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Effect of Injection Timing in Direct Injection Diesel Engine using Plastic Oil Diesel Blends with Biodiesel as an Additive

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ABSTRACT

Environmental Concern and depletion in petroleum reservoirs caused interest in search of alternate energies for internal combustion engine. Waste plastic materials being non-biodegradable, can be suitably processed using pyrolysis to obtain liquid fraction which has properties like petroleum fuels. 20% plastic oil (PO) blends with diesel may be utilized in diesel engines. However, adding biodiesel by 20% being renewable in nature reduces emissions. In the present work 20% PO and 20% biodiesel blend is considered to access the impact of injection timing on the engine performance. Engine tests were performed at four different injection timing 23^0, 21^0, 19^0, 25^0 and 27^0 before TDC. The blend (PO20+60D+B20) showed improved performance with advancing of injection timing with higher in-cylinder pressures and rapid heat release rate. Retarding the injection timings results in early combustion before the working stroke which reduces thermal efficiency. Further retarded IT of 19^o bTDC results in lower in-cylinder pressures which lead to reduced engine performance. However, advancing IT to 21^0 improvements in engine performance with higher BTE, and lower emissions of HC, CO, and Smoke respectively with higher NOx.

1. Introduction

The plastics sector has expanded quickly over the past 30 years. Polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC) are the four different polymers that are created, and their combined production has increased by more than 100 times in recent years. Those plastics are typically used in a wide range of important everyday applications, including clothing, home appliances, automobiles, and aviation. While the treatment of waste plastic has become a challenge. In this respect, there is a critical need of conversion of waste plastic oil into petroleum products, so

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that it can supplement fuel supply demand. Diesel engines utilize the products produced from discarded plastics [1]. Because they are drivable and have a high thermal efficiency, CI engines are the most popular engines. The smoke and oxides of nitrogen are not environmentally friendly and human beings also. Subsequently strict emission norms have an impact on substitute fuel for diesel engine [2]. To accomplish the engine performance, emission at satisfactory level, the fuel injection takes significant part. Injector pressure and timing are illustrations of fuel injection parameters. The NOx and smoke emissions from the engines are greatly impacted by these variables [3].

A study is conducted waste plastic oil with delayed injection timing and conventional injection timing to conduct an experimental investigation of the effects of injection time on the combustion, performance, and exhaust emission of a DI diesel engine. Lower cylinder pressure and higher thermal efficiency are seen when the injection timing is advanced from 23^0 bTDC to 14^0 bTDC. NOx decreases when the timing is retarded.

It was discovered that the best injection timing for using Honge oil in CI engines is 19^0 BTDC. The performance of the engine was found to be lower and increase in HC, CO, smoke and reduced NO emissions. It was found the efficiency decrease by 10% compared to diesel fuel. The pressure rise and heat release rate were lower with Honge oil operation compared to diesel fuel. Further ignition delay and combustion duration is increased with retarding injection timing [4].

Brake thermal efficiency of PPO was poor because of its lower heating value and high viscous. It was found the IT of 27^0 results in improved thermal efficiency in comparison with other injection timing. The cylinder pressure was lower for Plastic oil biodiesel blends and found it was increased with advancing injection timing [5].

The results showed that the test engine operated smoothly up to a point where plastic fuel blended with diesel by 30%, beyond which the operation became rough. Lower efficiency and greater emissions were the outcome of retarded timing of fuel injection. The practical solution to the issue of poorer thermal efficiency and higher carbon-based emissions, however, is to advance the fuel injection timing [6].

A test was conducted to evaluate efficiency and exhaust qualities of CI engines using different blends of diesel and Karanja biodiesel (B20, B40, B60, B80, and B100). The experimental study was done using internal ignition (IC) technology under varying loads and contrasted with regular diesel fuel. The results showed that B40 had improved fuel characteristics and engine performance. In every example, BSFC decreased as the load increased. Different blends' BSECs are lower than those of diesel fuel. The lower BSEC could be caused by the oxygen content of blends made from diesel and the methyl ester of Karanja oil. Heat loss reduces with increased load, improving brake thermal efficiency. It was discovered that the amount of CO and HC released decreased as the diesel fuel blend fraction increased. NOx emissions increased as the blend proportion for diesel fuel raised [7].

