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An Experimental Assessment of Performance, Emissions, and Combustion Characteristics on a Diesel Engine Burning Rapeseed Biodiesel Blends

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ABSTRACT

Biodiesel represents one of the alternative fuels to face depletion of fossil petroleum resources. In this study, combustion characteristics, performance, and emissions of a diesel engine burning different blends of rapeseed ethyl ester compared to diesel fuel were evaluated. Results indicated that properties of biodiesel derived through transesterification process and its blends were within acceptable limits of standards. Biodiesel blends achieved lower thermal efficiencies as compared to diesel oil. Therefore, using ethyl esters blends results in higher specific fuel consumptions by about 1.5, 7, 13, and 17% for B5, B10, B15, and B20 in comparison to diesel fuel at full load, respectively. Smoke opacity, unburned hydrocarbons, and carbon monoxide emissions of biodiesel blends were reduced but nitrogen monoxide emissions have slightly increased. Maximum cylinder pressures of biodiesel blends were lower in comparison to conventional diesel fuel. Ignition delay decreases for B5, B10, B15, and B20 at full load were 11, 19, 28, and 32 % lower than diesel fuel, respectively. Biodiesel produced from rapeseed oil could be a substitute fuel in diesel engine.

1. Introduction

Researchers and scientists are working hard to present solutions for daily increased demand for power and continuous depletion of the petroleum-based fuel. Biodiesel applications were grown dramatically over the past years. Biodiesel can be produced of various resources (vegetable oils, animal fats or waste cooking oil) through production processes, such as trans-esterification process. Waste cooking oil (WCO) is a recommended source to produce biodiesel. A blend of 2-30% biodiesel and fossil petroleum resources may be used directly in a diesel engine, while it may be necessary to make some adjustments to the engine when 100% pure biodiesel is used [1].

The main problems of using vegetable oil directly in diesel engines are their lower volatility, higher viscosity, poor combustion, and formation of deposits [2-6]. Biodiesel has combustion characteristics and engine power output similar to traditional diesel fuel [7-10]. Rapeseed oil is still the dominant source in producing biodiesel where 68% of total biodiesel production in 2016 is based on rapeseed oil.

Rapeseed ethyl ester calorific value is 12.5% lower than diesel fuel and its Cetane number is similar to crude diesel [11-17]. Rapeseed oil blends of 5, 20, and 70% with diesel oil were tested to investigate diesel engine performance and emissions. Biodiesel led to reduction in smoke emission up to 60%. An increase of 11% in comparison to diesel fuel was shown for and specific fuel consumption. B5 and B100 blends produced reductions in CO emissions about 9% and 32% reduction than diesel fuel, respectively [18]. Rapeseed biodiesel was used in a diesel engine as B20 and B100. Biodiesel fuel reduced CO and CO2 emissions. The increase in fuel consumption for pure biodiesel was from 20 to 25% in comparison to diesel oil [19].

Rapeseed biodiesel lower calorific value results in a higher fuel consumption compared to diesel oil [20]. Biodiesel contributes to a better combustion process, and carbon oxide reduction due to oxygen content. Reduction of CO emission is due to lower carbon content [21]. Diesel fuel with rapeseed methyl ester blends results in lower hydrocarbon emissions [22].

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Rapeseed oil was converted to biodiesel using transesterification process. The lowest specific fuel consumption was achieved for blend B10. B20 blend achieved the highest NO_x and reduced CO emissions for all fuel blends at 75% of engine load at 1800 rpm [23, 24]. Biodiesel blend B25 blend was recommended to be used in the diesel engine without any modifications led to performance improvement and emissions reductions [25].

In the literature, fewer studies covered the use of rapeseed oil biodiesel in diesel engine. The current paper focuses on the application of the extracted oil from seeds of higher oil content. Health problems due to the erucic acid in the oil led to conversion it to biodiesel. In our study, transesterification was used to produce biodiesel from Egyptian crude rapeseed oil. Rapeseed ethyl ester was blended with diesel fuel at lower recommended percentages from 5 to 20% based on a volume basis. Physical and chemical properties were evaluated to characterize biodiesel blends versus diesel oil. Different blends of rapeseed biodiesel with diesel are used to study their effect on the diesel engine emissions, performance, and combustion characteristics. These lower percentages produced near values of performance emissions to diesel oil.

