power at 2000 rpm.

For the application of partial loads, we used an air-cooled, Foucault-current-powered Eggers mobile dynamometric brake PT-170 SE (KL-Maschinenbau GmbH & Co. KG, Rendsburg, Germany) with a braking capacity of up to 300 kW. It was attached to the tractor's power takeoff shaft (PTO), which operates according to the DIN7 0020 standard. The schematics of the experimental system are shown in Figure 1.

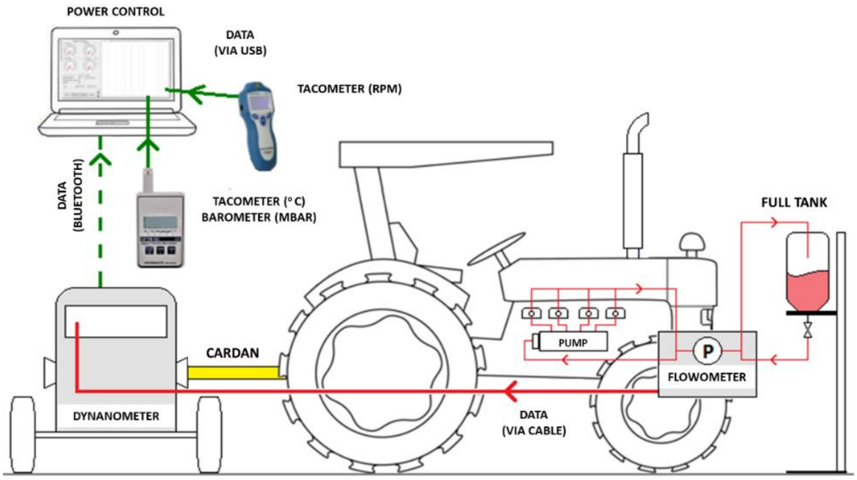

Figure 1. Schematic diagram of the experimental system.

The experiments were conducted using biodiesel blends, B0, B8, B15, and B20 at different injection angles of the injector pump, viz. 26° (original configuration), 28°, and 30°. The petroleum-based diesel used was type A S500. The biodiesel used was produced through the methylic route with the following composition: soybean oil (68%), bovine fat (25%), pork fat (5%), and poultry oil (2%). To ensure test uniformity, the engine was operated for 20 min. to achieve the ideal temperature for the load work of both the engine oil and cooling fluid.

For the measurements of torque, power, and specific consumption of the engine, Power Control 2.1 was used with default parameter settings. The measured points were initially set at the maximum engine speed. These tests were conducted at a rotational speed of 1000 rpm of the engine. An automatic measurement was obtained for each decrease of 100 rpm in engine speed. Thus, using the data obtained from the tests, the power, torque, and specific consumption curves were determined.

To evaluate the fuel consumption, we used an Eggers flowmeter (model FM 3-100) connected to an external fuel tank. The engine injection system sent information in the form of a dynamometer data package to the Power Control 2.1 management software via a cable.

To verify the atmospheric pressure and room temperature, we used a GFTB100-GRS-000-GE barometer/thermometer/hygrometer, produced by Greisinger Electronic GmbH (temperature measurement range: −25.0 to +70.0°C, resolution: 0.1°C; atmospheric pressure measurement range: 10.0 to 1100.0 mbar, resolution: 0.1 mbar). For the angular velocity of the engine, we used a PeakTech tachometer (model 2790) with a measuring range of 2 to 99999 rpm and a resolution of 0.1 rpm.

Using the measurements, we determined the maximum power (kW), rotation at maximum power (rpm), torque at maximum power (Nm), maximum torque (Nm), maximum torque power (kW), maximum torque rotation (rpm), specific fuel consumption (g kW^{-1} $hour^{-1}$), engine elasticity index, torque reserve (%), and rotation reserve (%). The torque reserve performance index (Equation 1) was calculated using the method described by Mialhe (1996).

$$RT = \left[\left(\frac{Tmax}{Tpmax}\right) - 1\right] x100 \qquad (1)$$

where:

Tmax is the maximum torque observed (Nm), and Tpmax is the maximum torque at the observed power (Nm).

We used a randomized experimental design in a 3 × 4 factorial scheme with 30 repetitions. In terms of statistical analysis, an analysis of variance (ANOVA) and Tukey's test with a 5% probability of error were performed using Sisvar 5.6.