At 800 bar of injection pressure and an advanced injection time, the test engine's performance, combustion, and emission characteristics were assessed (27^0 bTDC). A concentration on plastic oil clearly had an impact on burning, and performance factors significantly decreased, especially above 40% expansion. To test for reductions, methanol, and diethyl ether (DEE) were added to the P40 mixture in a variety of quantities. With 31.25% brake thermal efficiency and, at full load, 2.3, 20.28, 34.61 g/h of hydrocarbon, nitrogen oxides, carbon monoxide, and smoke, respectively, these gains demonstrated a notable improvement. The findings demonstrated that plastic oil may replace up to 40% of diesel fuel and that the drawbacks of using plastic oil could be offset by combining methanol fuel and a diethyl ether additive [8].

An experimental study showed improvements in emission performance and emission reduction are thought to be crucial in IC engines. One of the key elements of diesel engines that influences efficiency and performance is injection timing. Injection timing advancement reduces fuel, hydrocarbon, and carbon monoxide emissions while raising NOx and thermal efficiency in diesel engines. In biodiesel-diesel blends, delaying injection timing raises cylinder temperature with increasing biodiesel content while reducing NOx and producing more HC and CO. It was found that delaying injection pressure results in lower power, lower peak cylinder pressure, and higher temperature. As technology advances, thermal efficiency rises, CO and HC emissions fall, while NOx emissions drastically rise as cylinder temperature rises [9].

Dual biofuel was discovered to alter the diesel engine's injection timing. Based on BSFC (Brake Specific Fuel Consumption), CO (Carbon Monoxide), NOx (Nitrogen Oxide), and UHC, the performance and emissions for the tests (unburned hydrocarbon). These factors were studied at different load levels, from 0% to 100% load. According to the findings of the experiment, SFC is smaller for B20 mix in contrast with conventional straight fuel, even though B40 and B60 mixes come up with slightly better characteristics but are closer to B20 blend [10].

When the engine was running at engine loads of 25, 50, 75, and 100% and with various fuel injection timings of 19°, 21°, 23°, 25°, and 27° before TDC, experimental approaches were utilized to characterize the mixture. Results reveal that for 20% mix with a variation in injection time from 19° bTDC to 27° bTDC at full load, brake fuel consumption and exhaust gas temperature increased by 15.84% and 4.60%, respectively, while brake thermal efficiency declined by 4.4%. The amount of smoke decreased by 18.89%, the amount of CO2 increased by 5.26%, and the amount of NOx increased by 12.94% [11].

When compared to plastic oil and diesel, the study's findings showed an improvement in brake thermal efficiency. It was discovered that improving the combustion by adding an oxygenated additive result in a decrease in CO and NOx emissions. The viscosity of plastic oil decreases when DEE is added at a 10% blend, improved thermal efficiency. Increased DEE causes the heat release rate to increase and the cylinder pressure to decrease, which lowers NOx. Additionally, DEE blends produce less CO than WPPO due to their high cetane number and high heat of vaporization [12].

The performance and exhaust emissions of a single cylinder direct injection diesel engine running on waste plastic fuel (WPF) produced by pyrolyzing high-density polyethylene (HDPE) are investigated in the work (DIDE). Quaternary fuel blends were created by mixing three different WPF ratios with 10% ethanol and 10% oxygenated ethoxy ethyl acetic acid. A few benefits of ethanol include its low consistency, high oxygen content, and high hydrogen-to-carbon ratio. The quaternary fuel increases brake thermal efficiency while consuming less fuel and emitting fewer emissions. The sample WEE20 has a 7.8% lower fuel consumption and a 4.7% improvement in brake thermal performance. The quaternary fuel blends demonstrated decreased carbon monoxide of 3.7 to 13.4% and decreased hydrocarbons of 2 to 16% at various load levels [13].

