Experimental investigation on effect of injection timing in multiple injection on NOx and smoke from CRDI diesel engine fuelled with biodiesel blend

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Abstract

Diesel engines with their high thermal efficiency and fuel economy are very much successful in commercial applications compared to their counterpart gasoline engines. The emissions like HC and CO from diesel engines are less compared to gasoline engines because they run mostly with lean mixtures. But due to heterogeneous combustion NOx and smoke emissions from Diesel engines is high. Due to contradicting requirements for the reduction of NOx and smoke, the tradeoff between NOx and smoke emission without compromising fuel economy is a big challenge being faced by automotive industries and researchers in the field. Biodiesel produced from non-edible feed stock is found to be a good alternative to petro diesel. Cotton seed oil biodiesel is produced using transesterification process and characterized for its properties. The blend B20, which is most accepted and does not need any modifications of the engine, is used as fuel. It is observed that the formation of NOx is very much dependent on the peak temperature in the combustion chamber. Various types of techniques are being tried by the researchers to reduce high NOx emission from usage of biodiesel blended fuel in diesel engines. The techniques used are like dilution using EGR, injection of water, retardation of injection timing etc. With the development of CRDI systems split and multiple injection strategy attracting the attention of researchers as a promising technique in reducing the NOx emissions. In this work an attempt is made to study the effect of retardation of injection timing of a selected multiple injection with pilot-main-post strategy. The selected strategy is with 10% pilot fuel quantity with a dwell of 10 CAD and closely coupled fixed quantity of 0.5 mg post injection with 3 CAD after main injection. The main injection timing along with pilot and post was retarded from the recommended 23° bTDC in steps of 3 degrees. It is observed that the combination of multiple injection and retardation of injection reduced NOx emissions effectively without compromising power output and thermal efficieny.

Keywords: *Biodiesel blend, Emission, Pilot injection, Post injection, Transesterification*

1. Introduction

Recently, the extinction issue of fossil fuel due to continuous usage become the focus attention for all of people in the world who depend on this energy source in every of their activity. The people attention is also increasingly focused on fossil fuel due to the fact that continuous usage of this fuel believed causes environmental problem i.e. air pollution and global warming. Fossil fuels reservoirs around the world are declining due to their non-renewable nature. At the same time the demand for energy is, continuously, increasing to meet the needs of the world population, which is growing significantly. Global warming is being caused by the greenhouse gas emissions. Reducing the dependence on fossil fuels will be beneficial, from environmental point of view, since this will reduce the concentration of carbon dioxide in the atmosphere. Hence, currently the world has been tried to look for a solution by exploring and using an alternative fuel which is renewable, environmental friendly, sustainable availability and economically feasible sources of energy have emerged as a priority for research to resolve all these problems (Putrasar et al., 2013).

Therefore, explorations to find Biodiesel are one of the most promising alternative fuels to replace or to reduce dependency on the conventional petroleum-based fuels with multiple environmental advantages and application in compression ignition (CI) engines with no modification. Biodiesel is nonexclusive, biodegradable, non flammable, renewable, nontoxic, environment friendly, and similar to diesel fuel (Atabani et al., 2013).The main advantages of biodiesel include the following: it can be blended with diesel fuel at any proportion; it can be used in a CI engine with no modification; it does not contain any harmful substances; and it produces less harmful emissions to the environment than diesel fuel. Biodiesel, popularized as the mono alkyl esters are derived from triglycerides (vegetable oils or animal fats).Transesterification is the most convenient process to convert triglycerides to biodiesel. Transesterification process involves a reaction of the triglyceride feedstock with light alcohol in the presence of a catalyst to yield a mixture of mono alkyl esters currently, using hydroxides of sodium or potassium, is the common route for industrial production of biodiesel (Pushparaj et al., 2013).

The minimization of fuel consumption and the reduction of emissions have been two driving forces for engine development throughout the last decades. The first objective is in the financial interest of the vehicle owners. The second is imposed by legislation, sometimes also supported by excise reductions or customers' demands for clean engines.

