Effect of Fuel Injection Pressure on the Characteristics of Single Cylinder Diesel Engine Powered by Karanja-Biodiesel (KBD20) Fuel

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Abstract

Diesel engines are widely used due to higher efficiency and reliability as compared to petrol engines. However, losses associated with diesel engine required extensive study to minimize the losses by means of various passive means. The fuel injection pressure is one of the most important operating parameters effecting the characteristics of diesel engines. In this study, the effect of increase in fuel injection pressure was examined for test fuels diesel and karanja biodiesel blend(KBD20). The experimentation was conducted for single cylinder four stroke diesel engine at 23 °CA bTDC injection timing with constant engine speed of 1500 RPM. The experimentation was conducted for 200 bar, 225 bar and 250 bar fuel injection pressure. The test results indicated that diesel at 250 bar fuel injection pressure bar indicated slightly higher BTHE compared to Karanja diesel blend(KBD20) due to proper atomization of fuel and availability of oxygen for combustion at higher fuel injection pressure. As the BTHE increases brake specific fuel consumption decreased at higher loads. The higher in cylinder pressure and heat release rate was observed for KBD blend for increased fuel injection pressure of 250 bar. This is caused due to rapid burning of accumulated fuel due to longer combustion duration for KBD blend fuel. The KBD caused slight increased NOx emissions at 200 bar and 225 bar injection pressure due to lower cetane number of KBD fuel. The increase in fuel injection pressure increased NOx emissions. The test fuel diesel indicated decreased smoke opacity at all varying fuel injection pressure than KBD blend.

Keywords: *diesel engine, waste heat recovery, emission, exhaust gas recirculation*

1. Introduction

Internal combustion engines consumes large amount of fossil fuels and produce various exhaust emissions. The emissions cause environmental hazards and decrease the performance of the internal combustion engines. Many researchers studied thermodynamic analysis of internal combustion engine for improved engine performance and reduction in engine emissions. The fuel injection pressure is one of the most important operating parameters effecting the characteristics of diesel engines.The number of studies had been carried out on the effect of various biodiesel compositions and different fuel injection pressures on engine performance and emission

characteristics of engines to improve atomization of fuel and better performance of diesel engines.

The effects of different fuel Cetane numbers of 46, 51, 54.5 and 61.5 in four-cylinder diesel-engine for different injection pressures of 100, 150, 200 and 250 bar had been studied. It was reported that the NOx, and CO emissions were reduced about 15 and 5% respectively when the fuel's CN increased for the standard injection pressure of 150 bar . However, smoke value was increased as the injection pressure was reduced to 100 bar. In contrast with the lower pressure, $N0_2$ was increased and smoke decreased when the injection pressure was increased to 250 bar. When the CN was increased from 46 to 54.5, an increase in engine torque by 5% and power output by 4% were observed at the maximum torque speed of 2500 rpm while increasing CN above 54.5, there was no significant increase in the engine performance.[1] The effects of ethanol (10 and 15% in volume) and 1% isopropanol addition on the performance and emissions were investigated for a turbocharged indirect-injection diesel-engine with fuel injection pressures of 150, 200 and 250 bar without any engine modification . They reported reduction in CO and soot emissions caused approximately 12.5% (for 10% ethanol addition) and 20% (for 15% ethanol addition) power reduction along with an increase in NOx emission. Between 1500 and 2500 rpm of engine speed, The increase in the injection pressure and engine speed between 1500 and 2500 rpm reported decreased CO, smoke emissions and also power compared to diesel fuel.[2] .The effect of The effect of heated intake air by using exhaust heat and different percentage of EGR studied at normal fuel injection pressure for single cylinder diesel engine reported decreased specific fuel consumption for base diesel with and without heat exchanger. [3] The investigation carried out to find the effect of injection pressures of 215, 235 and 255 bar on the combustion process and exhaust emissions of a direct-injection diesel-engine fueled with 30% orange skin powder diesel solution . At 235 bar injection pressure with 30% solution, better thermal efficiency, higher NOx emissions, lower HC, smoke and CO emissions were observed compared to diesel fuel. They reported combustion, performance and emission characteristics of the engine operating on the test fuels at 235 bar injection pressure were observed better than other injection pressures.[4] A CFD model was developed to study the effect of injection timings of 16, 12 and 8 °CA bTDC and intake pressures such as 1.01, 1.21 and 1.71 bar with supercharged condition on the performance of the engine at 1000 rpm. Predicted performance and emission characteristics reveal that retarding the injection timing resulted in increase in-cylinder pressure and temperature, heat release along with NOx emissions. The shorter ignition delay showed lower peak heat release rate, maximum cumulative heat release, higher NOx with lower soot emissions.[5] The experimental tests were conducted with the use of untreated cotton seed oil in a single-cylinder, direct-injection diesel-engine to improve the combustion characteristics in an unmodified engine. The effect of increase in injection pressure was also studied. The injection pressure was increased from 180 bars to 240 bar. The investigation revealed that the optimum pressure for cottonseed oil was 210 bars. [6] The effect of pungamia methyl ester and their blends of PME10, PME20 with diesel was investigated in a direct-injection diesel-engine fueled with diesel It was