2. Production of biodiesel

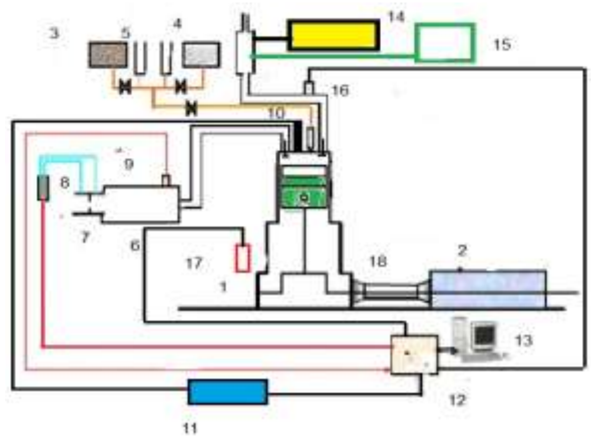
In this study, base catalyzed transesterification was used to produce biodiesel from rapeseed oil. Rapeseed oil was heated up to 70 ºC and stirred. Rapeseed oil triglyceride reacts with ethanol and potassium hydroxide which was dissolved in ethanol in molar a certain ratio (6:1 in a separate vessel and was stirred). The mixture was left to settle for 24 hours in a separating funnel after the production process [16-22]. The reaction products were biodiesel and glycerin. Rapeseed ethyl ester properties and its blends agreed with pure diesel according to ASTM D 6751-02 as shown in Table 1. Properties comparison with diesel fuel proved that rapeseed biodiesel properties were closer to diesel fuel. Viscosity and density of diesel fuel are lower than ethyl ester blends. The density and viscosity of B5, B10, B15 and B20 biodiesel mixtures are near to that of neat diesel fuel.

3. TEST SETUP

The experimental tests were achieved using diesel engine (one cylinder, 4 strokes, 5.775 kW rated power at 1500 rpm). U tube manometer was used to evaluate the pressure drop across the orifice. Thermocouple was used to measure the intake air and exhaust gas temperatures. A tachometer was used to measure the engine speed. The fuel consumption was evaluated be estimating the combustion time of fixed fuel volume. Exhaust gas concentrations were displayed using smoke meter OPA 100 and gas analyzer MRU DELTA 1600-V. A pressure transducer Kistler type (model 601A) was used to measure the cylinder pressure from 0 to 250 bar as pressure range with accuracy of 1.118% and sensitivity of 16.5 pc/bar. A Nexus charge amplifier of model 2692-A-0S4 was used. A proximity switch of Type LM12-3004NA was used to evaluate the dead center position. LABVIEW software and data acquisition card of NI-USB-6210 model were used. The tests were done from zero to 100% of load range at 1500 rpm constant speed. The schematic diagram is shown in Figure1.

Table 1: Fuel properties of diesel fuel and rapeseed biodiesel blends

Properties oil	Method	Diesel	Rapeseed biodiesel
Dynamic viscosity, at 40ºC, CP	ASTMD 445	4.5	5.6
Heating value MJ/kg	ASTMD 270	42.1	39.52
Density, at 15ºC kg/m^3	ASTMD 1298	825	875
Cetane number	ASTMD 613	50	58
Flash point, ºC	ASTMD 92	77	164



1- Diesel engine
2- AC generator
3- Diesel tank
4- Biodiesel tank
5- Burette
6- Air surge tank
7- Orifice
8- Pressure differential meter
9- Intake air temperature thermocouple
10- Piezo pressure transducer
11- Charge amplifier
12- Data acquisition card
13- Personal computer
14- Exhaust gas analyzer
15- Smoke meter
16- Exhaust gas temperature thermocouple
17- Proximity switch
18- Cardin shaft

Figure 1: Schematic diagram of the experimental setup.

