

JOURNAL OF SCIENCE



SAKARYA UNIVERSITY

Sakarya University Journal of Science

ISSN 1301-4048 | e-ISSN 2147-835X | Period Bimonthly | Founded: 1997 | Publisher Sakarya University |
<http://www.saujs.sakarya.edu.tr/>

Title: Performance And Heat Release Rate Of A Diesel Engine Using Sunflower Methyl Esters And Diesel Fuel Blends In Experimental Comparison

Authors: Aykut Safa

Received: 2019-06-12 14:29:56

Accepted: 2019-09-13 08:49:25

Article Type: Research Article

Volume: 23

Issue: 6

Month: December

Year: 2019

Pages: 1279-1288

How to cite

Aykut Safa; (2019), Performance And Heat Release Rate Of A Diesel Engine Using Sunflower Methyl Esters And Diesel Fuel Blends In Experimental Comparison.

Sakarya University Journal of Science, 23(6), 1279-1288, DOI:

10.16984/saufenbilder.576624

Access link

<http://www.saujs.sakarya.edu.tr/issue/44246/576624>

New submission to SAUJS

<http://dergipark.gov.tr/journal/1115/submission/start>



Performance and Heat Release Rate Comparison in a Diesel Engine fueled with Sunflower Methyl Esters/Diesel Fuel Blend

Aykut Safa^{*1}

Abstract

Biodiesel fuels are among the leading renewable alternative fuels. And, using biodiesel fuels is available and easy to implement on diesel engines. Biodiesel fuels, methyl/ethyl esters of various oils extracted from vegetables or animals, are being used by many researchers on various types of engines and they were tested at various conditions. Since chemical properties very close to diesel fuel, similar test results for nominal engine performance data with diesel can be obtained by using biodiesel fuels on engines. In this study, effect of sunflower oil methyl esters on engine performance, heat release rate and indicated engine parameters are investigated experimentally on a single cylinder, DI Diesel engine. Tests are performed with diesel fuel and B50 blend fuel, consisting of 50% diesel and 50% biodiesel fuels, at full load condition and at different speeds. Engine brake torque, brake power, brake specific fuel consumption, brake thermal efficiency, heat release rate, and indicated engine parameters are calculated from the test data, and the results obtained by using diesel fuel and B50 blend fuel are compared. Although some worsening on performance data and heat release rate on B50 side, results are very close to each other.

Keywords: Diesel Engine performance, Sunflower Biodiesel Fuel Blends, Heat Release Rate analysis

1. INTRODUCTION

In literature, studies on various biodiesels including Sunflower Methyl Ester (SFME) are present [1-4]. Biodiesel properties and effect on engine performance are investigated in various aspects [5-9]. And studies on heat release data calculated by pressure data can be found in

literature [15-18]. In this study, experimental results of a DI CI engine using diesel and biodiesel of SFME and blend fuels are investigated in comparison. Engine performance data, power, torque, and BSFC are revealed and heat release rates obtained from pressure data and engine data are calculated for diesel fuel and B50 blend fuels. The results found close to each other.

* Corresponding Author: safa@yildiz.edu.tr

¹ Yildiz Technical University, Naval Architecture and Marine Engineering Department, Istanbul, Turkey. ORCID: 0000-0002-9650-3651

Biodiesel fuel is a renewable and it can be obtained from waste/raw vegetable oils or animal fats, etc. Since biodiesels are produced by transesterification of fatty acids, they offer high energy density and serve for sustainability through conversion of fatty acids from bio-resources. Thus, the studies on biofuels are increasing in number due to these facts. For widespread usage of biodiesels, standardization is required. However, deviations occur in biodiesel characteristics depending on fuel content [3]. Therefore, for improved insight for correlating biodiesel properties and engine performance and emissions, the corresponding relations should be investigated. Another advantage of biodiesels is the opportunity to be used in a conventional diesel engine easily [9]. [12] Alptekin et al, 2008 reported densities and viscosities of blend fuels, blend of diesel and biodiesel. Experiments on blend fractions, B2-B75, were reported for biodiesel fuels, from sunflower, canola, soybean, cottonseed, corn oils and waste palm oils, according to ASTM test methods. It is reported that, densities and viscosities of the blend fuels increase with the increase of biodiesel fraction in the fuel. [8] Demirbas, 2008, studied viscosity, density, flash point and HHV properties of various biodiesels and concluded aspects to use biodiesels in comparison to conventional fuels of higher viscosity and lower HHV. And also, it is concluded that, viscosity and HHV were highly correlated for vegetable oil methyl esters. [6] Sayin et al, 2009, tested diesel and methanol blends with various fuel injection timings, to improve engine emissions, using a single cylinder CI test engine. As reported, increase in methanol fraction causes decrease in smoke opacity, CO and UHC emissions, but increase in NO_x emissions, and advance in injection timing cause reductions in smoke opacity, CO and UHC, but increase in NO_x and CO₂ emissions. [10] Ozsezen et al, 2011 tested COME and WPOME fuel on a DI diesel engine. Engine with compression ratio, 15.9, and fuel injection of pressure, 197 bar, are used at tests. Heat release analysis is also utilized. Reduction in engine brake power, CO, HC, CO₂, smoke and increase in BSFC and in NO_x emissions are reported compared to diesel fuel results under full load at constant engine speeds [5] Hoekman, 2012 studied 12 common biodiesel