reported that the combined increase of compression ratio injection timing and injection pressure, increased the BTE and reduced BSFC and lower emissions for PME20.[7] Experiments were carried out using different compression ratios 17, 18, and 19, injection timings of 15, 20, and 25 Â°CA bTDC and injection pressures 18, 20 and 22 MPa at 20 Nm engine load and 2200 rpm. It was reported increased BSFC,BSEC, Nox and decreased brake thermal efficiency, smoke opacity, carbon-monoxide and hydrocarbon with increase in the amount of biodiesel in the fuel mixture. For the all tested fuels, an increase in injection pressure, injection timing and compression ratio decreased the CO and HC emissions with increase in NOx emissions. They reported best results for BSFC, BSEC and BTE were observed for the increased compression ratio, injection pressure and original injection timing.[8]

The effect of preheated air on engine characteristics of diesel engine reported improved performance and reduction in emissions due to preheating of air by waste heat recovery system [9] The investigation was carried out to find the effect of biodiesel prepared from sea lemon oil at different injection pressures of 170, 190, 210 and 230 bars on the performance of DI diesel-engine running at constant-speed . It was reported that smoke and unburnt hydrocarbon reduced with increase in injection pressure, while the brake thermal efficiency also increased.[10] The effect of fuel injection pressure was investigated on emission characteristics of a single-cylinder DI diesel-engine using pongamia pinnata methyl ester mixed with diesel fuel from 0-30% with an increment of 5% at different injection pressures of 190, 200, 210, 220 and 230 KPa . It was found that the pressure of 220 KPa caused better atomization with improved emission characteristics for diesel and blends. The blend B5 showed the best results at 220 KPa injection pressure.[11] Diestrol, prepared from a blend of 30% waste cooking palm oil methyl ester, 60% diesel and 10% ethanol based on stability test and investigated the effect of diestrol fuel on the performance and emission characteristics of a direct-injection diesel-engine at varying injection pressure and timing. Maximum brake thermal efficiency of 31.3% and reduction in carbon-monoxide, carbon-dioxide and smoke emission by 33, 6.3 and 25.3% respectively, were obtained at an injection pressure of 240 bar and injection timing of 25.5 °CA bTDC.[12] The experiments designed using a statistical tool known as Design of Experiments (DOE) based on Response Surface Methodology (RSM) and The investigated the effect of injection system parameters such as injection pressure, injection timing and nozzle-tip protrusion on the performance and emission characteristics of a twin-cylinder water-cooled naturally-aspirated CIDI engine fueled with pongamia oil, blended with diesel. The results depicted that the BSEC, CO, HC and smoke opacity were lesser, and BTE and NOx were higher at 2.5 mm nozzle-tip protrusion, 225 bar of injection pressure and at 30 Â°CA bTDC of injection timing. Optimization of injection system parameters was performed using the desirability approach of the response surface methodology.[13] The effect of advancing the injection timing and increasing the Injector Opening Pressure (lOP) to a maximum of 220 bar was investigated in the test engine and results reported reduction in BSFC and increased peak in cylinder pressure. [14] The influence of four different injection pressures of 18, 20, 22 and 24 MPa on the combustion and performance characteristics of a direct-injection

