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Effect of Castor Biodiesel on Diesel Engine Performance, Emissions, and Combustion Characteristics

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Abstract

In this work, castor oil was used to produce biodiesel by transesterification process. The aim of this work was to study the performance, emissions and combustion characteristics of castor biodiesel blend B20 compared to diesel fuel using four stroke, single cylinder diesel engine. Diesel- biodiesel mixture B20 gives reasonable viscosity near to diesel oil. Brake thermal efficiency of castor biodiesel blend was higher than diesel oil by about 2%. Biodiesel blend B20 achieved higher exhaust gas temperature about diesel fuel. The smoke point increased with the blending ratio increase. Blend B20 achieved increase in smoke point by 30% about crude diesel. Cylinder pressure is higher for castor biodiesel blend compared to diesel oil at all loads. Performance and combustion characteristics of a diesel engine using biodiesel blends up to 20% with diesel fuel were close to diesel fuel. Non-edible castor oil which produced biodiesel could be a good substitute to diesel fuel in diesel engine.

Keywords: Castor biodiesel, Diesel engine, Performance, Smoke, Combustion characteristics;

1. Introduction

The problem of fossil fuel depletion and environmental degradation can be solved by using crude biodiesel or blends with diesel fuel. Biodiesel is fatty acid ethyl or methyl ester from vegetable oils or animal fats [1]. At different engine loads, biodiesel blends of 5, 20 and 35% for castor diesel -biodiesel blends were studied. At higher biodiesel concentration in the fuel, an increase in fuel consumption was shown [1, 2].

Small percentages of castor biodiesel blends with diesel fuel of 5, 10, 15 and 20% by volume were used. Biodiesel blends showed higher engine exhaust gas temperatures in comparison with diesel fuel [3]. Engine emission analysis and performance were performed using castor biodiesel blends of 2, 5 and 10% by volume at different loads. Specific fuel consumption and thermal efficiency of 10% castor biodiesel percentage were close to diesel fuel. Higher viscosity and lower net calorific value led to increase in specific fuel consumption for castor biodiesel blends about diesel oil [4]. Higher viscosities and lower net calorific value are the major problems associated with using vegetable oils. Thermal efficiency is slightly decreased, exhaust gas temperature and specific fuel consumption increased compared to diesel fuel for all biodiesel blends [5].

At different engine loads, castor biodiesel was run in a diesel engine. Transesterification was used for vegetable oil viscosity reduction. The increase in biodiesel concentration led to increase of exhaust gas temperature [7]. Blend B80 has the highest thermal efficiency and lowest specific fuel consumption. Blend B80 shows the overall optimum performance when used in diesel engine [8]. Castor biodiesel blends were prepared by blending biodiesel with different volumes of diesel fuel. Castor biodiesel blends of B5, B10, B20 and B30 were studied. Biodiesel fuel was evaluated in terms of its physical and chemical properties such as flash point, viscosity, density and lower heating value. Results showed that biodiesel has similar properties with diesel fuel [9].

Castor biodiesel blends of 5, 10, 15, 20, 30% by volume were investigated at various loads. The maximum increase in specific fuel consumption when compared to diesel fuel is 10.7 for B30 at half engine load, respectively. Blends B15 and B20 at full load operation gave the best specific fuel consumption of diesel engine [10]. Castor biodiesel blends with diesel oil from 0 to 40% by volume were investigated to examine engine performance and exhaust emissions. Transesterification process was used to produce biodiesel from castor oil. Specific fuel consumption of biodiesel blends increased with the blend percentage increase. Reduction in exhaust emissions and improvement in performance parameters made the blend of caster biodiesel reach up to 20% which is a suitable alternative fuel for diesel engine. Blend B20 can be selected due to its better combustion and lower emissions compared to diesel fuel [11].