feedstocks and presented a detailed report on several properties of biodiesels. [2] Santos et al., 2013 showed the effect of engine parameters and biodiesel fractions on performance and emissions using SFME, SME and neat diesel on two diesel engines. [13] Lahane, 2015 investigated fuel injection, performance, and emissions characteristics of a DI diesel engine at 1500 rpm, using diesel and biodiesel of karanja blend fuels. As reported, ignition delay and pressure rate are lowered for biodiesel fractions. Since biodiesel has a greater cetane number than diesel, CO, HC and smoke emissions are reduced, but NO_x emissions are increased. [4] Pearson et al, 2015 investigated iso-stoichiometric fuel blends and information on chemical properties of hydrous blends, containing water, gasoline, ethanol and methanol is given. [7] Prashant et al, 2016 using diesel and methanol blend fuel studied ignition delay, pressure rate and heat release rate on a dual fuel CI engine. As the methanol fraction is increased, ignition delay, and the angle corresponding to the maximum heat release is increased. [9] Prajapati et al, 2016 studied diesel and biodiesel of sunflower, blend fuels on a single cylinder, DI CI engine at 1500 rpm at various loads. And, for 25% fraction of biodiesel in diesel is concluded to have very close results specific fuel consumption and brake thermal efficiency, compared to neat diesel fuel. [1] Ayhan et al, 2018 proposed conditional blend fuel fractions containing diesel fuel, DEE, biodiesel (SFME) and water. The experimental study done at engine speeds, 1000-2200 rpm, and full load on DI diesel engine is used. The reason of DEE addition is reported to increase blend fuel cetane number and the surfactant addition to obtain a stabilized fuel with water addition. At the maximum torque condition, reductions in engine brake power, brake torque and in CO, NO and smoke levels but increase in brake efficiency and in HC are reported. Fuel injection pressure was 175 bar. [11] Kirankumar et al, 2018 was run a single cylinder diesel engine on neat diesel, B25, B50, B75, and B100 blend fuels of SFME at 1500 rpm. Engine of compression ratio with 16.5 is used in tests. And specific fuel consumption, brake thermal efficiency, exhaust gas temperature increase with brake power has been reported. While, at full load condition using diesel fuel causes lower CO, CO₂,

NO_x and smoke emissions, but using B100 fuel causes the lowest HC emission. In oxygenated fuel blends, complete combustion takes place resulting in high NO_x has also been reported. Because high combustion temperatures occur during the complete combustion, the resulting NO_x formation is high. And also presented that, decrease in the maximum in-cylinder pressure lowers as the blend fraction increases. And it was concluded that the maximum heat release rate for diesel fuel is twice the B100.

Heat release during combustion occur in cylinder is affected by various parameters such as mixture formation, heat loss, engine operational parameters, etc. Therefore, using experimental data, apparent heat release rate can be estimated. [14] Gogoi and Baruah, 2010 studied the effect of biodiesel, blends of karanja oil methyl ester and diesel fuel, on performance through a zero-dimensional cycle simulation model and experimental data. And an increase in brake power for B40 and B60 blend fuels, but a decrease for B20, and also, increase in thermal efficiency for all the biodiesel blends in comparison to neat diesel oil is reported. [15] Asad and Zheng, 2008 investigated heat release mechanisms in compression ignition engines. And they suggest importance of determining combustion parameters based on obtained experimental data. [16] Abbaszadehmosayebi and Ganippa, 2014 calculated the heat release using combustion burnt factor. They concluded, using combustion burnt factor, in comparison to Wiebe function, gives better results. [17] Vipavanich et al., 2018, conducted tests on a CI engine running on gasoline, injected into port, and diesel fuel. Thermal efficiency was evaluated through heat release analysis and combustion parameters are investigated.

This study presents the effect of using biodiesel from sunflower oil on engine performance parameters, brake torque, brake power, brake specific fuel consumption, cumulative heat release and heat release rate. For this reason, test results for fuel blend of diesel fuel and SFME fuel at 50% fraction and neat diesel fuel are given for comparison. And heat release data calculated from engine pressure data are investigated to

understand the effect of biodiesel blend fuel better.

2. EXPERIMENTAL SETUP

2.1. Production of Sunflower Oil Methyl Ester

Biodiesel from corn oil is produced by transesterification method. Methanol, with 99% pure alcohol, and KOH, catalyst, are used. Alcohol and catalyst are weighed, and placed in a glass container to dissolve completely. Later, corn oil is heated to the required temperature, and then alcohol and catalyst preparation is added in. The preparation is mixed with a mechanical mixer at a constant temperature for the transesterification reactions to take place. And, glycerin is separated from the ester. Extracted ester is washed with pure water and then taken to drying process. Fuels properties used in the study are given in Table 1.