Experiment was conducted an experiment using Mahua biodiesel and n-butanol. A mixture of 20 to 30 vol.% n-butanol and 80 vol.% diesel was attempted. The timing of the injection was changed from 21 to 25 CA bTDC. A mixture of B20, D80, and 30% n-butanol (NBM mix) had nitrogen oxide and carbon monoxide levels that were 49% and 5.88% smaller compared to straight fuel. When compared to diesel, the NBM mix's smoke and hydrocarbon emission are reduced by 40% and 38.07%, respectively, at 25 CA bTDC [14].

From the exhaustive literature survey carried out on the feasibility studies of using waste plastic oil as substitute to diesel in power generation reveals that the processing of plastics into oil by using pyrolysis could be considered as safest method of disposal. The novelty of the present work basically involves performance evaluation of diesel engine using optimized combination of plastic oil-biodiesel and diesel blends PO20KBD20. The objective of the study involves effect of injection timing on the performance, emission and combustion characteristics of diesel engine fueled with plastic oil-biodiesel and diesel blends.

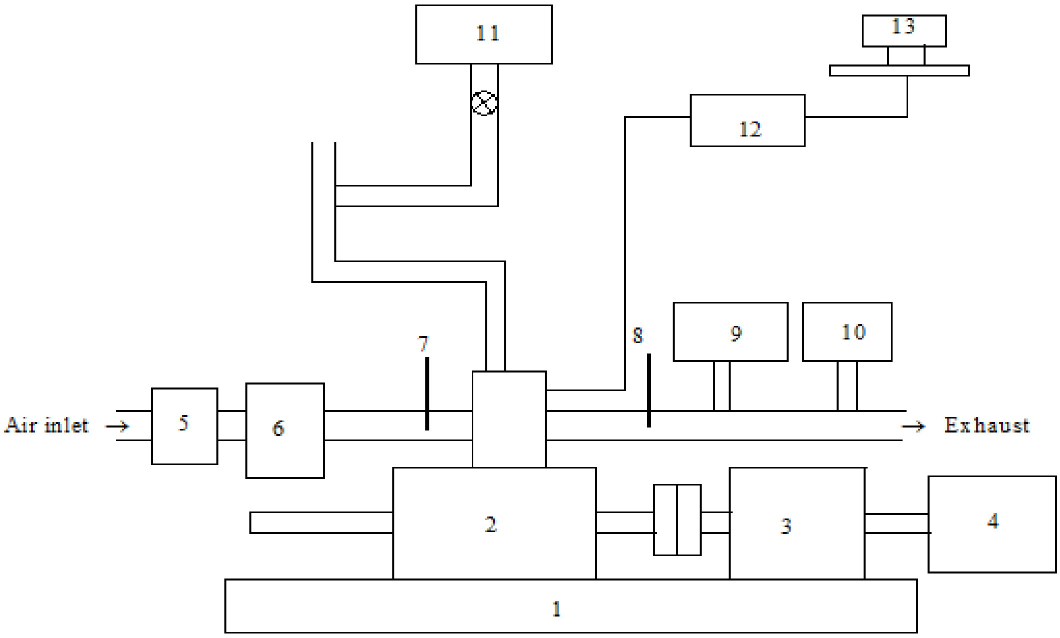
2. Materials and Methods

2.1 Plastic Oil Conversion Process

A reactor design, which will be used for catalytic transformation, is depicted. A 1300 mm-wide, hollow, circular vessel made of hardened steel served as the reactor. To heat the reactor, LPG was used. A thin coating surrounding the reactor. Glass wool was sandwiched in the center of a thin cylindrical sheet and a reactor vessel. The glass wool lessens the reactor's heat loss. The reactor was equipped with a safety valve, a pressure monitor, an airtight cock for the waste plastic input, and an exit connected to a water-cooled condenser. A safety valve can tolerate pressures of up to 500 kg/m^2. At the bottom of the reactor, a hand opening with a hermetically sealed stop valve was provided for removing the materials after degradation. To measure the reactors inside temperature, a thermocouple was installed at the lowest portion. An indication for the temperature is on the control panel. The temperature marker displays the reactor's internal temperature. A condenser is composed of a cooling loop and a water covering. The 1800 mm long and 20 mm wide stainless steel utilized in the condenser's construction. This coil was stored inside the water jacket and was 300 mm in width and 500 mm in height. The water jacket's lower section had an entrance at the bottom and an outlet at the top. Using the entrance and outflow, water was transferred inside the jacket. The tank made of stainless steel is where the produced oil is kept. Before being fed into the shredder, the feedstock—which comprises of various waste plastics—is sorted for different types of plastics. The material is classed according to sizes and states that are suitable for crushing, cutting, and destroying. To make the material easier to handle and soften throughout the liquefying/preheating process, it was crushed, cut, or destroyed, and evaluated into uniform size. The various waste plastic was taken care of