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Effect of castor biodiesel blends on diesel engine performance and emissions was studied. Specific fuel consumption, thermal efficiency, and exhaust emissions were analyzed. Volume percentages of biodiesel with diesel fuel of 5, 10, 15, 20 and 30% were used. Lower blends of biodiesel provide acceptable engine performance. Exhaust emissions were decreased. Castor biodiesel blend B15 was the optimum blend of biodiesel-diesel blends [12]. Specific consumption increased for castor biodiesel blends compared to diesel fuel. Using biodiesel blends from castor oil of B10 and B20 showed satisfactory results in comparison to diesel fuel [13]. A single cylinder diesel engine was used to run with diesel and various blends of castor biodiesel. Performance parameters and emission tests were compared for various blends of castor biodiesel with diesel fuel. At blend B60, specific fuel consumption was the lowest with the highest exhaust gas temperature as compared to other biodiesel blends. B60 showed the optimum performance for its use in diesel engines. Vegetable oils are alternative fuels for diesel engines. Use of vegetable oils in diesel engine causes problems due to their higher viscosity and poor volatility. Blending diesel oil with vegetable oils reduces the viscosity of these oils [14]. Thermal efficiencies of biodiesel blends were lower compared to diesel fuel [15].

The reduction of kinematic viscosity by seven times about diesel oil was due to the presence of ricin oleic acid. Up to 20% of castor biodiesel can be blended within the accepted standard range of viscosity. Diesel oil has lower net calorific value compared to castor biodiesel [16]. Diesel oil has lower surface tension about biodiesel. Biodiesel blend has higher pressure rise rate during the rapid combustion phase about diesel oil due to higher reactivity of biodiesel [17]. The engine fueled with 20% castor biodiesel performs better and does not require any change in engine design [18]. Biodiesel is a good alternative in winter conditions. Castor biodiesel has a very low pour and cloud points; therefore, castor biodiesel has a lower cetane number compared to diesel [19, 20].

Poor breakup, evaporation properties and oxygen content have effects on castor biodiesel emissions [21, 22]. Higher value of specific fuel consumption was related to B5 at 1500 and 2000 rpm [23]. The optimal reaction conditions at a molar ratio of 5.4:1, KOH concentration of 0.73%, reaction temperature of 64°C, reaction time of 2.5 hour and stirring rate of 320 rpm resulting in 97.82% biodiesel yield. Increase of biodiesel percentage led to significant reductions in exhaust emissions [24, 25, 26].

Due to its higher oil yield, castor oil is one of the most promising non-edible oil. Due to limited castor oil biodiesel performance and emissions studies, it is evident that further research is recommended. Non-edible oil was taken as a feedstock for biodiesel production from Egyptian castor because of its ecological, reproductive, and supportable nature. Literature review did not show the smoke points and flame visualization, but it was considered. In this study, transesterification process was used for production of castor biodiesel from crude oil. Castor biodiesel at volume percentage of 20% was blended with diesel fuel. Chemical and physical properties of castor biodiesel blend were compared to diesel fuel. Experiments were also conducted to investigate its effect on the performance, emissions and combustion characteristics of diesel engine.

2. Production of castor biodiesel

Biodiesel was made from castor oil by base catalyzed transesterification. In a round bottom flask, the oil is heated up to 70 °C and stirred vigorously. The triglyceride of castor oil reacted with potassium hydroxide NaOH which was mixed with methanol in molar ratio of 6:1 in a separate vessel. The mixture was poured into round bottom flask while stirring the mixture continuously and maintained at atmospheric pressure and 65°C for 90 minutes to form an ester and glycerol. Under gravity for 24 hours, the mixture was left to settle in a separating funnel. The bottom layer consisted of glycerin, excess alcohol, catalyst, impurities and traces of unreacted oil. The upper layer was biodiesel. The fatty acid methyl ester (FAME) was water washed with air-bubbling to remove unreacted methoxide. The mixture was then heated to remove the water traces to obtain clear biodiesel of 92% yield [27, 28].