Table 1 Properties of fuels used in tests

Fuel property	Diesel C ₁₅ H _{25.5}	Biodiesel C ₁₉ H ₃₅ O ₂	B50
Density [kg/m ³]	832	880	862.5
Cetane number	57	46.8	51.9
Lower heating value [MJ/kg]	42.6	39.5	41.05
Kinetic viscosity at 40 °C [mm ² /s]	4.5	4.7	4.6
Self-ignition temperature [°C]	250	125	187.5

As given in Tab.1 mass fractions are compared. Carbon content in biodiesel is lower compared to diesel fuel, 85.4%, and 87.6% respectively. Therefore, carbonaceous pollutants from biodiesel fueled diesel engines will be less than neat diesel. The physicochemical properties given in Tabl.1 is close to the data given by Richard J Pearson [4] et al. And intermediate data [4] are calculated by mass ratios.

2.2. Engine Tests

A single cylinder, 4-stroke, water cooled, direct injection Superstar make test engine is used in the experiments, Table 2.

Table 2 Test Engine specifications

Engine	Super Star 4 stroke CI engine
Aspiration	Atmospheric
Cooling	Water circulation
Injection	DI
Bore [mm]	108
Stroke [mm]	100
Displacement volume [dm ³]	0.92
Connecting rod length [mm]	219
Compression ratio	17
Rated power @2200 rpm, [kW]	13
Injection pressure, [bar]	225
Injection timing, [°CA bTDC]	29
Piston type	Bowl-in-piston

Dynamometer is loaded by a Type, “S” load cell of 0.1 accuracy, calibrated before the tests, precisely. Test engine specifications are given in Tab.2. Tests are performed at full load condition and at 1200, 1400, 1600, 1800, 2000 and 2200 rpm engine speeds. The optimum static injection advance angle is obtained 29°CA bTDC, as a result of conducting several tests. And the obtained optimum static injection advance angle is used at tests. In Fig. 1, test bed is sketched.

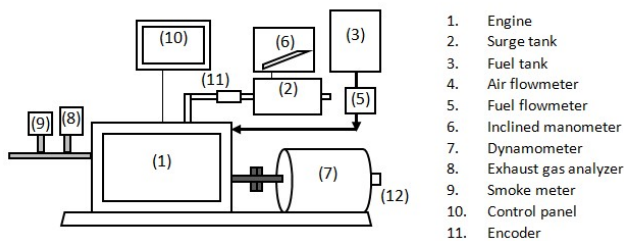


Figure 1 Engine test setup

During experiments, test engine is loaded by a 20 kW capacity electric dynamometer. Before testing, the oil temperature was measured $60 \pm 2^\circ\text{C}$. The Heat addition was kept constant, 17.3 mg fuel per cycle at 1100 rpm. Volumetric metering is used for fuel consumption measurements. Prior to experiments, test engine is run sufficient to maintain steady operating temperatures. In the closed circulation cooling system, cooling water outlet temperature was 85°C . Orifice plate – surge tank system is used for air consumption measurements. Kistler 6061B type water cooled piezoelectric sensor, using a Kistler 5011B charge amplifier and AVL make signal conditioner, software for pressure

measurements are used for in cylinder pressure measurements, and encoder on the engine crankshaft for angular position detection. Pressure sensor is placed in a bored slot on cylinder head opening to combustion chamber. Pressure sensor technical specifications are given in Tab. 3. For the cylinder pressure and top dead center (TDC) data acquisition, National Instrument PCIe 6251 fast data acquisition card is used for the signals from charge amplifier and the magnetic pick-up.

Table 3 Pressure sensor technical specifications

In-cylinder pressure sensor (6061B, water cooled, piezoelectric type)	
Pressure measuring range [bar]	0-250
Sensitivity	-26.09 pC/bar and +/- %0.3
Stable operating range [°C]	0-350
Natural frequency [kHz]	90
Overload capacity [bar]	300

2.3. Heat Release Analysis

Wiebe function, given in Eq.1, is frequently used in engine heat release analyses [16-17].

$$MFB(\theta) = 1 - e^{-a\left(\frac{\theta - \theta_0}{\theta_b}\right)^{m+1}} \quad (1)$$

where, MFB is fraction of burnt fuel, a is form factor, θ is instantaneous crank angle, θ_0 is crank angle for start of combustion, θ_b is engine crank angle for burn duration and m is efficiency factor.