naturally-aspirated diesel-engine using canola oil methyl esters blended with diesel fuel was investigated and the test results reported higher brake specific fuel consumption and brake specific energy consumption for the biodiesel than that for diesel fuel while brake thermal efficiency was lower than that of diesel fuel.[15] The comparative study was made using diesel fuel, the rapeseed oil methyl ester and the soybean oil methyl ester in a four-cylinder diesel-engine based on the experimentation conducted for three different injection pressures such as 250, 300 and 350 bar. They reported that the performance and emission values of rapeseed oil and soybean oil methyl esters were found to be nearly the same with those of diesel fuels when the injection pressure was increased to 300 bar.[16] An experimental study conducted using the rapeseed oil blended with the diesel with increase in the injection pressure and injection timing of the engine and reported significant reduction in NOx emissions at the expense of CO, THC, smoke number, BSFC for blended biodiesel compared to that of diesel fuel.[17] A comparative analysis performed with rapeseed oil and its blends of 50, 30, 20 and 10% with diesel for different fuel injection pressures of 800 to 1200 bar and for different percentages of EGR of 0 to 20% in a multi-cylinder diesel-engine. The results were compared against diesel fuel at 1500 rpm, 800 bar of the injection pressure, 0% of the EGR and 9Â°CA bTDC of the injection timing. They reported decrease in soot emission and increased NOx emissions for with increased fuel injection pressure.The EGR and the injection timing had the potential of reducing the NOx at the expense of CO and UHC emissions.[18] The effect of fuel injection pressures (18, 20, 22, and 24 MPa) and mean effective pressure (12.5, 25, 35.5, and 50 kPa) investigated experimentally in a direct-injection diesel-engine fueled with biodiesel and diesel blends. There was an increase in the BSFC, carbon-dioxide, nitrogen oxides and oxygen emission and decrease in smoke opacity, unburnt hydrocarbon and carbon-monoxide emissions. But increase in injection pressure, decreased BSFC of high percentage biodiesel - diesel blends (B20, B50, and B100), smoke opacity, CO, UHC emissions and increased the emissions of C02, 02 and NOx. For diesel fuel and low percentage biodiesel diesel blends (B5), the increased or decreased injection pressure caused increase in BSFC values compared to original injection pressure.[19] The effects of mineral diesel and diesel-karanja biodiesel blends at injection pressures of 190, 200 and 210 bar were investigated. They reported improved performance of the engine for a biodiesel blend of 40% and an injection pressure of 200 bar.[20] The effects of castor methyl ester and its blends of CMEIO, CME20 and CME30 were investigated in a direct-injection diesel-engine fueled with diesel. It was reported that the combined increase of compression ratio, injection timing and injection pressure increased the BTHE and reduced SFC while having lower emissions for CME20.[21] The experiments were carried out to evaluate the performance of 3 different versions of LHR engines with mohr oil based biodiesel with varied injection pressures. It was reported that the peak brake thermal efficiency increased by 7%, brake specific energy consumption decreased by 3.5%, smoke levels decreased by 11% and NOx levels increased by 58% with LHR-3 engine with MOBD at an injection pressure of 190 bar when compared with pure-diesel operation at an injection pressure of 190 bar.[22] The study was conducted with an engine with 500 and 1000 bar of pressures and different injection timings at 2500 rpm. The results reported that increasing injection pressures

