Production and Characterization of Catalytically Cracked Biofuel in DI Diesel Engine

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Abstract - *Biofuel, which is derived from triglycerides of vegetable oil by catalytic cracking, has the significant notice during the past decade as a renewable fuel, nontoxic and biodegradable. Several processes for biofuel fuel production have been developed, amongst which catalytic cracking gives high levels of conversion of triglycerides to their corresponding biofuel. In this paper, biofuel produced from Jatropha vegetable oil through catalytic cracking using zeolite as catalyst. The properties of Jatropha biofuel were analyzed using ASTM standard methods. From the tests it is clear that the, properties of Jatropha biofuel are similar to diesel fuel. The properties of biofuel also analyzed using FTIR analysis method. The diesel engine was tested using derived biofuel and its blends at constant speed of 1500 rpm. From the results, it was clear that brake thermal efficiency of the engine slightly reduced and emissions like HC, CO and smoke were increased when jatropha biofuel and its blends used as fuel.*

***Key Words*:** Catalytic cracking, Biofuel, Zeolite catalyst, Diesel engine, Characterization.

1. INTRODUCTION

The significant reduction in the petroleum fuels and consecutive raise in demand forced the humankind to find new alternatives which can fulfill the demand forecast and will be environmental friendly [1]. Many researches on environmental friendly and renewable fuel are growing rapidly and many scientists are paying special attention to cultivate it fast due to the inadequacy of fossil fuels and its harmful effect on nature [2-6]. Biofuels they are not only the best in nature but are easily existing fuels carried from renewable sources. In addition to their speedy growth, they are easy to cultivate and can make a higher yield of oil for biofuel production [7]. In a number of cases of biofuel production, a catalyst also presents. Depends on the quantity and quality of the feed, either transesterification or catalytic cracking reactions are used for biofuel production [8]. Usual feed stocks for biofuel production are soybean, jatropha, cottonseed, canola, sunflower, palm seed and mustard seed oil [9-12]. Waste oil and poultry fat also can be converted into biofuel [13]. Vegetable oils may have a high amount of free fatty acid content, which tends to soap formation that has adverse effects on downstream processing and leads to fall in yield [14]. Catalytic cracking process is proficient to crack the complex hydrocarbons to less complex structures [15]. The reaction is conducted at higher pressures and temperatures with the help of a catalyst, furthermore the quality and quantity of the biofuel is very nearer to that of diesel fuel, which is better to the oil produced by the trans-esterification method [16]. The most common catalysts used in catalytic cracking are aluminium, Zeolite and red-mud [17]. When heat is applied a quick chemical reaction takes place and the complex structure of triglycerides split into a simple structure, producing low viscosity and low density biofuel [18]. Figure 1 shows the scheme diagram of thermal cracking process and treated procedure.

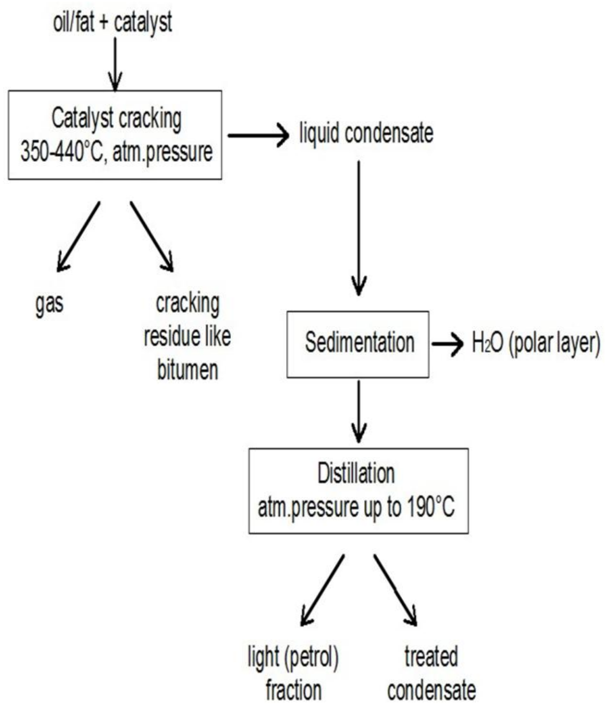

Figure 1 Scheme of thermal cracking process and treated procedure

In this research work the biofuel is produced from jatropha oil due to its high oil content and easy availability. Performance and emission characteristic on DI diesel engine were analyzed using catalytically cracked jatropha biofuel. In order to get the clear results, the biofuel is blended with diesel in different proportions like B25, B50, B75, B100, and is compared with conventional diesel fuel.