For comparison, modified Wiebe function given in Eq.2, can be used in engine heat release analyses for improved results [16], providing parameter, θ_{50} for burnt fuel fraction at 50% [18]. Instead of form factor, a , θ_{50} is used to obtain closer results.

$$MFB(\theta) = 1 - e^{\ln(0.5)\left(\frac{\theta - \theta_0}{\theta_{50} - \theta_0}\right)^{m+1}} \quad (2)$$

For heat release rate calculations, the first law of thermodynamics is utilized as given in literature [10]. Heat release rate data are obtained using in-cylinder pressure data and engine data as given in

Eq.3. Ratio of specific heats, γ , is considered 1.32 [17].

$$\frac{dQ}{d\theta} = \frac{\gamma}{\gamma - 1} P \frac{dV}{d\theta} + \frac{1}{\gamma - 1} V \frac{dP}{d\theta} \quad (3)$$

where, instantaneous cylinder volume,

$$V(\theta) = V_c + V_d(\theta) \quad (4)$$

and in Eq. 4, clearance volume, V_c is measured from the engine cylinder. Instantaneous cylinder displacement volume [19],

$$V_d(\theta) = \frac{\pi B^2}{4} S(\theta) \quad (5)$$

Instantaneous piston stroke,

$$S(\theta) = R \left((1 - \cos(\theta)) + \frac{L}{R} \left(1 - \sqrt{1 - \left(\frac{R}{L}\right)^2 \sin^2(\theta)} \right) \right) \quad (6)$$

Derivative of cylinder volume,

$$\frac{dV(\theta)}{d\theta} = \frac{\pi B^2}{4} \frac{dS(\theta)}{d\theta} \quad (7)$$

Derivative of piston stroke,

$$\frac{dS(\theta)}{d\theta} = R \left(\sin(\theta) + \frac{R}{2L} \frac{\sin(2\theta)}{\sqrt{1 - \left(\frac{R}{L}\right)^2 \sin^2(\theta)}} \right) \quad (8)$$

3. RESULTS

In this section, engine performance parameters are investigated at engine speeds of 1200-2400 rpm range. Throughout the experiments, while engine speed increases, fuel mass flow rates decrease, but injection timings are kept constant

at 29°bTDC. Experimental results are given in the Figs.2-7.

In Fig.2, engine torques, force times the cantilever arm length from measured on loadcell are given for using diesel and B50 blend fuels at full load condition at testing speeds.

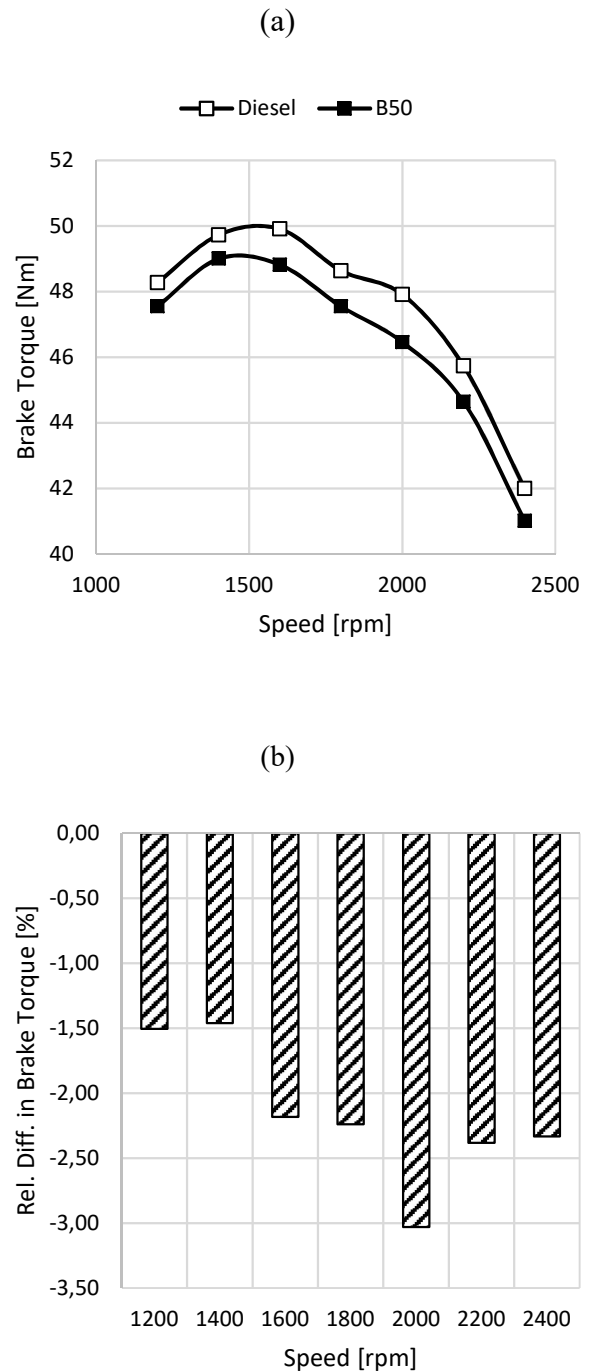


Figure 2 (a) Engine brake torque vs engine speed, (b) % Relative difference vs engine speed

During engine tests, the Maximum Brake Torque (MBT) conditions are sustained. And the results are shown below. At low speeds, engine torque increases, and after reaching a peak value, it starts decreasing. Compared to B50, obtained torques are higher at low speeds for neat diesel fuel and after the maximum value, obtained torques are very close to neat diesel fuel torques. Maximum torque is obtained at 1600 rpm, as given in Fig.2.a. The reasons of decrease in engine torque at low loads are higher heat losses, and degradation in mixture formation and volumetric efficiency. The speed at maximum torque condition also corresponds to the speed at the maximum fuel conversion efficiency condition. Above this speed, engine torque decreases, because of the decrease in volumetric efficiency, increase in mechanical friction loss and insufficient time for combustion to complete. As seen in Fig.2.b, using B50 fuel decreases the torque up to 3%, compared to neat diesel fuel. Highest torque obtained is 49.91 Nm for neat diesel fuel.