4. RESULTS AND DISCUSSION

4.1. Brake specific fuel consumption (SFC)

Specific fuel consumptions of different biodiesel blends are shown in Figure 2. Biodiesel blends achieved higher specific fuel consumptions at all levels of power output in comparison to diesel fuel value. The increase of biodiesel percentage led to an increase fuel consumption. Biodiesel calorific value is about 14.88% lower than diesel fuel. Consumption of pure biodiesel is higher than diesel fuel to produce the same power because rapeseed biodiesel has higher density than diesel oil [16, 17, and 20]. It could be seen in Figure 2 that about 1.5, 7, 13, and 17% higher percentages of SFC when running on B5, B10, B15, and B20 in comparison to diesel fuel at full load, respectively.

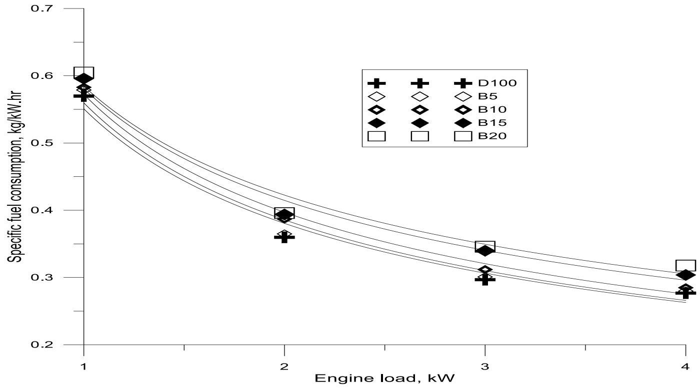


Figure 2: Specific fuel consumption with brake power for different biodiesel blends.

4.2 .Thermal efficiency (TE)

Figure 3 portrays the engine load effect on the thermal efficiency for ethyl ester and diesel blends. Rapeseed ethyl ester blends showed increase in TE with engine load increase. Heat generation in engine cylinder increases with the increase in output power. Biodiesel poor combustion characteristics caused drop in TE due to higher viscosity, lower calorific value, and poor volatility in compassion to diesel fuel [18, 19, 20]. Figure 3 showed that the brake thermal efficiencies for diesel oil, biodiesel blends of 5%, 10%, 15%, and 20% volume percentages are 31, 30.7, 30.3, 28.4, and 27.3 %, respectively at full load.

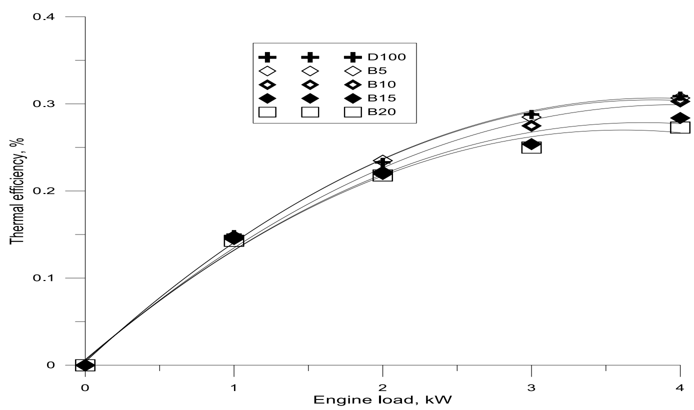


Figure 3: Thermal efficiency for biodiesel blends with the brake output power.

4.3. Exhaust gas temperature (T_{exh})

Variations of T_{exh} for all fuels at different loads were described in Figure 4. The increase in engine load led to increase of $\mathbf{T_{exh}}$ due to more fuel consumed at higher loads. There were increases in exhaust gas temperatures for ethyl ester blends with rapeseed biodiesel concentration in biodiesel blends due to lower heat transfer rate and lower thermal efficiency of biodiesel. As depicted in Figure 4, exhaust gas temperatures value for diesel fuel, B5, B10, B15 and B20 are 210, 215, 218, 223 and 228 ºC, respectively [20, 21].