3. Experimental Setup

Experimental tests were done using a single cylinder, four stroke diesel engines with a developing power of 5.775 kW at 1500 rpm. Technical specifications of tested diesel engine were given in Table 1. The experimental set up schematic diagram was shown in Fig. 1. DC generator had been connected to the tested engine output shaft with flexible coupling. AC voltage from the power supply was controlled with variac. The received voltage was converted into DC excitation voltage by a rectifier circuit and measured using a digital voltammeter (model DT9205A) with a resolution of 1 volt in the range up to 750 volt (AC). Voltage was measured using a digital voltammeter (clamp multi-meter model 266, measurement range 0-750 DC volt, and 1-volt resolution). The generator output current was measured using an ammeter. Series of heaters which hot water flowing through a water tank was used to measure the electric output power of DC generator. Six electric heaters (each of 19.5Ω resistance) were connected to the generator output terminals. The excitation voltage was regulated to produce generator power output that would be equal the expected power output. A burette in the front side of the panel was used to measure fuel flow rate and selection between both diesel and biodiesel fuels. The air flow was measured using MERIAM- 50MC2 laminar flow element equipped with digital differential pressure transducer. The adoption of damping air box with large volume reduced the pressure fluctuations across the airflow measurement device to negligible values. A digital stroboscope (model DS-303) optical tachometer was used for engine speed measurements. The tachometer had been placed directly toward the engine flywheel. A strip of reflective tape was applied to the engine flywheel. A light beam was generated from the digital stroboscope with specific frequency towards the flywheel circumference. This optical tachometer had a measurement range up to 9999 rpm with a resolution of 1 rpm. Thermocouples K connected to digital thermometer (Omega-model 650) was used to measure the ambient air, exhaust gas and intake air temperatures. A cooled piezoelectric pressure sensor (model 6061B of pressure range up to 25 MPa and sensitivity of -2.75 pc/MPa) connected with NEXUS charge amplifier (Type 2690-A-OS4) was used to measure the cylinder pressure. The piston top dead center (TDC) marking was done by using proximity switch (model LM12-3004NA) installed at detecting distance of 4 mm supplied with DC voltage up to 36 V. A digital linear displacement (Sony-Magnescale LY-1115) detected the location of TDC relative to the position of the proximity. Data-Acquisition Card (DAQ model NI PCI-6251 with terminal block SCB-68) installed on PC computer controlled by LABVIEW software was used to acquire the signals from charge amplifier and proximity switch. The average cylinder pressure for at least 25 cycles was taken. At engine load variation from zero to full load and constant speed of 1500 rpm, the tests were carried out.

Table 1. Engine specification

Type	DEUTZ F1L511
Number of cylinders	1
Number of strokes	Four stroke
Cooling type	Air cooled
Bore (mm)	100
Stroke (mm)	105
Compression ratio	17.5:1
Fuel injection advance angle	24° BTDC
Rated brake power (kW)	5.775 at 1500 rpm
Number of nozzle holes	1
Injector opening pressure (bar)	175

4. Results and discussion

4.1. Effect castor biodiesel blends on viscosity

Due to the higher viscosity of biodiesel, it cannot be used directly in diesel engine. Therefore, it can be preheated or blended with the fossil fuels to be able to supply fuel blend without engine modifications. Preheat of fuel needs the addition of the eaters and the corresponding controllers, while the use of fuel blending does not need any additional equipment for engine [29, 30]. The mixture viscosity had been affected by the effect of the blend percentage as shown in Fig.2. Viscosity is directed proportional with the castor biodiesel increase in blends. Viscosity of methyl ester is higher compared with standard biodiesel value. The ratios of biodiesel blend and diesel oil viscosities are 5.7, 16.7, 29.6, 42.4, 58.1, 73, 113.3 and 387% for B5, B10, B15, B20, B25, B30, B40 and B100. We use biodiesel blend B20 because it gave reasonable viscosity according to literature review made by the researcher. Net calorific value of castor biodiesel blend was lower than diesel oil. Castor biodiesel achieved higher flash point compared to diesel oil, so, it is safer than crude diesel in handling and storage. Chemical and physical properties of diesel and castor biodiesel blends are shown in Table 2.

Table 2. Physical and chemical properties of diesel and castor biodiesel blends.