As seen in Fig. 3.a, engine power increases with speed, and reaching a peak, then starts decreasing. Slightly higher powers are obtained by using neat diesel fuel, compared to B50 fuel. And, lowest reduction in power is 3% as given in Fig.3.b. Highest power obtained is 10.54 kW for neat diesel fuel.

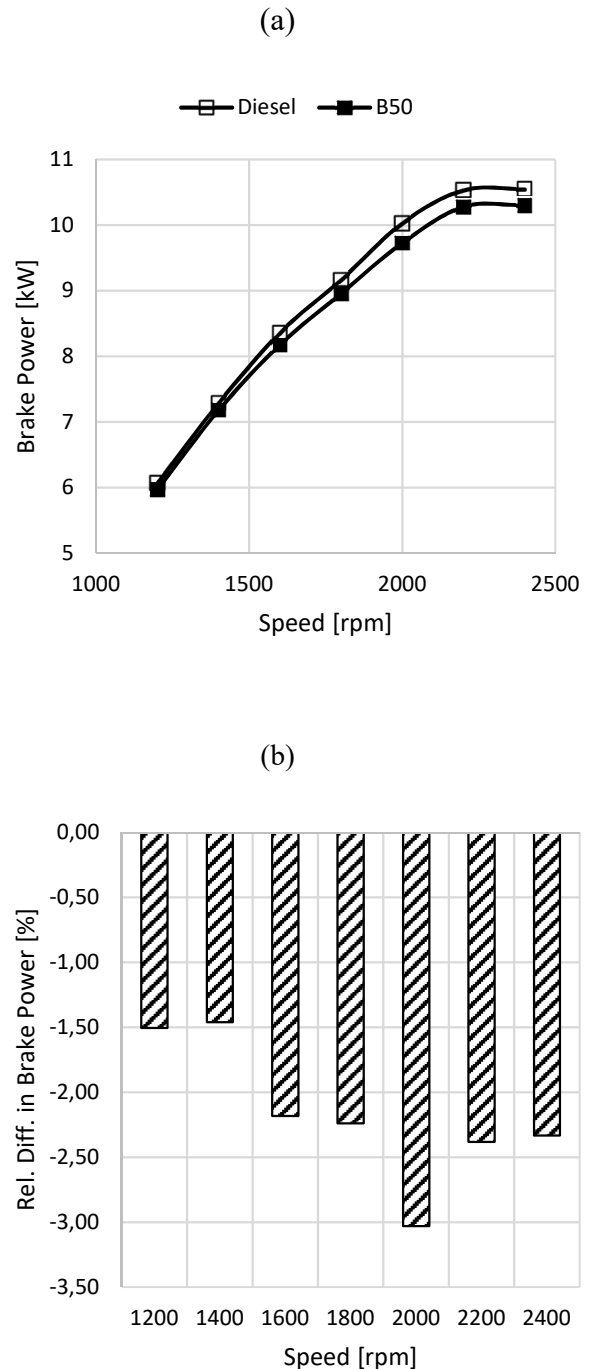
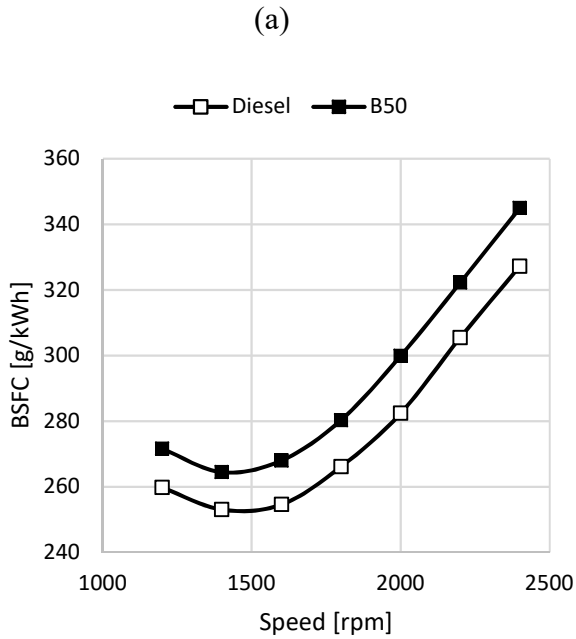
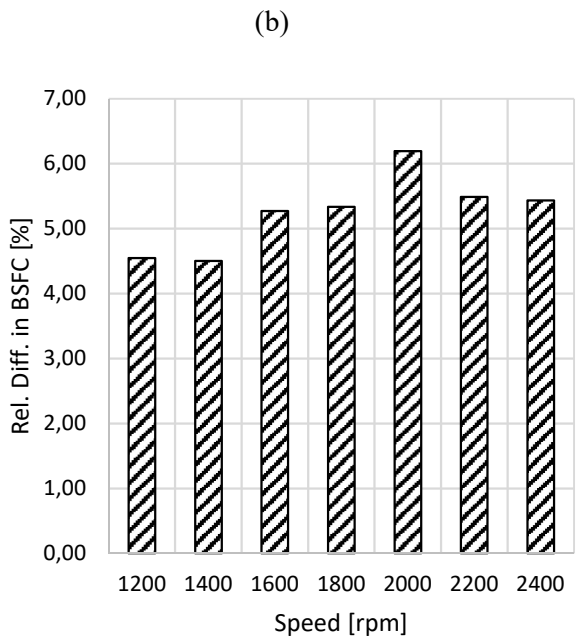