Results and discussion

The maximum power was affected by the interplay between the biodiesel blend and changes in the injection angle (Table 1). Using blend B15, the injection angle configuration of 28° resulted in a slight increase in the maximum power compared to the original configuration of 26° as well as the injection angle configuration of 30° (Figure 2). The 28° angle may have resulted in an increased heat release and early combustion onset owing to a better air-fuel blend (Ye & Boehman, 2012).

Table 1. Maximum power, torque at full power, maximum torque, torque reserve, and specific consumption in different injection angles and biodiesel blends.

Sources of variation	Maximum power (kW)	Torque at full power (N.m)	Maximum torque (N.m)	Torque reserve (%)	Specific consumption (g kW^{-1} $hour^{-1}$)
			Biodiesel blends		
B0	55.11	162.0	200.7 a	23.94	231.6
B8	55.00	163.3	198.4 b	21.49	222.8
B15	55.00	163.5	198.7 b	21.49	223.9
B20	55.55	164.7	199.6 ab	21.13	225.5
			Injection angle		
26°	55.25	165.4 a	208.0 a	25.84 a	236.4 a
28°	55.33	164.1 a	201.9 ab	23.02 b	207.3 b
30°	54.91	160.6 b	188.2 b	17.19 c	234.2 a
	F test			p-value	
Biodiesel blends (A)	0.3106	0.2820	0.0070	0.0702	0.2479
Injection angle (B)	0.3284	0.0017	< 0.000	< 0.000	< 0.000
A × B	0.0409	0.6145	0.0511	0.9785	0.0022
CV (%)	1.28	1.80	0.69	10.79	4.30

Means followed by the same letters in the column do not differ according to the Tukey test at 5% significance. Means without letter in columns do not differ statistically.

There was no significant difference between the maximum power in the original configuration of 26° for B0 or B20. In the injection angle configuration of 28°, biodiesel blends B15 and B20 provided a maximum power that was slightly higher than that of B0 and B8 (Figure 2). This indicates that the oxygen content of biodiesel improves fuel combustion in the engine cylinder. A similar inference was drawn by Dhar and Agarwal (2015), who noted that the use of B10 or B20 of Karanja biodiesel blends in common-rail direct-injection engines with pilot injection may be useful for improving engine efficiency.

The torque at maximum power, maximum torque, and torque reserve were reduced when the injection angle was changed from the original configuration of 26° to 30°. However, the torque at maximum power and the maximum torque did not vary when the injection point configuration was changed to 28° (Table 1). An injection point configuration of 30° may result in excessive angle advancement that may cause adverse effects due to inadequate temperature at the start of combustion (Deep et al., 2017). With the angle advancement owing to the increase in the crank angle, combustion is expected to occur earlier, and the fuel will be burned before the piston reaches the top dead center position. The peak pressure in the cylinder occurs near the top dead center (Raheman & Ghadge, 2008; Panneerselvam et al., 2015).

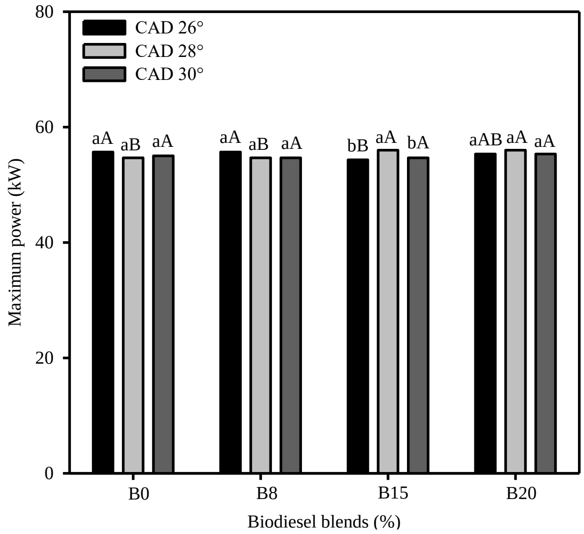

Figure 2. Maximum power affected by injection angles and biodiesel blends. Values followed by a different lowercase letter are significantly different between injection angles with the same biodiesel blends. Values followed by a different capital letter are significantly different among biodiesel blends under the same injection angle (Tukey test, $p < 0.05$). CAD: Crank angle degree.