Properties	Method	Biodiesel B100	Diesel oil	Biodiesel blend B20
Density @ 15.56°C	ASTM D-4052	925	835	845
Kinematic viscosity, cSt, @ 40° C	ASTM D-445	16	2.5	4
Flash point, °C	ASTM D-93	148	72	82
Cetane number	----------------	58	50	52
Net calorific value kJ/ kg	ASTM D-224	41000	44000	43000

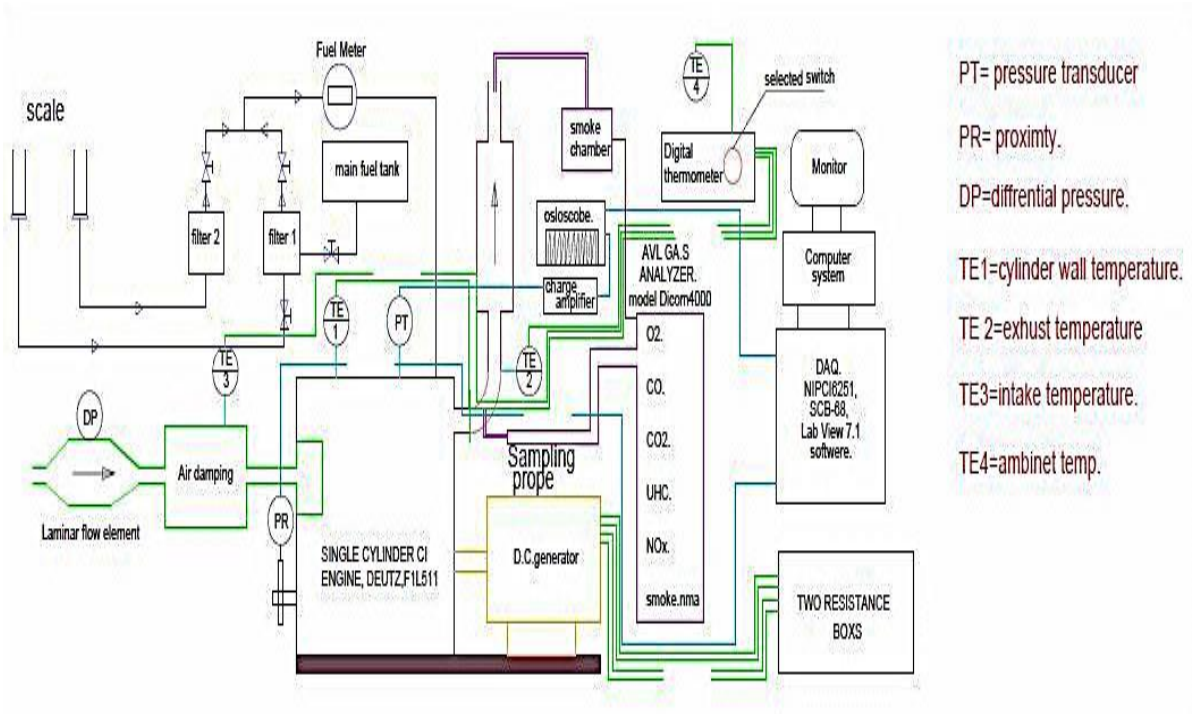


Figure1. Schematic of the experimental setup.