2. CATALYTIC CRACKING PROCESS

Catalytic cracking reactor consists of an oil inlet to pour raw jatropha oil mixed with the zeolite catalyst pallets, safety valve to safeguard the reactor, a pressure gauge to indicate the pressure inside the reactor and drain hole to remove the residue and waste. The experimental procedure of catalytic cracking reaction consisted of crude jatropha oil and the zeolite catalyst (30% by weight of the feed of oil). The crude jatropha oil was flowing through the pre-heater, in order to increase the temperature to 150°C. The sludge bed reactor is heated up to 400-500°C using heating coil. When the cracking reaction time reached 60 min, the reactor bottom temperature was 250°C and the temperature of the condensates at the inlet of the shell and tube heat exchanger is 90°C. The incessant formation of condensable gases at the catalytic reactor has been observed when the temperature at the bottom was 400°C and the temperature of the condensates at the inlet of the shell and tube heat exchanger was 100°C. The condensable gases from the reactor were collected and condensed through heat exchanger as biofuel. The thermo-physical characteristics of cracked biofuel were analyzed using ASTM standard methods and tabulated in Table 1.

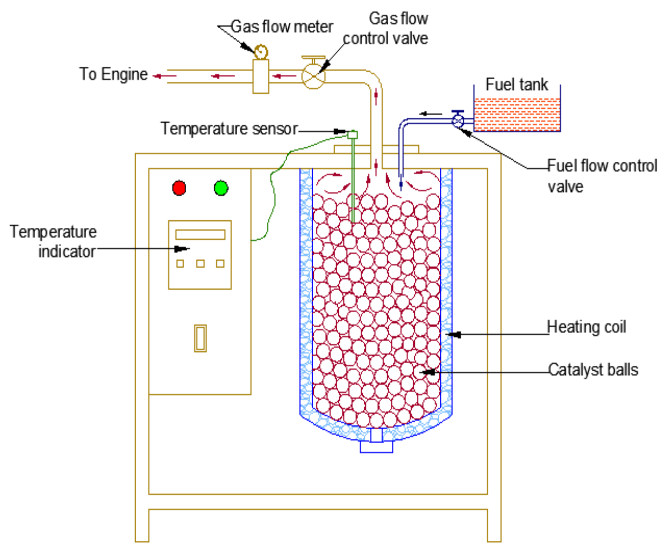

Figure 2 Schematic diagram of catalytic reactor

Table 1 Properties of diesel and cracked jatropha biofuel

Properties	**Diesel**	**Cracked jatropha biofuel**
Density (gm/cc), 30°C	0.836 – 0.850	0.9451
Kinematic viscosity (cSt)	4 – 8	43.64
Cetane No.	40 – 55	39.00
Flash point, °C	45 – 60	178.00
Calorific value, MJ/kg	42 – 46	38.80

2.1 Fourier Transform Infrared (FTIR) analysis

The functional groups and the bands corresponding to the various stretching and bending vibrations of neat diesel and cracked jatropha biofuel are identified by FTIR spectrum which is shown in figure 3 and 4. The spectrum of diesel and cracked biofuel is very similar since the two components have almost the same chemical groups; however, some differences are detachable. The FTIR spectrum of cracked Jatropha oil showed C=O stretching frequently, at 1744.37 and 1741.5cm^{-1} respectively. This is very intense and relatively free from interference. From the spectral data of FTIR, it is clearly identified that cracked jatropha biofuel contains a good quality and quantity of esters carboxylic acid and alkanes functional group and presence of hydrocarbon groups C-H indicating that the cracked liquids have a potential to be used as fuels.