Figure 3 (a) Engine brake power vs engine speed, (b) % Relative difference vs engine speed

Obtained BSFCs are shown in Fig.4.a. For B50 fuel case, more fuel is consumed compared to neat diesel fuel, up to 6.4%. Lowest BSFC obtained is 254.58 g/kWh for neat diesel fuel.



(a)

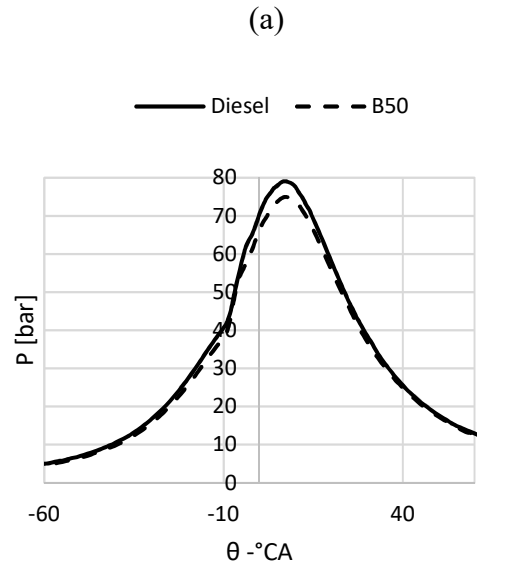


(b)

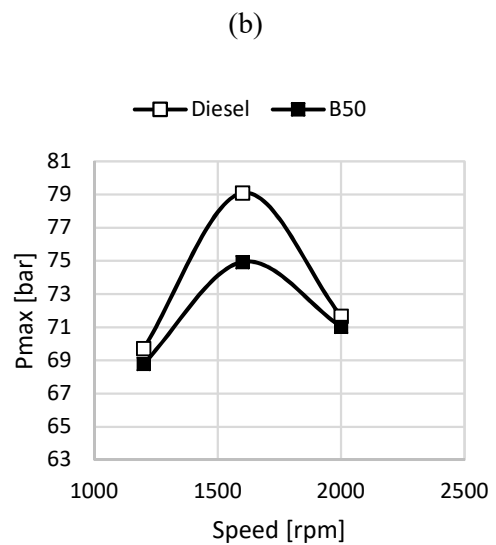
Figure 4 (a) Engine brake torque vs engine speed for the fuels, (b) % Relative difference vs engine speed

In-cylinder pressure data is used in engine performance analyses. In Fig.5a in-cylinder

pressure data versus crank angle is shown. When compared, pressure histories are close and similar. And, maximum pressures at MBT condition are depicted in Fig.5.b. Peak values are obtained around 1600 rpm for both fuels, and 79.1 bar for neat diesel fuel.



(a)



(b)

Figure 5 (a) In-cylinder pressure vs crank angle for the fuels, (b) Maximum pressures vs engine speed

In Fig.6, experimental heat release data are presented. Heat release rate curves start from the beginning of ignition and end with combustion. When compared, heat release at premixed combustion stage for neat diesel is less than B50

fuel. Maximum heat release rate is obtained earlier for B50 fuel. As seen Fig.7, the angles for MFB50 are pretty close. However, diesel fuel reaches MFB50 slightly before B50 fuel during combustion at 1600 rpm engine speed. In the evaluation of start and end angles for MFB, θ_5 and θ_{95} are considered, respectively [18]. Cumulative heat release curves are calculated by using equations (3-8).