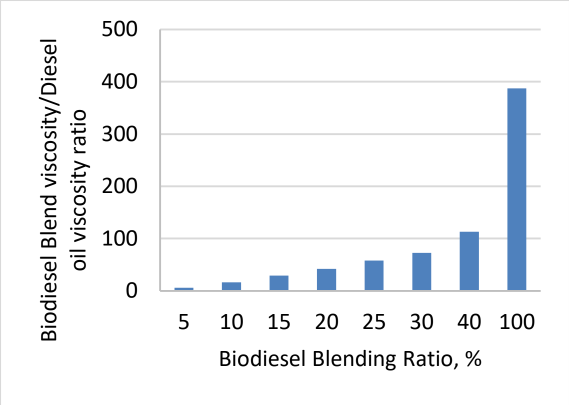


Figure 2. Effect of biodiesel blends on fuel viscosity

4.2. Brake specific fuel consumption (BSFC)

The variation in brake specific fuel consumption with respect to change in engine load for castor biodiesel blend and fossil diesel was shown in Fig. 3. The heat generated in the cylinder increased as the load increased. BSFC of castor biodiesel blend B20 was lower at all loads in comparison to diesel oil due to net calorific value of biodiesel blend B20 was near to diesel fuel. The engine consumes less fuel than compared to diesel oil to produce the same power. Lower viscosity, higher volatility led to combustion characteristics improvement of biodiesel blend. Castor biodiesel blend has lower density near to diesel oil. The fuel injection system operates on a volume metering system, so the oil density has an effect on engine performance. The reduction in specific fuel consumption for B20 about diesel oil is about 2% at 50% of engine load. The results are similar with literature [17, 31].

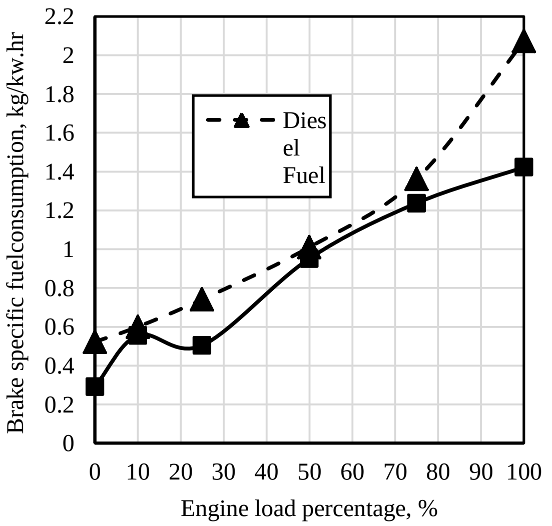


Figure 3. Variation of specific fuel consumption with engine brake power.

4.3. Brake thermal efficiency (BTE)

Figure 4 portrayed the brake thermal efficiency variation with engine load for diesel and biodiesel blend B20. Thermal efficiency of diesel and castor biodiesel blend increased with engine brake power increase due to fuel consumption increase. The increase in engine load led to increasing of heat generated in the cylinder. BTE was slightly higher for biodiesel blend B20 at all loads due to its net calorific value, density and viscosity near to diesel oil. The same displacement of the injection pump plunger with less discharge fuel for due to lower bulk modulus of biodiesel blend was shown. Value of biodiesel blend viscosity was near to diesel oil that gave a good atomization and efficient mixing of air and fuel. The higher lubricity and oxygen present in biodiesel improved the thermal efficiency. The increase in BTE for biodiesel blend was 2% about diesel oil at 50% of engine load. The results matched with these references [17, 31].

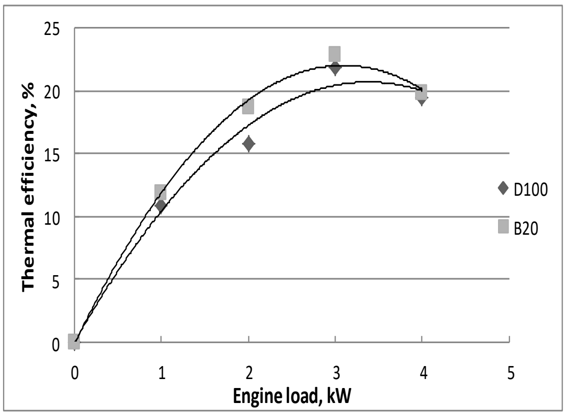


Figure 4. Variation of thermal efficiency with engine brake power.