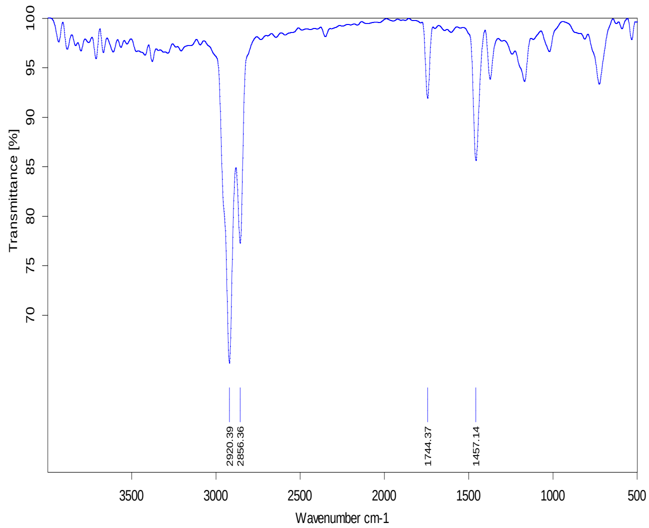

Figure 3 FTIR spectrum of diesel fuel

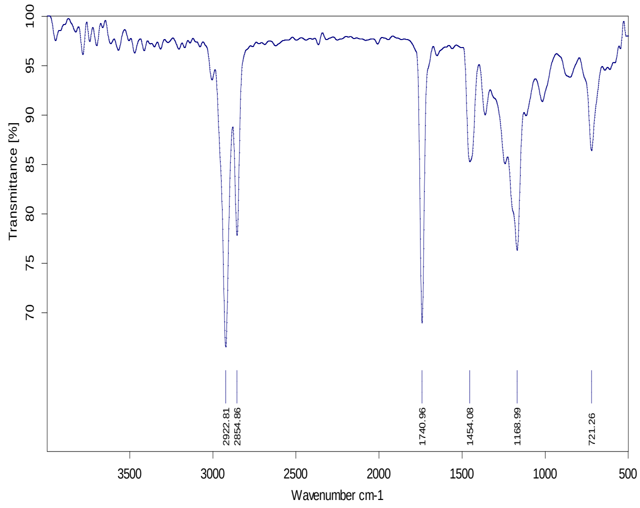

Figure 4 FTIR spectrum of catalytically cracked jatropha oil

3. EXPERIMENTAL SETUP

The diesel engine used for experimentation is Kirloskar TV1, single cylinder, water cooled engine coupled to eddy current dynamometer with computer interface. The detailed specification of the engine is shown in Table 2. A data acquisition system is used to collect and analyze the combustion data like in-cylinder pressure and heat release rate during the experiment by using AVL transducer. The tests are conducted at the rated speed of 1500 rpm. In every test, exhaust emission such as nitrogen oxides (NO_x), hydrocarbon (HC), carbon monoxide (CO) and smoke are measured. From the initial measurement, brake thermal efficiency (BTE) with respect to brake power (BP) for different blends was calculated. The blends of biofuel and diesel used were B20 and B40. B20 means 20 % biofuel fuel and 80% of diesel fuel by volume. In order to study the effect of biofuel blends on the engine combustion and emission characteristics, the injection timing was kept constant at 23° bTDC. The effect of biofuel blends was studied and results were compared with neat diesel. The schematic diagram of experimental setup is shown in Figure 5.

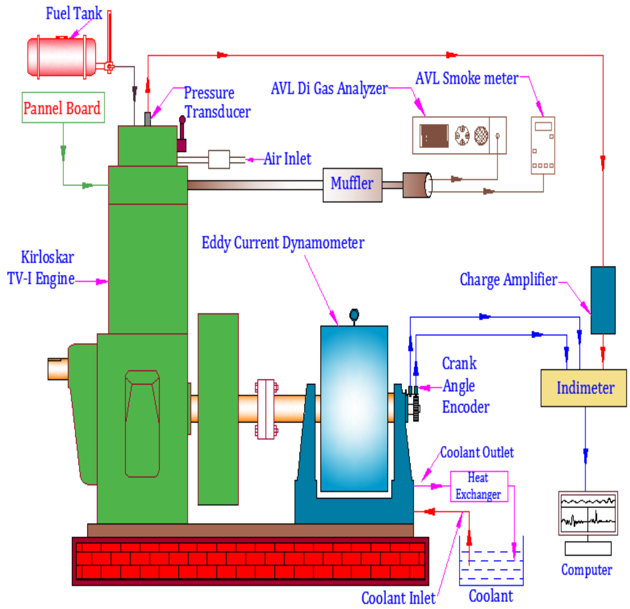

Figure 5 Schematic diagram of the experimental setup

Table 2 Specification of test engine

Make	:	Kirloskar TV – I
Type	:	Vertical cylinder, DI diesel engine
Number of cylinder	:	1
Bore X Stroke	:	87.5 mm X 110 mm
Compression ratio	:	17.5:1
Speed	:	1500 rpm
Rated brake power	:	5.2 kW
Cooling system	:	Water
Fuel	:	Diesel
Injection Pressure	:	220 bar
Ignition timing	:	23° before TDC
Ignition system	:	Compression Ignition