The ongoing emission of NOx is a serious persistent environmental problem due to; it plays an important role in the atmospheric ozone destruction and global warming (Busca et al., 1998). NOx is one of the most important precursors to the photochemical smog.

Component of smog irritate eyes and throat, stir up asthmatic attacks, decrease visibility and damages plants and materials as well. By dissolving with water vapor NOx form acid rain which has direct and indirect effects both on human and plants. An SCR (Selective Catalytic Reduction) exhaust gas after treatment system which uses urea solution as a reducing agent has a high NOx reduction potential and is a well-known technique for stationary applications (Bosch et al., 1988). The idea of using urea SCR systems for the reduction of NOx emissions in diesel engines is two decades old. Since then, many applications have been developed, some of which have reached commercialization (Perry et al., 2013). But, it is still a challenge for researchers.

With the recent development of common rail direct injection system, it became possible to reduce NOx and other emissions by adopting multiple injection strategy (Imarisio et al., 2000; Badami et al., 2002).

Split fuel injection involves reducing splitting the injection as two or more events which can lead to a reduction in the ignition delay in the initial fuel pulse. This leads greater fraction of combustion to occur later in the expansion stroke. As majority of NOx occurs during premixed stage, the net amount of NOx formed during the split fuel injection is lowered (Gao et al., 2001). Multiple injections method is found to be very effective at reducing particulate emissions at high load, and combined technique of multiple injections with EGR is effective at intermediate and light loads. However, increased particulate emissions due to EGR causes increased engine wear due to degradation of lubricant. Increased Brake Specific Fuel Consumption (BSFC) is another concern. Split injection up to 5 splits, are experimented in combination with EGR (Wang et al., 2007). The injection timing of 35° bTDC leads to insufficient combustion causing increase in the level of HC. Fuel consumption increases with early injection due to insufficient combustion in the initial combustion duration. Introduction of pilot injection reduces the flame temperature reducing the amount of NOx emission. When the quantity of pilot injection is increased the level of noise reduces (Syed et al., 2015). Effects of start of pilot injection, start of main injection and fuel injection pressure on engine performance, emissions and combustion characteristics of Karanja biodiesel blends compared to mineral diesel were investigated at 1500 rpm in a single cylinder CRDI engine. BSFC of test fuels increased with increasing concentration of Karanja biodiesel. Lower Karanja biodiesel blends showed lower brake specific CO and HC emissions in comparison to mineral diesel but BSHC emissions of KOME50 were higher than mineral diesel at some operating conditions. Brake specific NOx emissions from KOME20 and KOME10 were higher than mineral diesel. At different SOPI timings and fixed SOMI timing, BSNOx emissions were almost similar for all test fuels. BSNOx emissions were higher for 1000 bar FIP in comparison to 500 bar FIP. Combustion duration of KOME50 was higher than mineral diesel due to relatively inferior mixing characteristics and requirement of larger fuel quantity. This experimental investigation shows that utilization of 10% or 20% Karanja biodiesel blends in CRDI engines with pilot injection can be useful in improving engine efficiency and reducing emissions (AtulDhar et al., 2015).

For solving the problems like depletion of fossil fuels and environmental degradation, biodiesel usage in diesel engines is widely investigated. The performance of cotton seed oil biodiesel is investigated on a single cylinder CIDI engine at a constant speed of 1500 rpm and field compression ratio 0f 17.5 at different load conditions. The performance, combustion and emission parameters are measured and compared with baseline results of diesel fuel. The brake thermal efficiency of cotton seed oil methyl ester (CSOME) was lower than that of petro diesel and brake specific fuel consumption was found to be higher. However, biodiesel resulted in the reduction of carbon dioxide, un-burnt hydrocarbon, and smoke opacity at the expense of nitrogen oxides. Carbon monoxide emissions for biodiesel was higher at maximum output power. It has been found that the combustion characteristics of cotton seed oil methyl ester closely followed those of standard petro diesel. The experimental results suggested that biodiesel derived from cotton seed oil could be used as a good substitute to petro diesel fuel in a conventional diesel without any modification (Rao et al., 2014). In this work B20 was used as fuel, since B20 is mostly accepted and does not need in modifications of the engine.