When the injection angle configuration was changed to 28°, the specific consumption of the biodiesel mixture was reduced regardless of the blend (Table 1). Hwang et al. (2014) studied the effect of injection angle (25° to 0°) on the combustion characteristics of a direct-injection mono-cylindrical diesel engine powered by diesel oil and biodiesel (from cooking oil residues). They verified that the specific fuel consumption decreased when there was a delay during the injection start. Agarwal et al. (2015) observed that the specific fuel consumption decreased as the injection angle started decreasing from 24° to 18°. In contrast, the specific consumption remained the same in all other configurations for all biodiesel blends (Figure 3). This result is important because in an earlier study, an increase in specific consumption was related to an increase in the biodiesel fraction in the test blends owing to the reduction in calorific value (Dhar & Agarwal, 2015). When the engine was powered only by diesel, no variation in the maximum power or specific consumption was observed in relation to the increase in the crank angle (Figure 3).

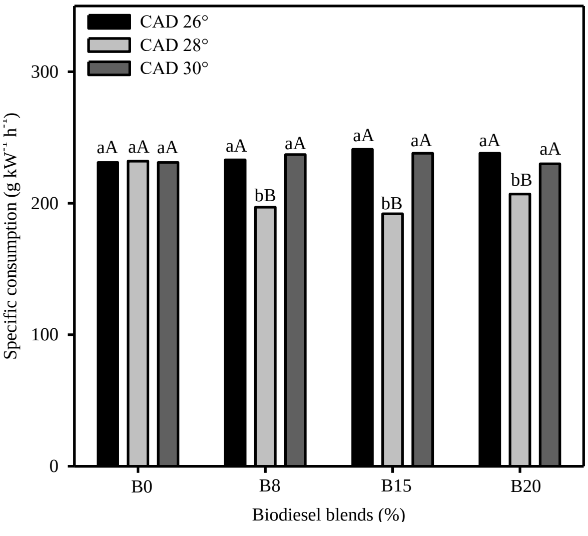

Figure 3. Specific consumption affected by injection angles and biodiesel blends. Values followed by a different lowercase letter are significantly different between injection angles with the same biodiesel blends. Values followed by a different capital letter are significantly different among biodiesel blends under the same injection angle (Tukey test, $p < 0.05$). CAD: Crank angle degree.

Schlosser, Camargo, and Machado (2004) used different diesel oil blends and injection angles of 21° and 24° and observed that the modifications in the injection angle did not result in adequate regularity of engine operation. In contrast, Kannan and Anand (2012) found that the injection advancement significantly improved the thermal efficiency of a single-cylinder diesel engine powered by biodiesel cooking oil.

Conclusion

The performance of a diesel engine using different biodiesel blends and altered injection angle configurations was investigated in this study. The engine fueled with biodiesel blends showed a lower specific consumption without loss of power or torque when the crank angle of the injector pump was changed from the original configuration of 26° to 28°. The torque at maximum power, maximum torque, and torque reserve were reduced when the injection point was changed from the original 26° to 30°. However, the aforementioned parameters did not vary when the injection angle configuration was changed to 28°.

References

Agarwal, A. K., Dhar, A., Gupta, J. G., Kim, W. I., Choi, K., Lee, C. S., & Park, S. (2015). Effect of fuel injection pressure and injection timing of Karanja biodiesel blends on fuel spray, engine performance, emissions and combustion characteristics. *Energy Conversion and Management, 91*, 302-314. DOI: https://doi.org/10.1016/j.enconman.2014.12.004

Deep, A., Sandhu, S. S., & Chander, S. (2017). Experimental investigations on the influence of fuel injection timing and pressure on single cylinder C.I. engine fueled with 20% blend of castor biodiesel in diesel. *Fuel, 210*, 15-22. DOI: https://doi.org/10.1016/j.fuel.2017.08.023

Dhar, A., & Agarwal, A. K. (2015). Experimental investigations of the effect of pilot injection on performance, emissions and combustion characteristics of Karanja biodiesel fuelled CRDI engine. *Energy Conversion and Management, 93*, 357-366. DOI: https://doi.org/10.1016/j.enconman.2014.12.090

Fang, T., Coverdill, R. E., Chia-fon, F. L., & White, R. A. (2008). Effects of injection angles on combustion processes using multiple injection strategies in an HSDI diesel engine. *Fuel, 87*(15-16), 3232-3239. DOI: https://doi.org/10.1016/j.fuel.2008.05.012

Hossain, A. K., & Davies, P. A. (2010). Plant oils as fuels for compression ignition engines: A technical review and life-cycle analysis. *Renewable Energy, 35*(1), 1-13. DOI: https://doi.org/10.1016/j.renene.2009.05.009