4. RESULT AND DISCUSSION

The operation of the diesel engine was found to be very smooth through the all load conditions, without any operational problems for the catalytically cracked jatropha biofuel blended diesel fuel. In the present section, CO, HC and smoke emissions are plotted against brake power and based on the combustion data, cylinder pressure and heat release rate are plotted against crank angle.

4.1 Engine Performance

Figure 6 shows the variations in brake thermal efficiency with respect to brake power. The Brake thermal efficiency (BTE) of neat diesel is more when compared with cracked jatropha biofuel blends and B25 fuel blend has lower brake thermal efficiency followed by B50, B75 and B100 respectively. It may be the higher viscosity of the catalytically cracked biofuel and its blends that leads to poor atomization and air-fuel mixture in combustion chamber. B25 has shown better results than other blends since it has lower viscosity when compared to other biofuel blends. The BTE of blend B25 shows an increase of 2.14% when compared to B100 at full load.

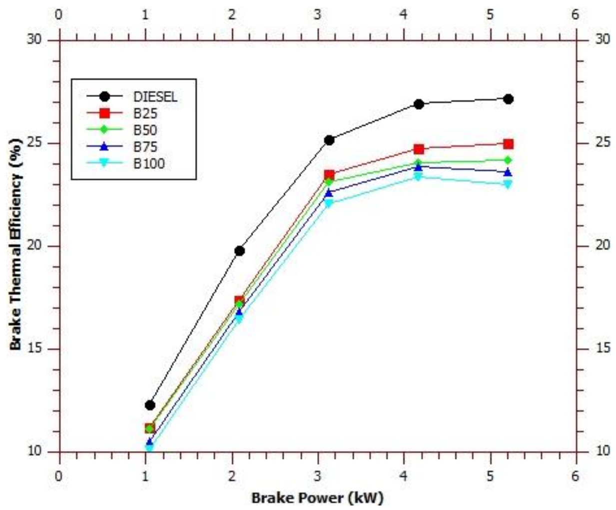

Figure 6 Brake thermal efficiency against brake power

4.2 Engine Emission

The variation of the NOx emission with respect to brake power is shown in Figure 7. NOx emissions mainly depend up on the combustion temperature and the heat release rate. At all load conditions, NOx emission of cracked jatropha biofuel blends is always minimum than that of standard diesel fuel due to the lower calorific value and cetane index. The longer ignition delay due to higher viscosity also could be reason of decreased NOx emission. The NOx emission for diesel fuel was 362ppm and where it was 330ppm in the case of B100.

It is observed from Figure 8 that as the load increases the HC emissions increases for all cases of cracked jatropha biofuel blends. Many authors' results show a significant increase in HC emissions when replacing diesel fuel with biodiesel [4-7]. The lower calorific value of cracked jatropha biofuel blends reduces the heat release rate and the reduction has been connected to increases in the HC emissions. From the figure, it is shown that the diesel fuel had the lowest HC emission at full load. There was an increase of 16.11% hydrocarbon emission for the cracked jatropha biofuel (B100) case.

The variation of CO emission with brake power is shown in Figures 9. From the figures it was observed that, CO emission was increased gradually with increase in brake power because of high viscosity and low heat content in comparison to that of diesel which may cause incomplete combustion. A lower cetane number of biofuel blends exhibits a longer ignition delay and allows longer combustion duration. The CO emission obtained at full load for diesel, B25, B50, B75 and B100 are 0.06, 0.09, 0.1, 0.11 and 0.12 % by volume respectively.