4.4. Exhaust gas temperature (Texh.)

It describes the combustion status and shows the heat amount going waste in the exhaust gases. Figure 5 illustrated the exhaust gas temperature variation with engine brake power for diesel and castor biodiesel blend fuels. The increase in exhaust gas temperature with engine load increase was due to the increase in fuel consumption and cylinder temperature. Higher bulk modulus of biodiesel and heat loss increase of biodiesel blend B20 about diesel oil. Using biodiesel blends more than 20% led to higher increases of T_{exh} about diesel oil. Castor biodiesel blend B20 showed higher exhaust gas temperature compared to diesel oil. $T_{exh.}$ for diesel and biodiesel blend are 394 and 491°C, respectively at full load. The results confirmed with literature [17, 31]

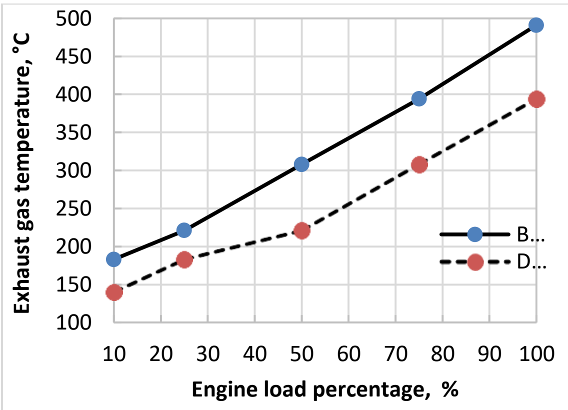


Figure 5. Variation of exhaust gas temperature with engine brake power.

4.5. Effect of biodiesel blends on smoke point

The smoke point is the maximum flame height produced by a specific wick fed lamp at which the flame starts to soot as stated by ASTMD1322-12 and as shown in Fig.6. The level A was above the smoke point, the level B at the smoke point and the level C below the smoke point. The flame in the wick feed lamb is laminar diffusion flame. The fuel flowed through the wick by the capillary effect. It was vaporized before entering the pre-combustion zone due to higher temperature then broke down in the preheat zone of the flame forming soot. As the temperature was raised at the flame front, the formed soot was oxidized and the combustion was completed. The completeness of soot oxidation depends on the amount of cracked hydrocarbons and the reaction rate. The existence of oxygen leads to higher reaction rate as a result of active radical formation in particular OH. The same results can be obtained if the hydrocarbon contents were reduced as already done by the transesterification process where the R-group was replaced by OH-group [32].

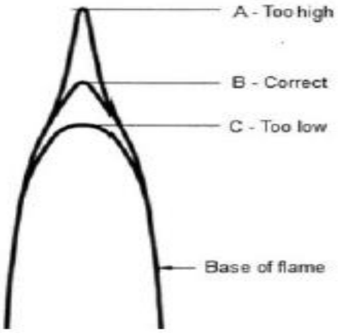


Figure 6. Smoke point evaluation

The candle was washed by methanol and left it until dry. The extracted oil was soaked and dried wick not less than 125 mm long in the sample. Then, it was placed in the candle wick tube. After that, the burning end of the wick was resoaked in the sample. The wick tube was placed in the candle. The candle was lighted and adjusted the wick until the flame was approximately 10 mm high and allowed the wick to burn for 5 min. The candle was raised until a smoky tail appear, then the candle was lowered slowly. The end of wick should be burned at the start of ruler. The observed layer of flame was flame A which was an elongated, pointed tip with the sides of the tip appearing concave upward (orange), Flame B was a blunted flame observed near the true flame tip and Flame C which is the downward white layer (white). The height of flame tip was determined. Smoke points for castor biodiesel blends were shown in Table 3 [33].

This method showed the relative smoke of diesel oil and it`s blends with castor biodiesel in a diffusion flame. The combustion products radiant heat transfer of the fuel was responsible quantitatively for the smoke point. The smoke point increased with blending ratio because of higher oxygen content in castor biodiesel as shown in Fig.7. The smoke points for biodiesel blends were affected by the oxygen content. The Smoke points increase about diesel oil which were23, 30, 40, 55 and 257% for B10, B20, B30, B40 and B100, respectively.