resulted increase in brake thermal efficiency with exhaust gas temperature and brake mean effective pressure. They also reported that Carbon-dioxide and hydrocarbon emissions decreased and nitrogen-oxide emissions increased with increasing injection pressures and advanced injection timings.[23] Researchers compared the performance and emission for different values of compression ratios and fuel injection pressures to find the best possible combinations of engine design parameters. They reported increase in BTE and reduction in BSFC were achieved with lower emissions. It was also reported that the CR of 18 with IP of 250 bar yielded the optimum combination in small-sized DI constant-speed engine, which is used for agricultural purpose.[24] Investigation was carried out on the effect of two different injection pressures 50 and 100 MPa on combustion and emission characteristics under near-stoichiometric conditions in a single-cylinder applied diesel-engine . The EGR rate was changed keeping the amount of fuel constant to control the equivalence ratio. It was reported that at high injection pressure (100 MPa), operating range of injection timing was extended by which extremely low NOx emission and significant increase of soot emission was achieved. The results also reported that as equivalence ratio was increased at near TDC injection, the mean effective pressure (IMEP) gradually decreased.[25] The effect of producer gas on dual fuel mode was studied using honge, neem and rice brain oils at different injection timings and injection pressures. The producer gas has higher cetane number 100 to 105 and higher calorific value of 5 to 6 MJ/Nm3 . They reported decrease in Nox and smoke and increased CO emissions. [26] The effect of butanol-diesel fuel blend and the impact of fuel injection pressure on combustion, engine performance and exhaust emission of a single cylinder diesel engine was observed . The test results reported butanol-diesel blend (Bu10) earlier injection and had a longer ignition duration than diesel fuel when fuel injection pressure was increased. It was also observed that ignition delay and combustion duration decreased with increased in injection pressure. It was also reported increased brake thermal efficiency and decreased brake specific fuel consumption when fuel injection pressure decreased.[27] The experimental investigations was conducted on evaporating sprays of diesel, tetradecane (as a diesel surrogate) and methyl oleate (as a biodiesel surrogate) fuels with varying injection pressure and ambient density. Experiments were conducted in a rapid compression and expansion machine (RCEM) working under diesel engine-like conditions. It was reported that high injection pressure causes the least reduction in spray cone angle for biodiesel .The results reported increase of vapor penetration by up to 33.2%, 21.5% and 24.4% for diesel, tetradecane and methyl oleate, respectively for varied injection pressure from 50 MPa to 150 MPa.[28] The effect of injection pressure on the biodiesel preapared from waste cooing oil in the blend of 20% cooking oil and 80% mineral diesel experimentally investigated at 180 bar, 210 bar and 240 bar fuel injection pressures and with addition of cerium oxide nanoparticle concentration of 80 ppm.The improved combustion was observed for higher injection pressure associated with addition on nano particles which resulted into higher peak pressure and higher heat release rate. They reported optimum performance at injection pressure of 240 bar with a 80 ppm nanoparticle concentration .It also reported reduction in HC, NOX and smoke at higher injection pressures with addition of nanoparticles.[29] The experimental study was conducted to find the effect of 25% of

Pumpkin seed oil methyl ester on Kirloskar make TV1 model single cylinder four stroke direct injection diesel engine with standard compression ratio: 17.5:1, Injection timing: 21Â° bTDC and injection pressure: 210 bar to determine performance, combustion and emission characteristics.The results reported higher performance characteristics with high CR (19.5:1), IP (250 bar) and IT (25 °*CA bTDC*) operating conditions. It was reported significant reduction in CO.HC, and smoke except at higher operating conditions. [30] The experimental investigation conducted to study the effect of effects of injection pressure (IP) and exhaust gas recirculation (EGR) ratio on the combustion and emission of diesel/NG dual-fuel engines. They reported increase in indicated thermal efficiency and observed rapid flame propagation of methane when there was increase in the injection pressure . They also reported when when the EGR rate was less than 10% then CO and CH4 were non sensitive whereas when EGR rate increased beyond 30% then CO and CH4 emissions can be significantly reduced by increasing the injection pressure IP. Accordingly, when the injection pressure is 160 MPa and the EGR rate was 20%, then diesel/NG DF engine can achieve higher ITE and lower emissions.[31] The effect of 15% propanol-85% diesel blend (Pro15) varying injection pressure (190, 210, and 230 bar) for two engine loads (brake mean effective pressure (BMEP) of 2 bar and 4 bar) at two engine speeds (1800 rpm and 2400 rpm) studied to determine performance, emission and combustion characteristics of a single-cylinder diesel engine . Their results reported increased ignition delay at high injection pressure for blend Pro15. Also it was reported shorter combustion duration of Pro15 compared to conventional diesel fuel. It was seen slight reduction in combustion duration with increasing the injection pressure. The lowest brake specific fuel was observed at low injection pressure for both engine loads at 2400 rpm.[32]

In the present investigation the effect fuel injection pressures 200 bar, 225 bar and 250 bar examined on a single cylinder four stroke diesel engine at 23 ºCA start of injection timing with constant engine speed of 1500 RPM for test fuels diesel and karanja diesel blend(KBD20) to study its effects on engine characteristics.