into a reactor alongside of 5% catalyst and maintained at temperature of 30^0-350^{0}C for about 3-4 hours in absence of oxygen. The process gives liquid fraction which is combination of different petroleum fuels. The burner was lit using a lighter after the LPG gas handle was turned to the ON position. With the aid of a stopwatch, the time was recorded. The vapour produced by the plastic breaking was reduced using the water-cooled condenser. Condensable gas turned into liquid after condensation, which was collected in the collecting tank. As a result of heating, the reactor inside temperature rises. It was noted when the oil arrangement began and at what temperature. The cracking process in the reactor accelerated as the reactor's temperature slowly increased. More WPO was obtained as a result. It was documented the temps and the moment the oil stopped [15].

2.2 Experimental Setup

The engine under test was a water-cooled, single-cylinder, four-stroke CI engine operating at a constant speed. The test rig's schematic diagram is depicted in Figure 1. The table below displays the engine specifications. The engine is loaded on an eddy current dynamometer. The chamber pressure was measured using a pressure transducer and a crank encoder. The engine crank angle was measured using a TDC encoder. NOx, HC, and CO exhaust were measured using a fumes gas analyzer. Using an AVL smoke metre, smoke was measured in Bosch Smoke Units (BSU). The experiments were conducted at a motor speed of 1500 revolutions per minute (rpm). The engine was started with diesel to simulate running every test. Then blended plastic oil was used to drive the engine at that moment. To remove the used plastic oil from the fuel line, the engine was run on diesel for a considerable amount of time after the test. Table 1 contains the engine's specifications. Table 2 provides information on the sample's characteristics as well as the measuring equipment employed. PO20KBD20 blend is prepared considering 20% plastic oil that is blended with B20 Karanja biodiesel.



1. Base 2. Engine 3. AC generator 4. Loading rheostat 5. Air filter 6. Anti-pulsating drum
7. Inlet thermocouple 8. Exhaust thermocouple 9. Exhaust gas analyzer 10. Smoke meter

Fig. 1. Experimental test rig used

Table 1
Specification of engine

Engine	Make Kirloskar, Model TV1, Type 1
Cylinder power	5.2 kW
Number of cylinders	4 stroke Diesel, water cooled,
Speed	1500 rpm
Stroke	110 mm
Bore	87.5 mm
Compression ratio	17.5

Table 2
Properties of fuels and its blend

Property	Method	PPO	Diesel	Karanja biodiesel	PO20KBD20	ASTM Standard
Density, kg/m^3	IS1448	870	830	890	864	ASTM D5052
Kinematic viscosity at 40°C, cSt	IS1448	2.77	3.78	5.6	3.6	ASTM D2270
Flash point, ^{0}C	IS:1448	>25	65	163	38	ASTM D93
Heating Value, MJ/kg	IS1448	35.4	42.46	35.8	39.3	ASTM D5865

Uncertainty analysis:

To minimize the errors, at each load of the engine operation six readings were taken and averaged out readings of performance, emission and combustion values are used to plot the graphs accordingly. Table 3 indicates the accuracy with which the emission parameters were recorded.