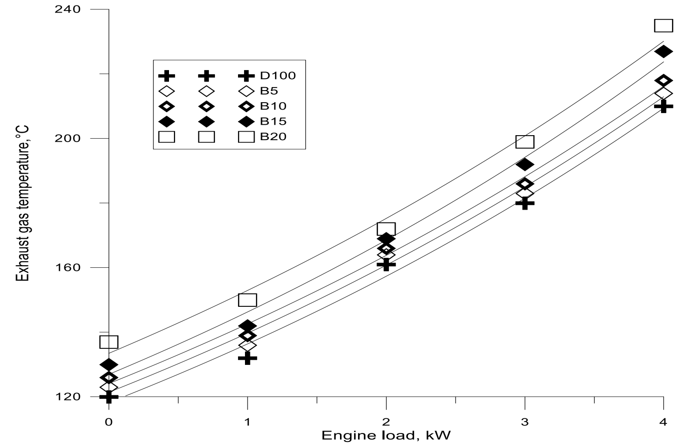


Figure 4: Variation of exhaust gas temperature against engine brake load for all fuels.

4.4. Carbon monoxide (CO) emission

Carbon monoxide emission for diesel and rapeseed ethyl esters related to engine load was also investigated, and presented in Figure 5. As brake-power increases, CO emission decreases. CO emissions of diesel engines are reduced by the use of biodiesel blends. For rapeseed ethyl ester blends, improved combustion led to decreased CO emissions due to presence of. Improved combustion was due to biodiesel oxygen content [20-23]. Figure 5, show that CO emissions were reduced as the percentage of biodiesel concentration increased, CO emissions values; for diesel, 5%, 10%, 15% and 20% by volume percentage, are 0.044, 0.042, 0.041, 0.037 and 0.035%, respectively, at full load operation.

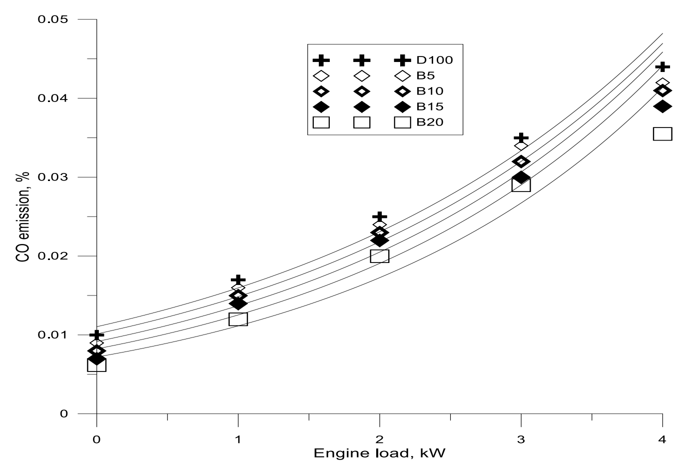


Figure 5: CO emissions for biodiesel blends with output brake power.

4.5. Hydrocarbon (HC) emission

Hydrocarbon emissions values; with respect to engine load, for various ethyl ester blends are shown in Figure 6. HC emission was decreased at lower output power and increased at higher loads. Presence of fuel rich mixture and lower HC emissions are due to oxygen lack at higher equivalence ratio. Biodiesel blend oxygen content resulted in improved combustion and lower HC emissions. It could be seen in Figure 6 that HC emissions values for B5, B10, B15, B20, el are 21, 19, 16, 14, and 12 ppm, respectively at full load [21-23].

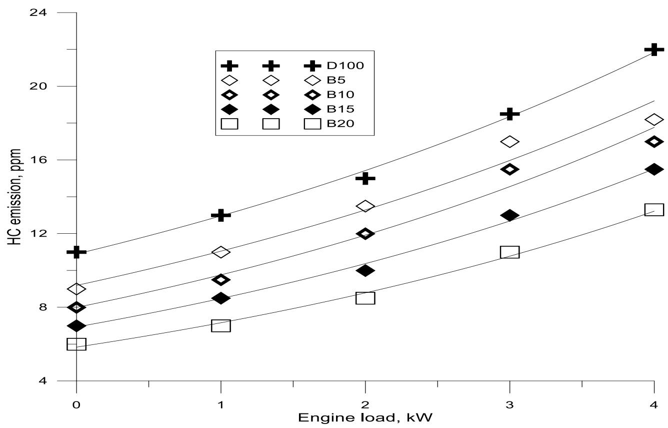


Figure 6: Effect of biodiesel blends and engine load on hydrocarbons emissions.