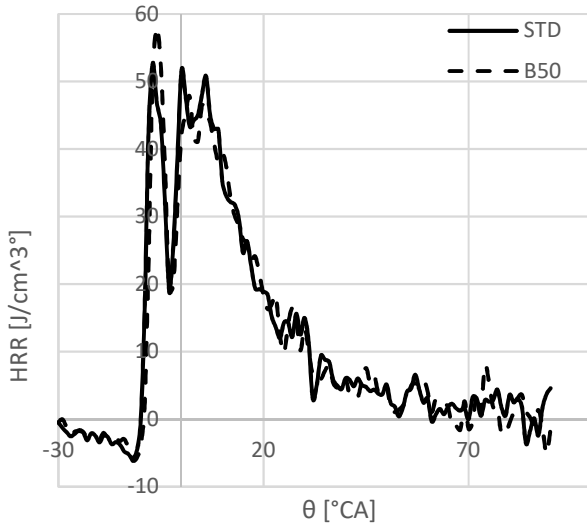


Figure 6 Heat release rate at 1600 rpm vs crank angle for diesel (solid) and B50 (dashed) fuels

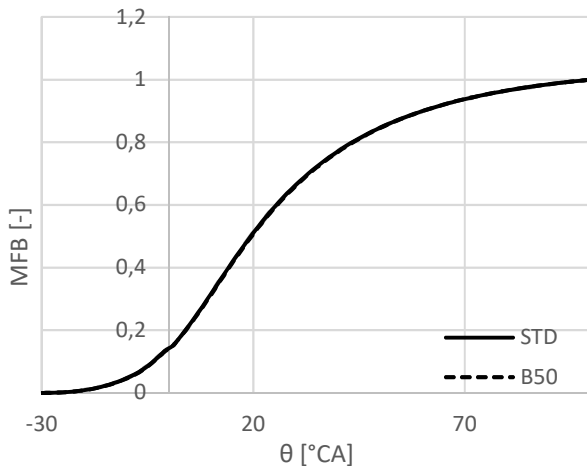


Figure 7 Burned fuel mass vs crank angle for diesel (solid) and B50 (dashed) fuels

4. CONCLUSION

Biodiesels have very high potential to be blended or used as a substitute of diesel fuel. Today, most of the classification societies and legal authorities

have issued standards for biodiesels, ASTM, EN etc. Therefore, a gate for a widespread of biodiesels is available.

In this study, biodiesel of sunflower oil, a common vegetable oil, is used to investigate the performance in comparison to neat diesel fuel. It is concluded that, torque, brake power and in-cylinder maximum pressure decrease by using biodiesel blend fuel, B50, and, BSFC increases with biodiesel, since SFME has lower LHV than diesel fuel. However, bearing in mind that, this discrepancy can be overcome by using cheaper biodiesel fuel production methods. Also, using biodiesel fuels is sustainable for being renewable.

Heat release rate data obtained is also presented. And, it is concluded that, for B50 fuel combustion premixed combustion stage is significant compared to neat diesel fuel. Premixed combustion stage is longer in B50 fuel than neat diesel fuel, while, diffusive combustion stage is longer for neat diesel fuel.

As a result, there is a difference in performance parameters compared to diesel fuel. However, this situation is not important considering the economic and diffusive potential of biodiesel fuel.

5. NOMENCLATURE

ASTM	American Society for Testing and Materials
B	Cylinder bore
B10	Blend fuel of 90% Diesel and 10% Biodiesel (by mass)
B20	Blend fuel of 80% Diesel and 20% Biodiesel (by mass)
B5	Blend fuel of 95% Diesel and 5% Biodiesel (by mass)
B50	Blend fuel of 50% Diesel and 50% Biodiesel (by mass)
B75	Blend fuel of 25% Diesel and 75% Biodiesel (by mass)
BSFC	Brake Specific Fuel Consumption
CI	Compression ignition
CO	Carbon monoxide
CO ₂	Carbon dioxide
COME	Canola oil methyl ester
DEE	Diethyl ether
DI	Direct injection
EN	European Norm
HC	Hydrocarbons
HHV	Higher heating Value
L	Connecting rod length

LHV	Lower heating Value
m	Wiebe function efficiency factor
NO _x	Nitrogen oxides
P _{inj}	Fuel injection pressure
R	Crank shaft radius
r _c	Compression ratio
S	Stroke
SFME	Sunflower methyl ester
V	Volume
V _c	Clearance volume
V _d	Cylinder displacement volume
WPOME	Waste palm oil methyl ester
ρ	Density
θ	Instantaneous crank angle
θ ₀	Crank angle for start of combustion
θ ₅	Crank angle for burnt fuel fraction at 5%
θ ₅₀	Crank angle for burnt fuel fraction at 50%
θ _b	Burn duration
γ	Ratio of specific heats