Smoke is one of the most hazardous problems with the engine; minimize this problem either by engine modification or by changing the fuel. Figure 10 shows that smoke density with different brake powers of catalytically cracked biofuel and its blends, and compared with diesel fuel. From the results it can seen that each brake power, smoke density is less in case of B25 due to complete combustion of fuel, which in turn due to lower flash point and higher cloud point. Smoke emission was 42HSU in the case of diesel fuel but it was 67HSU in the case of B100. Smoke emission found minimum of 51HSU in the case of B25 when compared with other biofuel blends.

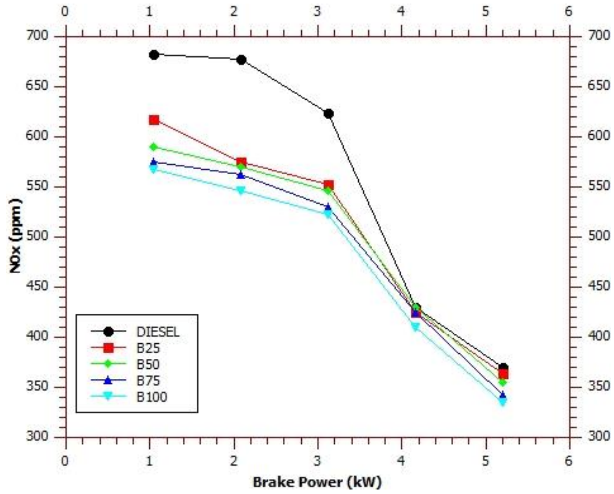

Figure 7 Oxides of nitrogen emission against brake power

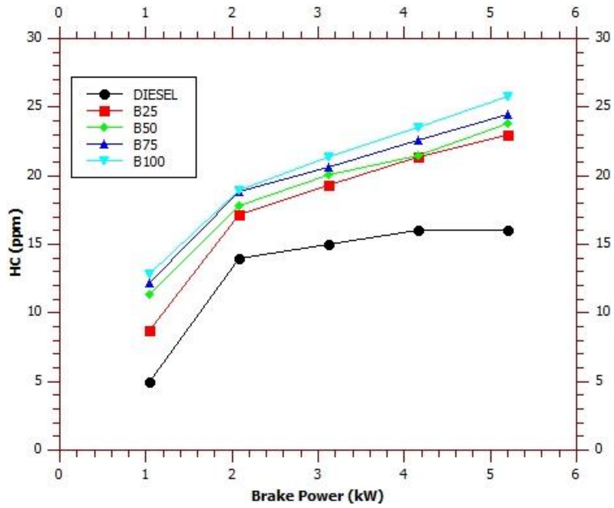

Figure 8 Hydrocarbon emission against brake power

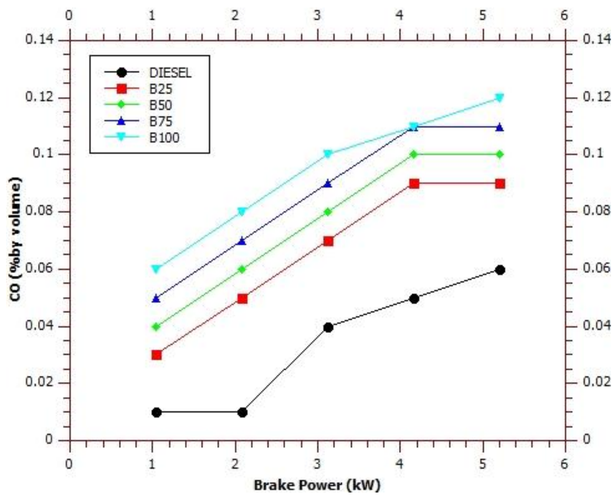

Figure 9 Carbon-monoxide emission against brake power

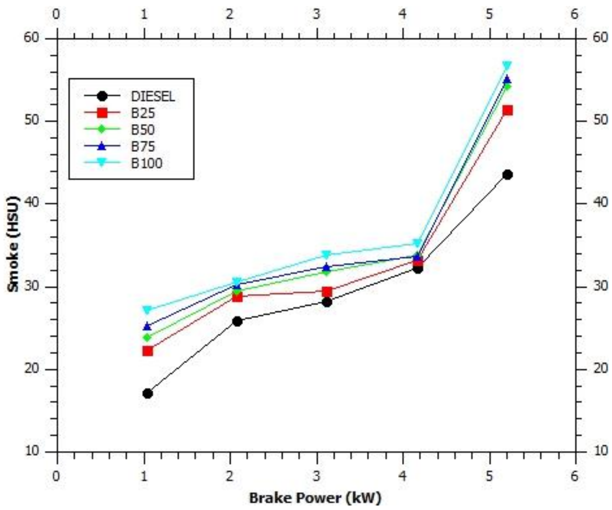

Figure 10 Smoke density against brake power

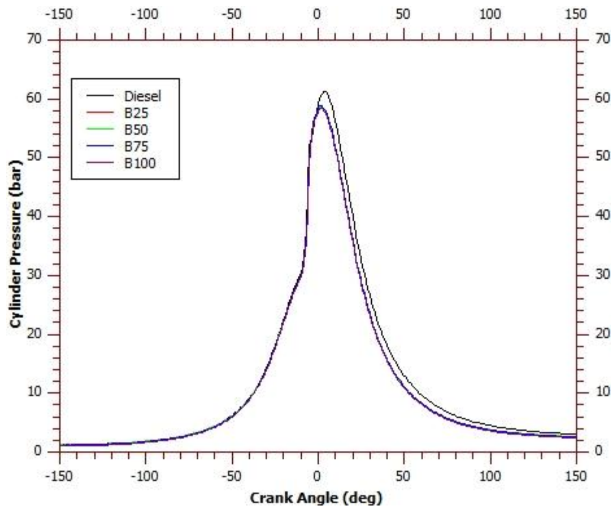

Figure 11 In-cylinder pressure against crank angle

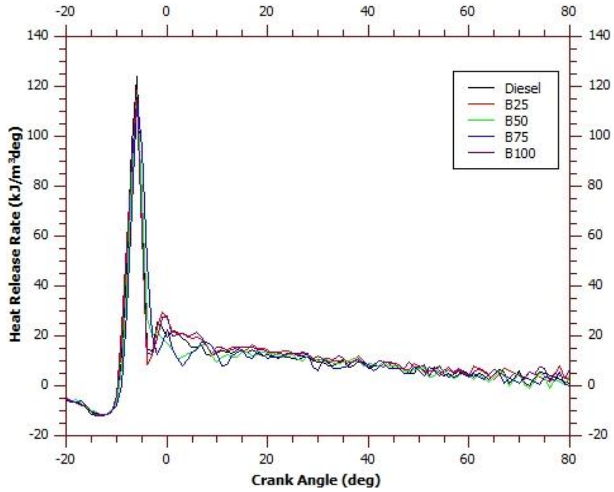

Figure 12 Heat release rate against crank angle

4.3 Engine Combustion

The increase in viscosity, particularly for the biofuel and its blends, results in poor atomisation of fuel, slower mixing and reduced cone angle. These phenomena results in a longer ignition delay during combustion. However, diesel has seen the opposite trend in the case of biofuel and their blends. The ignition quality of a fuel is usually characterised by its cetane number, and a higher cetane number generally