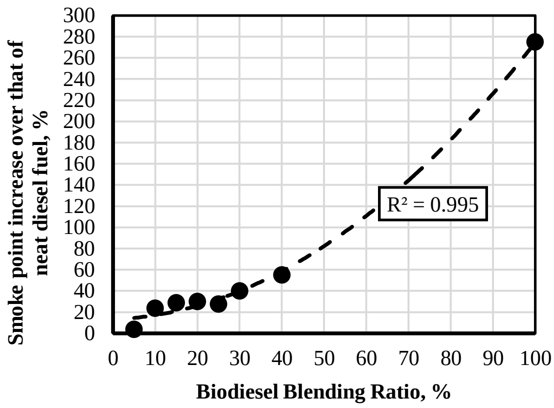
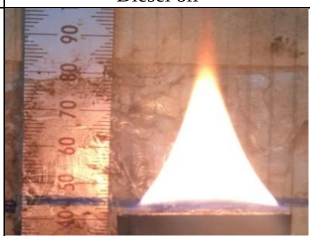
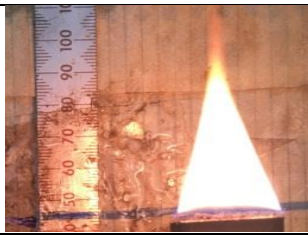


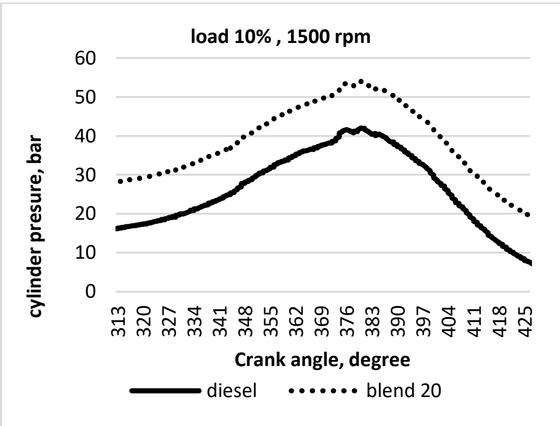
Figure 7. Smoke points for castor biodiesel blends.

Table 3. Smoke point for castor biodiesel blends.

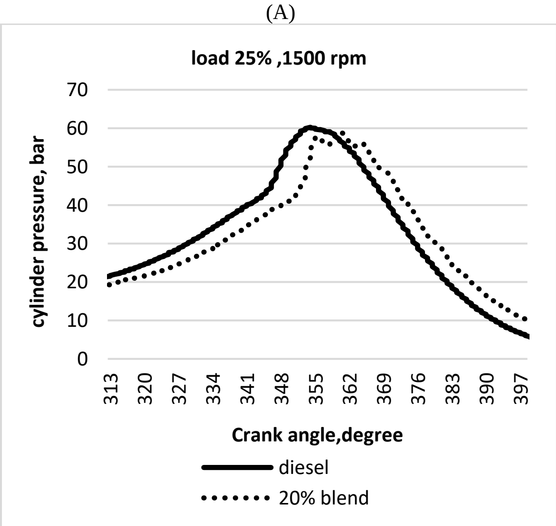
Biodiesel blend	Diesel oil	B10	B20
Smoke point			
Biodiesel blend	B30	B40	B100
Smoke point			

4.6. Variation of cylinder pressure with crank angle

Cylinder pressure describes the ability of the fuel to mix well with air. The large amount of fuel burnt in premixed combustion stage was related to the maximum rate of pressure rise and higher peak pressure. Figure 8 (A, B, C and D) showed the cylinder pressure variation with crank angle for diesel and castor biodiesel blend B20 at different engine loads of 10, 25, 75 and 100%. Castor biodiesel blend B20 followed by a cylinder pressure pattern similar to diesel fuel at load variation. Cylinder pressure was higher for biodiesel blend compared to diesel oil due to lower cetane number, longer ignition delay and less fuel burnt in diffusion stage of castor biodiesel blend. Higher cylinder pressure for biodiesel blend about diesel oil was due to more fuel burnt in premixed stage, improved reaction rate, higher heat release, air-fuel mixing and improved combustion characteristics. The cylinder peak pressure for diesel fuel is 55 MPa was attained at a crank angle of 5° before TDC. In case of biodiesel blend, the cylinder peak pressure was 65 MPa at a crank angle of 5° after TDC at full load. These results matched with references [17, 31].