Nomenclature

bTDC	before top dead centre
BTHE	Brake thermal efficiency
BSFC	Brake specific fuel consumption
°CA	Degree Crank Angle
D	Diesel
KBD	Karanja biodiesel
NOx	Nitrides of oxygen

2. Experimental details

The measurements reported in this paper were performed on a stationary single cylinder, four stroke, constant speed , water cooled, naturally aspirated, DI (open chamber), diesel engine. It is designed for operating with diesel fuel with a conventional fuel injection system and loaded with an eddy current -type dynamometer. The karanja biodiesel was prepared by transesterification process using karnja oil. The Optimization of CI Engine parameters for Karanja oil methyl ester (KOME) biodiesel was done experimentally by conducting series of tests on experimental set-up and decided to use 20% by volume karanja diesel blend for experimentation. The basic engine setup is shown in figure 1 .The design details of the diesel engine are given in table 1. The basic engine provided with 23 $^{\circ}$CA bTDC SOI(Start of injection timing) , 200 bar IOP(Injection opening pressure), 3 holes nozzle injector with nozzle diameter φ = 0.3 mm size, EGR rate 0%, load variation 3 kg to 12 kg in step of 3 kg. The cooling of the engine is accomplished by circulating water through the jackets of the engine block and cylinder head. Piezoelectric transducer used for in cylinder pressure measurement. The signals are interfaced with computer with engine indicator for pressure-crank angle, pressure-volume and engine indicated power plots. The liquid fuels are supplied from fuel tank under gravity feed to fuel injection pump. The intake air is passed through air box and the air flow is monitored by air box with orifice meter and manometer. The software is fully configured for various engine performance plots at different operating points. All tests were conducted and parameters were measured under steady state operation. Injector pressure setting instrument was used to set pressure of various nozzle hole injectors.The pressure setting device is as shown in figure 2.

Table 1 Specifications of diesel engine

Title	Description
Product	Computerized single cylinder four stroke VCR Engine test setup
Engine make	Kirloskar make
Engine type	Single cylinder , 4 stroke constant speed engine diesel engine
Dynamometer	Eddy current water cooled with loading unit
Power	3.5 Kw at 1500 rpm
Stroke	110 mm
Bore	87.5 mm
Compression ratio	18
Data acquisition device	NI USB-6210, 16-bit, 250kS/s.

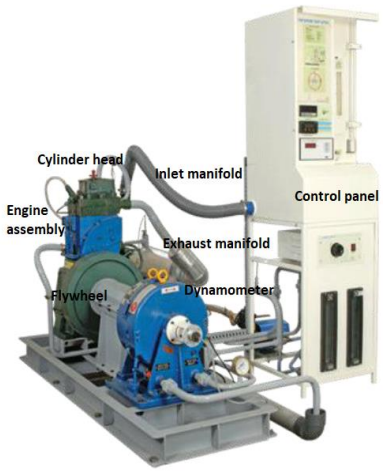


Figure 1: Basic experimental setup

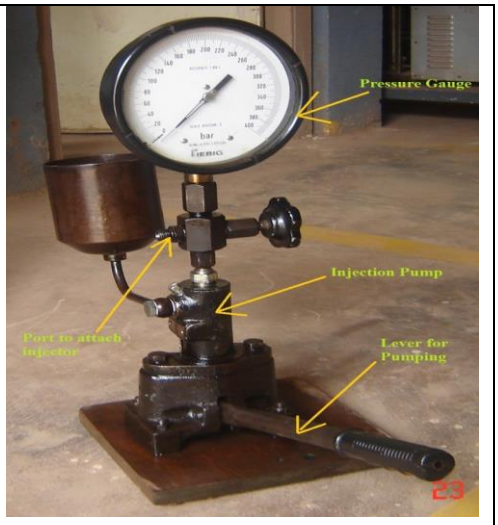


Figure 2 Pressure setting device

3. Results and discussion

The present experimentation was carried out on a single cylinder diesel engine running at constant speed for 200 bar, 225 bar and 250 bar fuel injection pressure at 23 ºCA bTDC injection timing. All tests were conducted and parameters were measured under steady state operation. The results obtained through experimentation are analyzed and presented in this section.