Table 3
Analytical instruments used

Gas Analyzer	Range	Accuracy
CO	0-15%	5%
CO_2	0-20%	3%
HC	0-30000 ppm	3%
NOx	0-5000 ppm	1%
Smoke	0-100%	1%
Crank angle encoder	720 x 1^0	1^0

3. Results

3.1 Performance Analysis

3.1.1 Brake thermal efficiency

As illustrated in Figure 2, the brake thermal efficiency rises when the injection timing is delayed. Retarded injection timing outperforms regular injection timing in terms of brake thermal efficiency at full load. With delayed injection timing, the waste plastic oil blend (PO20KBD20) has a thermal efficiency that is clearly higher [1]. Diesel fuel shows lower BTE compared to waste plastic oil-biodiesel blend (P20KBD20) due to its lower calorific value. The ignition starts immediately when the injection time is slowed, and it keeps burning throughout the power stroke. As a result, the rate of heat release slowed down and pressure increased. High work production for delayed timing and an improvement in brake thermal efficiency are produced by complete combustion. At 21° injection-timing retardation, which is identical to that of standard injection timing of 23°, the highest brake thermal efficiency, 33%, was attained.

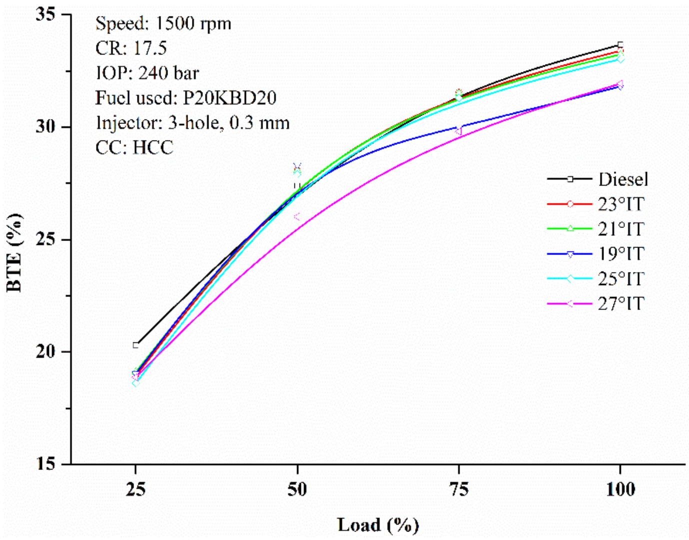


Fig. 2. Variation of brake thermal efficiency against load

3.2 Emission Analysis

3.2.1 CO emission

CO production is a result of the burning efficiency and is related to the fuel-to-air ratio. Diesel fuel shows lower CO compared to waste plastic oil-biodiesel blend (P20KBD20) due to its lower calorific value. The CO discharges were decreased with a delayed injection timing at low loads as opposed to the waste plastic oil operation's regular injection time [4]. This can be due to increased heat intensity encouraging complete fuel combustion. CO emissions are lowest at the usual injection timing. As indicated in Figure 3, it was discovered that CO emissions are lower at standard injection timing of 23^0 at full load and that advanced injection timing of 27° has reduced CO emissions by 0.3% compared to retard injection timing of 19°.