results in a shorter ignition delay. The variation in cylinder pressure against crank angle is shown in Figure 11. From the figure it was clear that the in-cylinder pressure reduced with the increase in the percentage of biofuel with diesel fuel. B25 having the nearest value with diesel fuel compared with other biofuel blends. The maximum in cylinder pressure was found in the case of diesel fuel as 62.3bar and it was 61.7bar for B25 fuel blend. Figure 12 shows the heat release rate (HRR) during the combustion for different fuel blends. From the figure, it was found that the peak heat release rate for all biofuel blends were minimum when compared to diesel fuel. A longer ignition delay for the biofuel blends fuel allowed for more air/fuel preparation, which is ready to auto ignite and results a lower premixed peak.

5. CONCLUSIONS

The following conclusions are drawn based on this experimental investigation on diesel engine when catalytically cracked jatropha biofuel and its blends were used as fuel.

- An average of 3.86% BTE decrease was observed for 100% cracked jatropha biofuel. Viscosity, density, and cetane number of the cracked jatropha biofuel played vital role in engine performance.
- Hazardous emissions like HC, CO and smoke have been gradually decreased when using cracked jatropha biofuel.

- The NO_x emission is decreased by 2.15% to 14.1% for the addition of 25% to 100% cracked jatropha biofuel, respectively. Diesel fuel exhibited a moderate level of NOx emission.
- Lower in-cylinder pressure and lower heat release rate was found in all the cracked jatropha biofuel cases.

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