3.1 Brake Thermal Efficiency

The brake thermal efficiency is the measure of conversion of heat released during combustion to net work output. The variation of the BTHE for different injection pressures at constant engine speed is shown in figure 3. The brake thermal efficiency was increased from 12.9 % to 27.32% at low load to full load for test mode of diesel D200 bar. There was no significant effect of increased fuel injection pressure from 200

bar to 225 bar and the variation of BTHE was from 14.89 % to 27.29% at low load to full load for test mode of diesel D 225 bar 225 bar. It was observed that further increased fuel injection pressure from 225 bar to 250 bar effected into reduced BTHE to 25.61% at full load for D250 bar. It was observed that D250 bar indicated slightly higher BTHE compared to KBD20 due to proper atomization of fuel and availability of oxygen for combustion at higher fuel injection pressure.

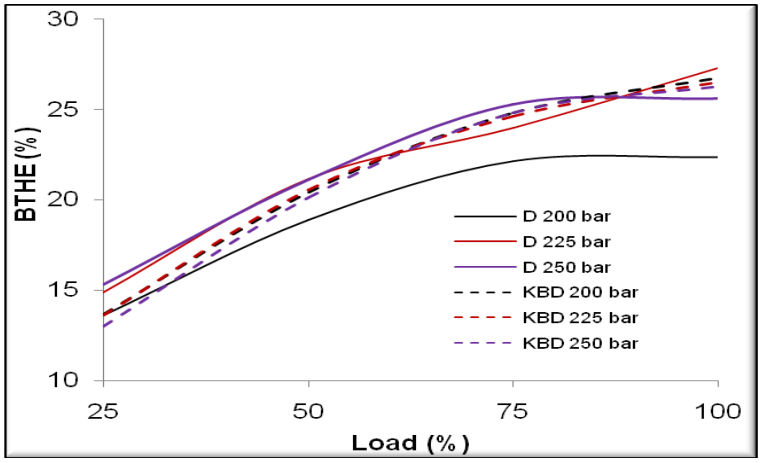


Figure 3: Variation of brake thermal efficiency w.r.t load

3.2 Brake specific fuel consumptions (BSFC)

The specific fuel consumption is derived directly from the mass of fuel consumed in the presence of oxygen and release the heat. This heat released during combustion is converted into power. The change of BSFC is shown in figure 4. It is observed that the trend of decrease in BSFC with load is observed for all the test modes of diesel and KBD20. The test mode of Diesel D 200 bar has shown maximum BSFC of 0.66 kg/kwhr at low load and when the load gradually increased, the BSFC decreased to 0.31 kg/kwhr at full load. It was observed slight increased BSFC for B250 bar at low load compared to other test modes of diesel and KBD . The slight increase in BSFC at low load seems to be due to rich fuel operation as compared to part load onwards to full load. It could be due to less availability of fresh air for dense and viscous fuel atomization of karanja biodiesel(KBD 20%). It was also observed increased BSFC for increased injection pressure to 250 bar for D250 bar at full load as compared to both test fuels.