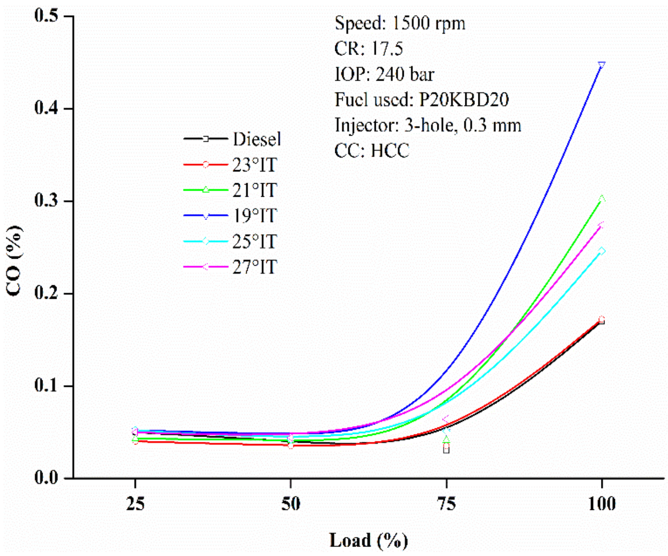


Fig. 3. Variation of CO emission against load

3.2.2 HC emission

Unburned hydrocarbon emissions are made up of unfinished fuel consumption. Strong hydrocarbons are crucial for the particulate matter; the name "hydrocarbon" denotes natural mixes in the vaporous state. Unburned fuel is a common issue with CI engines operating at light loads. Lean fuel-air blend areas may nevertheless manage to escape into the exhaust despite low loads decreasing the possibility of fuel penetration on surfaces due to poor fuel circulation, an excess of air, and cold exhaust temperatures. It is very likely that a shorter time results in more unburned hydrocarbons escaping the system. Since the fuel sample has more time to mix with the air and participate in combustion under partial load conditions, advanced timing results in lower HC emissions [5]. HC emission at 50% of load at 27°CA bTDC is found lesser by 0.6% compared to injection timing of 19^0. The variation of HC emissions is shown in Figure 4. Diesel fuel shows higher HC compared to waste plastic oil-biodiesel blend (P20KBD20) due to its incomplete combustion.

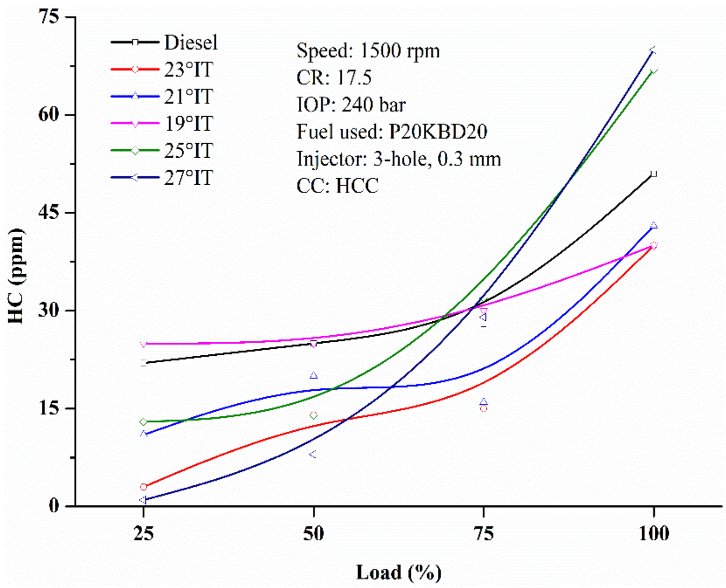


Fig. 4. Variation of HC emission against load

3.2.3 NOx emission

The decrease in NOx was observed for retarding injection timing for all loads as shown in Figure 5. When the timing of the fuel injection is delayed, the top pressure rise happens at a delayed crank angle. Delaying the injection time results in less fuel being accumulated at the beginning of combustion, which lowers the premixed ignition stage and lowers heat discharge. Lesser temperature results from lower pressure. Thus, NOx emission will be less [1]. With advancing injection timing results in peak pressure and temperature consequently NOx increases. Retarding injection time of 19°bTDC by 0.6% resulted in lower NOx emissions when compared to advanced injection timing of 27°bTDC at full load. Waste plastic oil-biodiesel blend (P20KBD20) shows higher NOx compared to Diesel fuel due to its improved combustion with higher in-cylinder pressure and higher heat release rate.