4.6. Nitrogen Oxides (NOx) emissions

Figure 7 showed NOx emissions values for biodiesel blends. NOx emissions increase associated with the engine load increase. Increase of ethyl ester percentage led to NOx emissions increase. Thermal NOx formation was due to cylinder combustion temperature increase. The increase in engine led to thermal NOx formation enhancing. NOx is formed during the diffusion phase. Ethyl ester blends showed the increase of NOx emissions about diesel fuel. This is due to the adiabatic flame temperature, oxygen content, higher Cetane number, and higher cylinder temperature in comparison to diesel oil. NOx emission values for diesel, B5, B10, B15, and B20 are 180,195, 210, 218 and 233 ppm; respectively at full load [20, 22, 26].

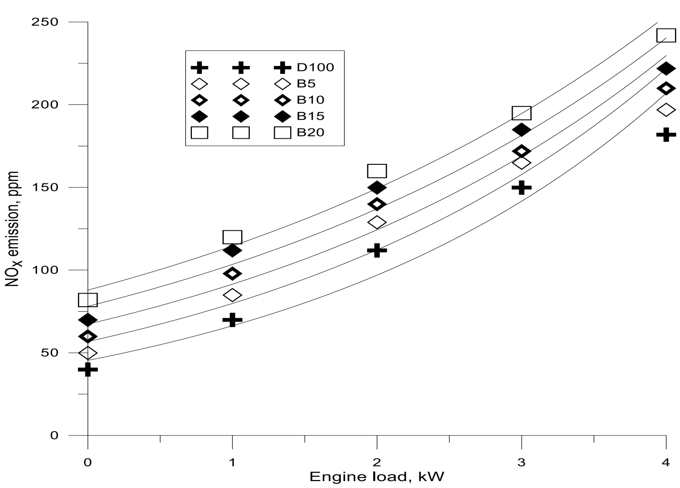


Figure 7: Variation of nitrogen oxides with engine load for biodiesel blends.

4.7 Smoke emissions

Measured smoke emissions for different fuel blends are shown in Figure 8. Smoke emissions are increased as diesel percentage increase; in the fuel blend, and increased engine load which is due to the increase in volumetric fuel consumption with output power. Smoke opacities for rapeseed ethyl ester blends are lower than crude diesel. Biodiesel inbuilt oxygen led to improved combustion and smoke reduction. The smoke values for diesel, 5%, 10%, 15%, and 20% volume percentage are 76, 71, 67, 63 and 59%, respectively, at full load. Increase in ethyl ester percentage in oil blends led to smoke opacity decrease [21, 23, 26].

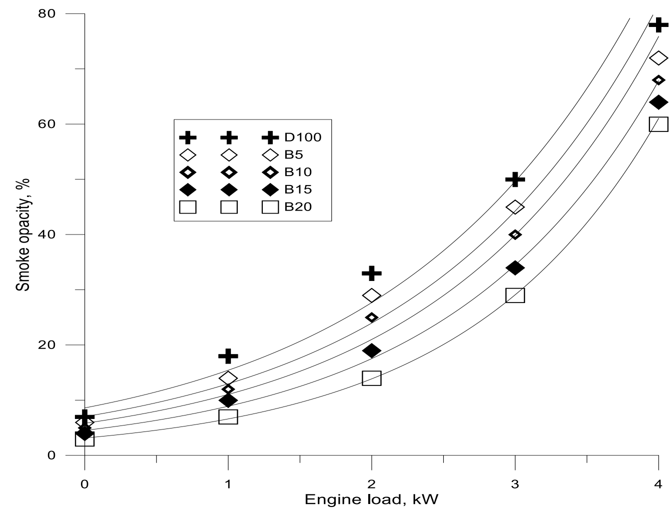


Figure 8: Smoke opacity with brake power for tested fuels.