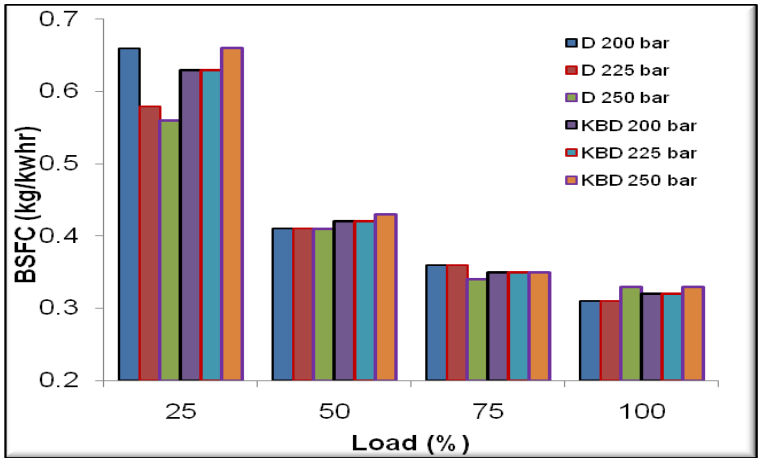


Figure 4 Comparison of brake specific fuel consumption w.r.t load

3.3 Nitrides of Oxygen

The fixation of NOx generally takes place at higher temperature and advanced injection timings. The variation of Nitric oxides (NOx) w.r.t load is shown in figure 5 for varying injection pressure at constant speed for diesel and KBD20. The results indicated that KBD caused slight increased NOx emissions due to availability of oxygen and lower cetane number of karanja biodiesel at 200 bar and 225 bar fuel injection pressure.

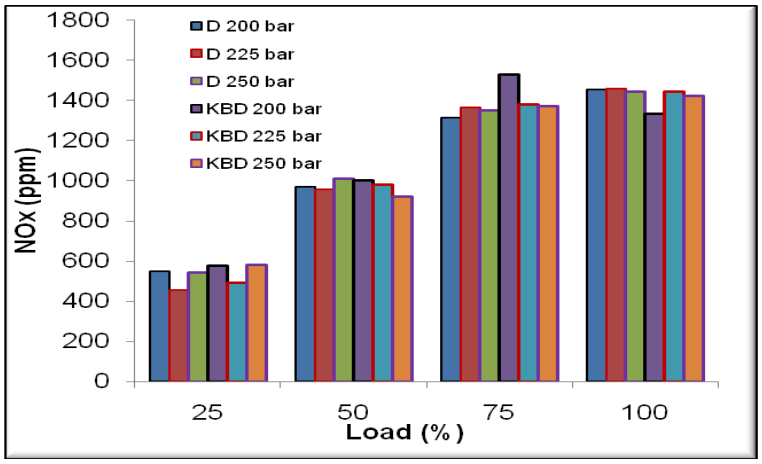


Figure 5 Variation of NOx w.r.t load

3.4 Smoke Opacity(%)

Solid particulates are formed in diesel engine and are seen as black smoke in the exhaust of these engines due to less oxygen availability of oxygen in the cylinder. It is seen from the figure 6 that KBD caused higher smoke opacity than diesel at increased fuel injection pressure due to less oxygen content. The test fuel diesel indicated decreased smoke opacity at all varying fuel injection pressure than KBD due to availability of oxygen and higher combustion temperature in the cylinder.

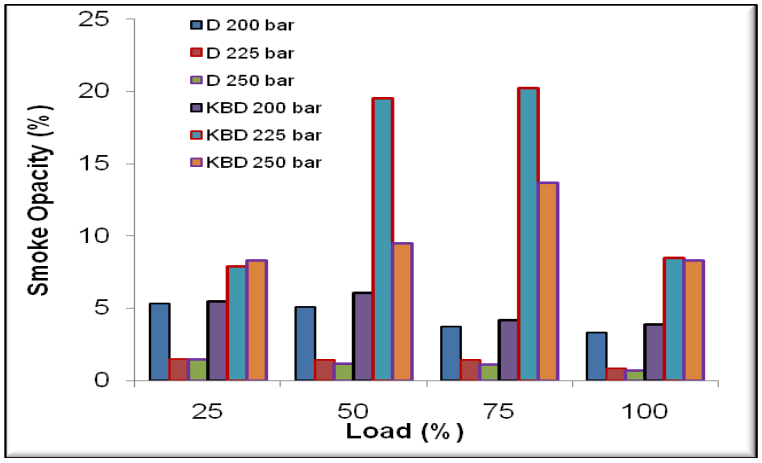


Figure 6 Variation of opacity w.r.t load

3.5 In-cylinder pressure

The power output, combustion and emission characteristics of engine largely depend on in-cylinder pressure- crank angle history. The in cylinder pressure development is solely depends upon the quality of fuel burned during premixed combustion phase. It is proper mixing and burning ability of fuel. The variation of in-cylinder pressure at different fuel injection pressure for diesel and KBD test fuels is shown in figure7. The cylinder pressure traces were found to be similar to that of base diesel mode when for all the configurations of tested fuels. It was observed that the KBD blend caused peak in cylinder pressure with increase in fuel injection pressure than diesel.This could be due to higher oxygen content of KBD blend fuel and higher heat release rate caused higher injection temperature.