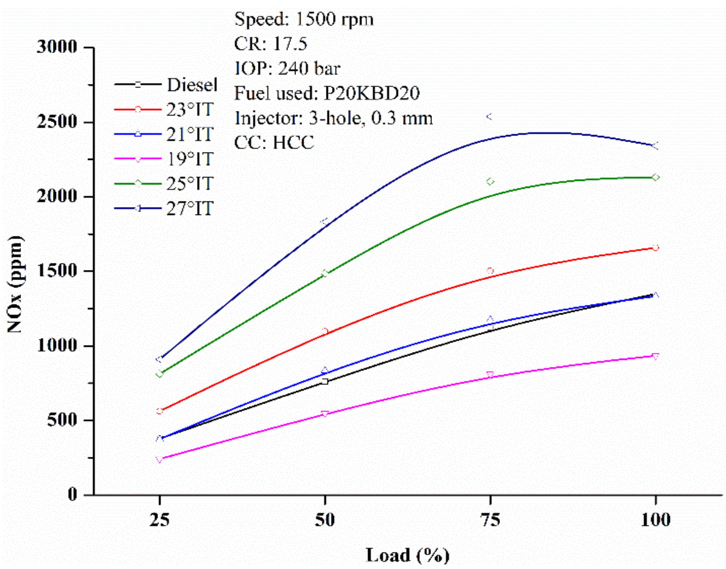


Fig. 5. Variation of NOx emission against load

3.2.4 Smoke emission

Smoke intensity is found to be less for diesel compared to P20KBD20 as shown in Figure 6 and for all injection timing the intensity of smoke found to be increased. At full load for IT of 25^0 has intensity of smoke less than diesel fuel at standard IT of 23^0 [1,16].

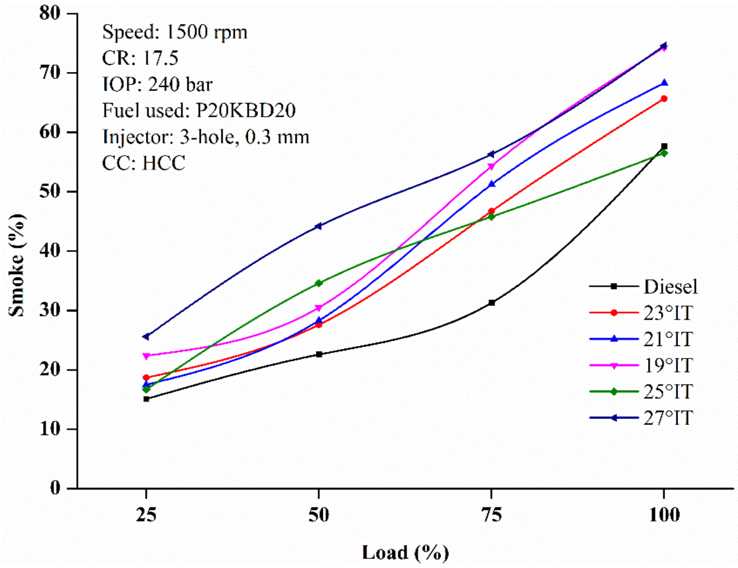


Fig. 6. Variation of smoke emission against load

Diesel fuel shows lower smoke emission compared to waste plastic oil-biodiesel blend (P20KBD20) due to its incomplete combustion. The mixture formation of P20KBD20 with air being non-uniform results into higher smoke compared to diesel fuel.

3.3 Combustion Analysis
3.3.1 Pressure crank angle diagram

Pressure Crank angle diagram: Fuel ability to burn when mixed with air determines the cylinder pressure. High pressure rises results from fuel combustion in the premixed phase as shown in Figure 7. Because the ignition delay is larger than the retarded injection time, the pressure for the mixture increases during standard injection timing. The amount of fuel contributing to the uncontrolled combustion phase affects the early stage of combustion, which determines how much pressure builds during combustion in CI engines [5,17,18]. It also depends on how the fuel is prepared for blending during the wait. The shorter the ignition delay, the more the pressure increases for waste plastic oil at all loads. Higher pressure is seen at injection timing 27^0 because the ignition delay shortens with advanced injection timing. The pressure recorded for 19^0 IT is 60 bar which is lower than standard injection timing. While advancing injection timing increased pressure in cylinder and found to be 79.25 bar at 27°bTDC.