Hwang, J., Qi, D., Jung, Y., & Bae, C. (2014). Effect of injection parameters on the combustion and emission characteristics in a common-rail direct injection diesel engine fueled with waste cooking oil biodiesel. *Renewable Energy, 63*, 9-17. DOI: https://doi.org/10.1016/j.renene.2013.08.051

Kannan, G. R., & Anand, R. (2012). Effect of injection pressure and injection timing on DI diesel engine fuelled with biodiesel from waste cooking oil. *Biomass and Bioenergy, 46*, 343-352. DOI: https://doi.org/10.1016/j.biombioe.2012.08.006

Kumar, S., Dinesha, P., & Rosen, M. A. (2019). Effect of injection pressure on the combustion, performance and emission characteristics of a biodiesel engine with cerium oxide nanoparticle additive. *Energy, 185*, 1163-1173. DOI: https://doi.org/10.1016/j.energy.2019.07.124

Leite, D., Santos, R. F., Bassegio, D., Souza, S. N. M., Secco, D., Gurgacz, F., & Silva, T. R. B. (2019). Emissions and performance of a diesel engine affected by soybean, linseed, and crambe biodiesel. *Industrial Crops and Products, 130*, 267-272. DOI: https://doi.org/10.1016/j.indcrop.2018.12.092

Mialhe, L. G. (1996). Ensaio & certificação de máquinas motoras. In L. G. Mialhe (Ed.)*, Máquinas agrícolas: ensaios & certificação* (p. 321-370). Piracicaba, SP: FEALQ.

Miranda, A. C., Silva Filho, S. C., Tambourgi, E. B., CurveloSantana, J. C., Vanalle, R. M., & Guerhardt, F. (2018). Analysis of the costs and logistics of biodiesel production from used cooking oil in the metropolitan region of Campinas (Brazil). *Renewable and Sustainable Energy Reviews, 88*, 373-379. DOI: https://doi.org/10.1016/j.rser.2018.02.028

Panneerselvam, N., Murugesan, A., Vijayakumar, C., Kumaravel, A., Subramaniam, D., & Avinash, A. (2015). Effects of injection timing on bio-diesel fuelled engine characteristics—An overview. *Renewable and Sustainable Energy Reviews, 50*, 17-31. DOI: https://doi.org/10.1016/j.rser.2015.04.157

Raheman, H., & Ghadge, S. V. (2008). Performance of diesel engine with biodiesel at varying compression ratio and ignition timing. *Fuel, 87*(12), 2659-2666. DOI: https://doi.org/10.1016/j.fuel.2008.03.006

Reddy, J. N., & Ramesh, A. (2006). Parametric studies for improving the performance of a Jatropha oil-fuelled compression ignition engine. *Renewable Energy, 31*(12), 1994-2016. DOI: https://doi.org/10.1016/j.renene.2005.10.006

Schlosser, J. F., Camargo, M. N., & Machado, P. R. M. (2004). Comportamento de um motor de ignição por compressão trabalhando com óleo diesel e gás natural. *Engenharia Agrícola, 24*(3), 736-744. DOI: https://doi.org/10.1590/S0100-69162004000300026

Silva, M. J., Souza, S. N. M., Chaves, L. I., Rosa, H. A., Secco, D., Santos, R. F., ... Nogueira, C. E. C. (2013). Comparative analysis of engine generator performance using diesel oil and biodiesels available in Paraná State, Brazil. *Renewable and Sustainable Energy Reviews, 17*, 278-282. DOI: https://doi.org/10.1016/j.rser.2012.09.037

Teoh, Y. H., Masjuki, H. H., How, H. G., Kalam, M. A., Yu, K. H., & Alabdulkarem, A. (2018). Effect of two-stage injection dwell angle on engine combustion and performance characteristics of a common-rail diesel engine fueled with coconut oil methyl esters-diesel fuel blends. *Fuel, 234*, 227-237. DOI: https://doi.org/10.1016/j.fuel.2018.07.036

Ye, P., & Boehman, A. L. (2012). An investigation of the impact of injection strategy and biodiesel on engine NOx and particulate matter emissions with a common-rail turbocharged DI diesel engine. *Fuel, 97*, 476-488. DOI: https://doi.org/10.1016/j.fuel.2012.02.021

Yusuf, N. N. A. N., Kamarudin, S. K., & Yaakub, Z. (2011). Overview on the current trends in biodiesel production. *Energy Conversion and Management, 52*(7), 2741-2751. DOI: https://doi.org/10.1016/j.enconman.2010.12.004