6. REFERENCES

- [1] Vezir Ayhan, Serdar Tunca, Experimental investigation on using emulsified fuels with different biofuel additives in a DI diesel engine for performance and emissions, *Applied Thermal Engineering* 129 (2018) 841–854, <https://doi.org/10.1016/j.applthermaleng.2017.10.106>.
- [2] Bjorn S. Santos, Sergio C. Capareda, and Jewel A. Capunitan, Sunflower Methyl Ester as an Engine Fuel: Performance Evaluation and Emissions Analysis, *ISRN Renewable Energy*, Volume 2013, Article ID 352024, 12 pages, <http://dx.doi.org/10.1155/2013/352024>
- [3] Estelvina Rodríguez Portillo, Araceli Amaya Chávez, Arturo Colín Cruz and Rubí Romero Romero, *Biofuels - Status and Perspective: Chapter 13: Qualitative Characteristics of Biodiesel Obtained from Sunflower Oil*, IntechOpen, <http://dx.doi.org/10.5772/59673>.
- [4] Richard J Pearson, James WG Turner , Arthur Bell , Stefan de Goede , Chris Woolard and Martin H Davy, Iso-stoichiometric fuel blends: characterisation of physicochemical properties for mixtures of gasoline, ethanol, methanol and water, *Proc IMechE Part D: J Automobile Engineering* 2015, Vol. 229(1) 111–139
- IMEchE 2014, DOI: 10.1177/0954407014529424.
- [5] S. Kent Hoekman, Amber Broch, Curtis Robbins, Eric Cenicerros, Mani Natarajan, Review of biodiesel composition, properties, and specifications, *Renewable and Sustainable Energy Reviews* 16 (2012) 143–169, doi:10.1016/j.rser.2011.07.143.
- [6] Cenk Sayin, Murat Ilhan, Mustafa Canakci, Metin Gumus, Effect of injection timing on the exhaust emissions of a diesel engine using diesel–methanol blends, *Renewable Energy* 34 (2009) 1261–1269, 10.1016/j.renene.2008.10.010.
- [7] G.K. Prashant, D.B. Lata, P.C. Joshi , Investigations on the effect of methanol blend on the combustion parameters of dual fuel diesel engine, *Applied Thermal Engineering* 103 (2016) 187–194, 10.1016/j.applthermaleng.2016.04.061.
- [8] Ayhan Demirbas, Relationships derived from physical properties of vegetable oil and biodiesel fuels, *Fuel* 87 (2008) 1743–1748, doi.org/10.1016/j.fuel.2007.08.007.
- [9] Ankush Prajapati, Kuladeep Kumar Pandey, Devesh Kumar, Performance and Study of Diesel Engine Using Blends of Sunflower Oil with Diesel, *International Journal for Research in Applied Science & Engineering Technology (IJRASET)*, Volume 4 Issue IV, April 2016.
- [10] Ahmet Necati Ozsezen, Mustafa Canakci, Determination of performance and combustion characteristics of a diesel engine fueled with canola and waste palm oil methyl esters, *Energy Conversion and Management* 52 (2011) 108–116. 10.1016/j.enconman.2010.06.049.
- [11] S. Kirankumar, N. Govind, Performance, Emission and Combustion Evaluation of Diesel Engine Using Methyl Esters of Sunflower Oil. *Journal of Mechanical Engineering Research and Developments*, Vol. 41, No. 1, 2018, pp. 1-8, 10.7508/jmerd.2018.01.001.
- [12] Ertan Alptekin, Mustafa Canakci, Determination of the density and the viscosities of biodiesel– diesel fuel blends, *Renewable Energy* 33 (2008) 2623– 2630, 10.1016/j.renene.2008.02.020.

- [13] S. Lahane and K. A. Subramanian, Effect of different percentages of biodiesel–diesel blends on injection, spray, combustion, performance, and emission characteristics of a diesel engine, *Fuel*, vol. 139, pp. 537–545, Jan. 2015, 10.1016/j.fuel.2014.09.036.
- [14] T. K. Gogoi and D. C. Baruah, A cycle simulation model for predicting the performance of a diesel engine fuelled by diesel and biodiesel blends, *Energy*, vol. 35, no. 3, pp. 1317–1323, Mar. 2010, 10.1016/j.energy.2009.11.014.
- [15] Asad and M. Zheng, Fast heat release characterization of a diesel engine, *Int. J. Therm. Sci.*, vol. 47, no. 12, pp. 1688–1700, 2008, 10.1016/j.ijthermalsci.2008.01.009.
- [16] G. Abbaszadehmosayebi and L. Ganippa, Characterising Wiebe Equation for Heat Release Analysis based on Combustion Burn Factor (C_i), *Fuel*, vol. 119, pp. 301–307, 2014, 10.1016/j.fuel.2013.11.006.
- [17] C. Vipavanich, S. Chuepeng, and S. Skullong, Heat release analysis and thermal efficiency of a single cylinder diesel dual fuel engine with gasoline port injection, *Case Stud. Therm. Eng.*, vol. 12, no. February, pp. 143–148, 2018, 10.1016/j.csite.2018.04.011.
- [18] S. Hu, H. Wang, C. Yang, and Y. Wang, Burnt fraction sensitivity analysis and 0-D modelling of common rail diesel engine using Wiebe function, *Appl. Therm. Eng.*, vol. 115, pp. 170–177, Mar. 2017, 10.1016/j.applthermaleng.2016.12.080.
- [19] Günter P. Merker, Christian Schwarz, Gunnar Stiesch, Frank Otto, *Simulating Combustion Simulation of combustion and pollutant formation for engine-development*, Springer-Verlag Berlin Heidelberg, Germany, 2006.