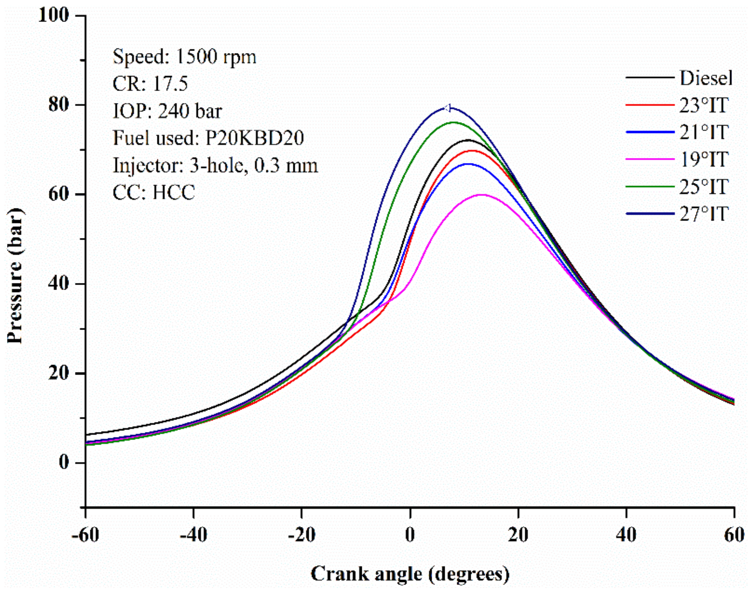


Fig. 7. Pressure crank angle diagram

3.3.2 Heat release rate

The beginning of the process, up until the start of the fuel-air combination planned during the delay period, is the initial phase. This phase lasts from that point until the intensity of the heat rate starts to fall. The next stage starts after the primary stage and continues to the end of ignition. While delaying the injection timing, the intensity heat rate is decreasing [6,17,18]. Additionally, it may be observed that normal timing with plastic oil produces the most heat discharge when compared to delayed injection timing. The advanced IT has higher heat release rate due to instant burning of fuel at 27°CA bTDC as shown in Figure 8. The amount of heat release recorded for retarding injection timing of 19°bTDC is 29.75 J/°C and is greater than standard injection timing due to which there is increase in efficiency.

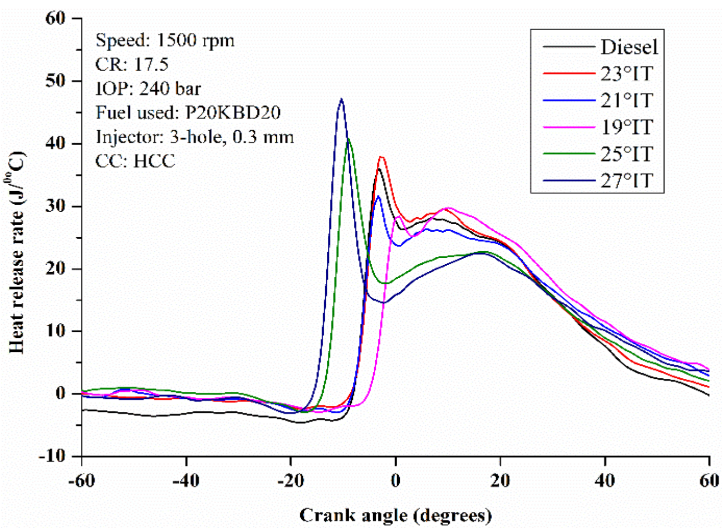


Fig. 8. Heat release rate

4. Conclusions

The injection time has a significant impact on how effectively a combination of biodiesel and plastic oil performs in an engine. Since burning of the fuel occurs close to the power stroke, it was discovered that retarding injection timing of 19° results in higher thermal efficiency of 33% when compared to conventional injection timing. Delay injection timing lowers NO emissions by reducing heat release and cylinder pressure. Advancement of timing causes higher cylinder pressure, a faster rate of heat release, and more NOx emissions because more fuel is ignited but before the working stroke, which results in an inferior thermal efficiency. As opposed to regular injection timing, CO_2 and HC emissions rise with delayed injection timing. According to the results of the investigation, the following conclusions were made

i. 21°BTDC injection timing produces better NOx emissions and performance.
ii. Brake thermal efficiency was found to be 33% at 19°bTDC which is equivalent to standard injection timing.
iii. When compared to more advanced injection timing of 27°bTDC, the NOx is found to be 0.6% lower at 19°bTDC.
iv. At maximum load, advanced injection timing emits less HC than retarded injection timing.
v. A maximum heat release obtained for advanced IT of 27^0 bTDC is 46.32 J/°C but it is before the commencement of working stoke which results in lower thermal efficiency.
vi. The lower heat release rate and pressure rise for retard injection timing results reduced NOx emission.

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