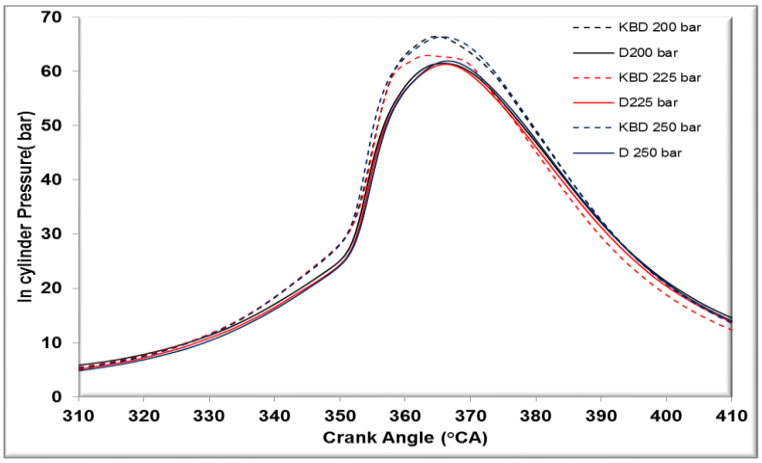


Figure 7 Variation of in-cylinder pressure vs crank angle for the test fuels

3.6 Net heat release rate

Heat release rate is one of the important tool to optimize the engine parameters. The comparison of net heat release rate for different fuel injection pressures at constant speed is shown in figure 8 for test fuels diesel and KBD20.The combustion process in engines is monitored by the rate of heat release as determined from the cylinder pressure. The HRR correlation based on first law of thermodynamics with respect to crank angle is used for determination of HRR.

It is seen from the figure that net heat release rate is maximum for KBD as compared to diesel blend for almost all fuel injection pressures. The maximum NHRR was 55.78

J/CA at 352 CA for KBD blend at 250 bar fuel injection pressure. This is caused due availability of higher pressure and temperature for combustion as oxygen content in KBD blend is higher and also higher combustion duration for KBD test fuel than diesel fuel.

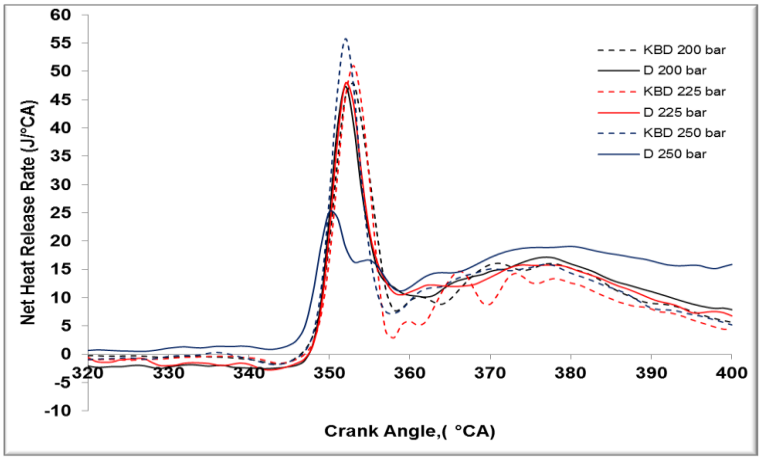


Figure 8 Variation of net heat release rate vs crank angle for the test fuels

4 . Conclusions

The experimentation with increased fuel injection pressure noticed the following observations.

1. There was caused slightly increased BTHE for test fuel diesel at 250 bar fuel injection pressure due to proper atomization and smooth combustion of fuel.
2. Decrease in BSFC was caused at higher injection pressure due to increased BTHE.
3. The higher in cylinder pressure and heat release rate was observed for KBD blend for increased fuel injection pressure of 250 bar.
4. The KBD caused slight increased NOx emissions at 200 bar and 225 bar injection pressure due to lower cetane number of KBD fuel. The increase in fuel injection pressure increased NOx emissions.
5. The test fuel diesel indicated decreased smoke opacity at all varying fuel injection pressure than KBD blend.

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