4.8. In -cylinder pressure (P_{cy})

The combustion cylinder pressure for different biodiesel blends; at 100% of load range, are shown in Figure 9. Cylinder pressure showed the same pattern for all fuel blends. The increase in engine load led to the increase of P_{cy}. Peak cylinder pressures of biodiesel mixtures were lower compared to crude diesel. The decrease of P_{cy} with the increase in ethyl ester percentage is due to biodiesel shorter ignition delay compared to diesel. Biodiesel oxygen content speed-up the evaporation process of the fuel droplets and reduced the ignition delay. Higher speed of sound and higher bulk modulus of diesel led to early injection. Diesel oil achieved 72bar at 390º ATDC. Rapeseed biodiesel blends. B5, B10, B15, and B20 showed maximum pressure of 71, 69.5, 68.5, and 68 bar, respectively [26].

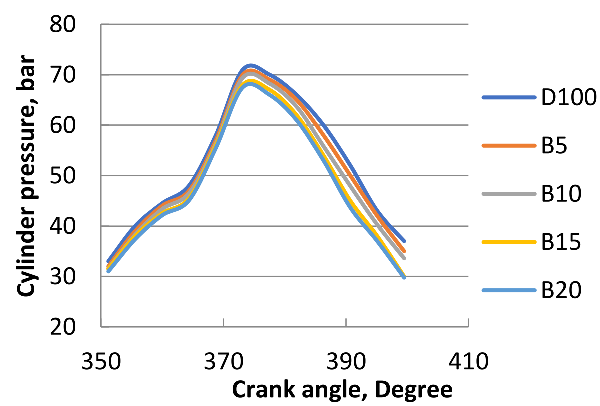


Figure 9: Cylinder pressure with crank angle at engine full load for biodiesel blends at full load.

4.9. Peak cylinder pressure

All tested blends showed an increased peak cylinder pressure with the increase in engine output power. Peak pressure increase is due to additional fuel burned at higher engine loads. Poor atomization and lower calorific value of biodiesel mixtures are responsible for lower peak cylinder pressure. Ethyl ester blends showed lower peak pressures in comparison to diesel oil as shown in Figure10. As the concentration of ethyl ester in the blend increased, the peak cylinder pressure decreased. The decrease in peak cylinder pressures at full load 4 kW are 2, 3, 4.5, and 6% for B5, B10, B15, and B20, respectively related to diesel fuel [26].

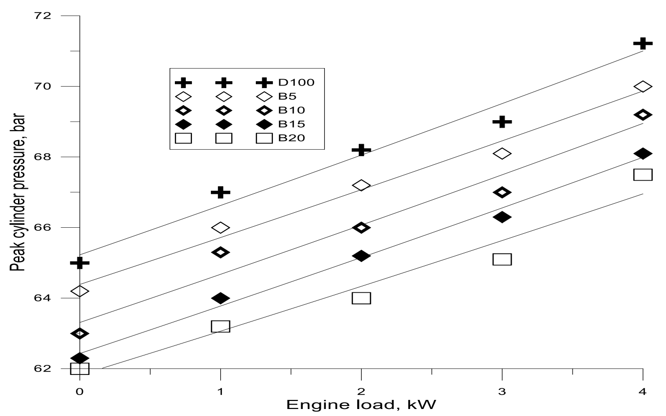


Figure 10: Peak cylinder pressure with engine load for biodiesel blends.

4.10. Heat release rate (HRR)

HRR for rapeseed ethyl ester blends with pure diesel at different engine loads at rated speed is depicted in Figure11. Rapeseed ethyl ester and diesel oil blends show similar patterns. As the concentration of ethyl ester in the blend increased respect to pure diesel, peak heat release rate is decreased. Shorter ignition delay and higher Cetane number of biodiesel is compared to diesel fuel. Biodiesel blends had less fuel accumulation in the premixed zone combustion causes lower peak HRR compared to crude diesel. The peak heat release rates of diesel, B5, B10, B15 and B20 are 51 J/ Degree, 49 J/ Degree, 48 J/ Degree, 46 J/ Degree and 45 J/ Degree, respectively [26].