(A)



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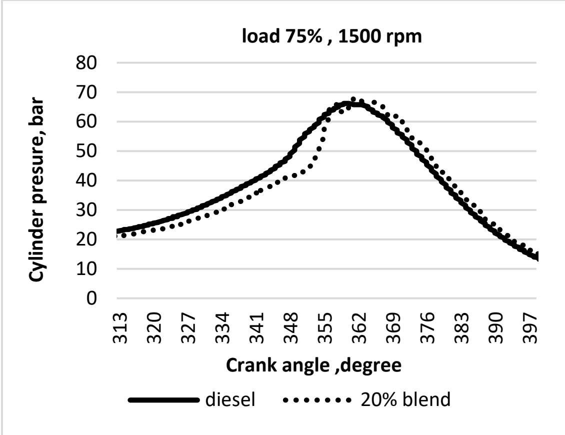

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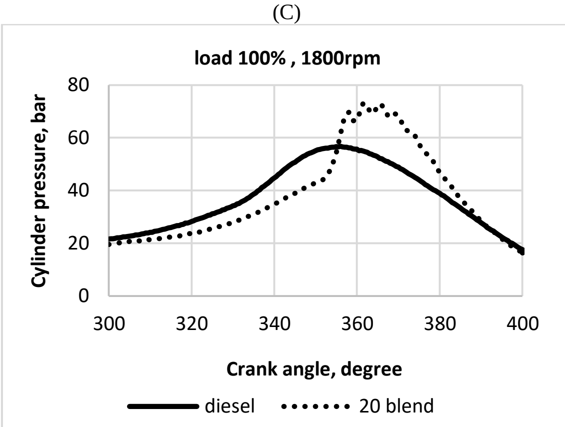

(D)

Figure 8. Variation of cylinder pressure with crank angle for diesel and biodiesel blend at 10, 25, 75 and 100% of engine load.

Conclusions

Biodiesel produced from castor oil can be used as alternative fuel in diesel engines. Castor biodiesel blend B20 was tested in a diesel engine at a constant engine speed of 1500 rpm and variable engine loads. Castor biodiesel was produced from raw oil by transesterification process. Experimental results were compared with diesel fuel and show the following**:**

- Methanol to oil molar ratio 6:1, 70 min reaction time, and 70 ^{o}C reaction temperature were the best conditions for castor biodiesel production using transesterification process.
- Viscosity is directly proportional with increase amount of castor biodiesel in blends. Castor biodiesel viscosity was higher compared with standard diesel. We use biodiesel blend B20 because it gave reasonable viscosity near to diesel.
- Castor biodiesel blend B20 showed a decrease in specific fuel consumption with respect to diesel fuel by about 2% at 50% of engine load.
- Biodiesel blend B20 showed an increase in engine thermal efficiency in comparison to diesel fuel by about 2% at 50% of engine load.
- There was an increase in exhaust gas temperature for biodiesel blend about diesel fuel. Its values for diesel and biodiesel blend were 394 and 491°C at full load.
- The smoke points for biodiesel blends were affected by the oxygen content. Increase in smoke points about

diesel oil are 23, 30, 40, 55 and 257% for B10, B20, B30, B40 and B100.

- The cylinder peak pressure for diesel fuel was 55 MPa at a crank angle of 5° before TDC. In case of biodiesel blend, the cylinder peak pressure was 65 MPa at a crank angle of 5° after TDC at full load.
- Castor biodiesel blends can be run up to 20% biodiesel volume with diesel fuel without any engine modifications because of engine performance, emission and combustion were close to diesel fuel.
- Biodiesel produced from non-edible castor oil could be a good alternative fuel for diesel engine without any modification.

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