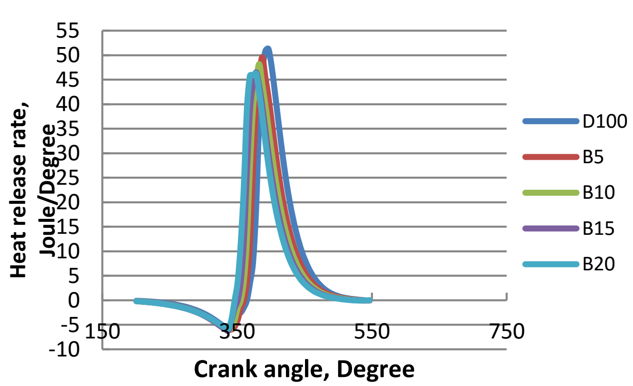


Figure 11: Variation of HHR with crank angle at engine full load for biodiesel blends.

4.11. Ignition delay (ID)

Figure 12 shows ID values of the fuels at different engine output power. Shorter ignition delay was shown for ethyl ester blends in comparison to diesel oil because of higher Cetane number. As the engine load increased, ignition delay decreased for all blends. Ignition delay periods of ethyl esters were lower than diesel fuel and decreased with biodiesel concentration increase when compared to diesel oil. B5, B10, B15, and B20 blends achieved decreases of 11, 19, 28, and 32 % about diesel fuel, respectively. Ignition delay of rapeseed ethyl ester decreased with the increase of biodiesel percentage of because it has higher Cetane number [26].

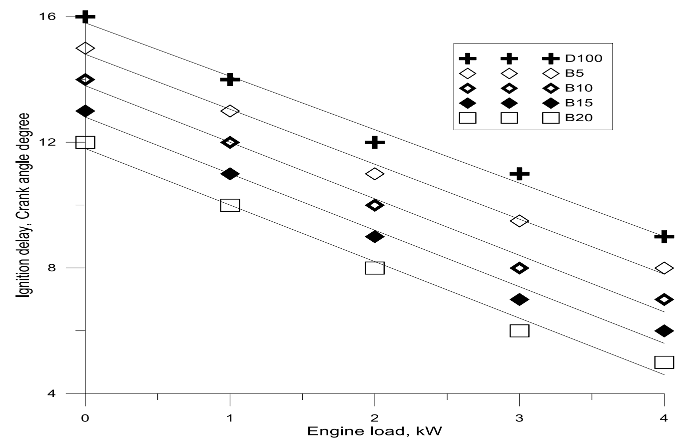


Figure 12: Ignition delay period with engine load for different biodiesel blends.

5. CONCLUSIONS

A comparative study has been conducted to compare diesel engine emissions, performance, and combustion characteristics burning rapeseed biodiesel blends compared to pure diesel fuel. The following can be concluded:

1. There were variations in biodiesel blends properties in comparison to crude diesel by biodiesel percentage increase and agreed with ASTM standards.
2. Engine performance for biodiesel rapeseed blends was comparable to neat diesel fuel. Rapeseed ethyl ester blends showed higher SFC and lower TE related to diesel oil. . B20 showed of 17% higher percentages in SFC compared to diesel.
3. Oxides of nitrogen and exhaust gas temperature for ethyl ester mixtures were higher than crude diesel. HC, smoke, CO emissions were reduced compared to diesel fuel for these blends. The smoke values for diesel and 20% volume percentage are 76 and 59%, respectively, at full load. CO emissions values are 0.044 and 0.035, but HC emissions achieved values of 21 and 12 ppm, respectively for diesel and B20 at full load operation.
4. Peak cylinder pressures and heat release of biodiesel blends were lower in comparison to conventional diesel and it decreased with ethyl ester percentage increase. The maximum decrease in peak cylinder pressure for B20 at full

load is 6% related to diesel fuel. The peak heat release rates of diesel and B20 are 51 and 45 J/ Degree, respectively.

5. Ignition delay period of ethyl esters blends decreased about diesel oil with the increase of ethyl ester percentage. The ignition delay decreases for B5, B10, B15 and B20 at full load were 11, 19, 28 and 32 % about diesel fuel, respectively.
6. Repressed ethyl ester could be a good substitute fuel in diesel engine without hardware modification.

Conflict of Interest

The authors declare no conflict of interest.

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