2. Methodology

This work is done with the main objective of investigating the effect of multiple injection strategy with varying injection timing and dwell period on harmful emissions from CRDI diesel engine fueled with biodiesel blend. Cotton seed oil is used for the preparation of biodiesel. Biodiesel is prepared using transesterification process.

A novel scheme of experiments is adopted in the work to understand the influence of multiple injections by varying different parameters on the emissions from the engine.

The used injection strategy is pilot (pre)-main-post. The pilot is fixed at 10% and post fuel quantity is fixed as 0.5mg/cycle.

The following were the steps followed in this work:

- Extraction of oil from cotton seeds using mechanical press
- Preparation of biodiesel using tranesterification process
- Characterization of biodiesel
- Preparation of B20 blend
- Testing the performance of CRDI diesel engine with B20 with multiple injection strategy varying injection timing
- Comparing the emissions from multiple injection and single injection.

Engine setup

The setup consists of single cylinder, four stroke, CRDI VCR (Variable Compression Ratio) engine connected to eddy current dynamometer. Specification of the CRDI Engine is given in Table 1. It is provided with necessary instruments for combustion pressure, crank angle, airflow, fuel flow, temperatures and load measurements. These signals are interfaced to computer through high speed data acquisition device.

The setup has stand-alone panel box consisting of air box, twin fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and piezo powering unit.

Rotameter are provided for engine cooling water flow measurement. CRDI VCR engine works with programmable Open ECU for Diesel injection, fuel injector, common rail with rail pressure sensor and pressure regulating valve, crank position sensor, fuel pump and wiring harness.

The setup enables study of CRDI VCR engine performance with programmable ECU at different compression ratios and with different EGR. Engine performance study includes brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, Air fuel ratio, heat balance and combustion analysis. NOx is measured using AVL Digas 444N exhaust gas analyser and Smoke is measured using AVL 437C Smoke meter.

A novel scheme of experiments is adopted in the work to understand the influence of multiple injections by varying different parameters on the emissions from the engine. The injection is split into pilot (pre)-main-post. After different trials the quantity of Pilot injection is fixed as 10% and post fuel quantity is fixed as 0.5 mg/cycle. The dwell between main and pilot is maintained as 10 degrees. Closely coupled post injection is used with 3 degrees after main injection. Main injection timing is retarded from recommended injection timing of 23^o to 11^o bTDC. The influence of this retardation on NOx emission and smoke is measured. B20P10M20P3 stands for Biodiesel blend 20, pilot injection with dwell of 10^o, Main injection at 20^o and post injection with dwell of 3^o.

Table 1. Specification of the CRDI Engine

Engine	**Kirloskar, single cylinder, four stroke water cooled, VCR**
Stroke	110 mm
Bore	87.5 mm
Capacity	661 cc
Power	3.5 kW
Speed	1500 RPM
Compression Ratio	12-18

3. Result and Discussion

The properties of prepared cotton seed oil biodiesel is given in table 2. It is observed from the chart (Figure 1 to 4) that the NOx emission is greatly affected by injection timing. At all loads the selected injection strategy has influence on the NOx emission. At part loads the the effect is very much prominent.

As the injection timing is retarded the NOx emission observed to be reducing due to reduction in the peak temperatures developed in the combustion chamber. The reduction is about 45.93% with 75% load at P10 M11 P3 compared to M23. The reduction is 50.58% with 50% load at P10 M11 P3 compared to M23. Splitting the injection at M23 observed to be not beneficial

Multiple injection strategy is observed to be more effective in reducing NOx at part load condition. There is an increment in NOx with P10 M23 P3.

With B20 the engine was not running smoothly with splitting the injection at M23 and M20.

Table 2. Properties of biodiesel

Properties	**B100**
Density@15 °C, (gm/cm^3)	0.8865
Kinematics viscosity@40 °C	4.85
Flash point, °C	149
Fire Point, °C	160
Cloud point, °C	+1
Gross Calorific Value, kJ/kg	40,695
Cetane number	50.8
Copper strip corrosion @ 50oC for 3 hrs	Not worse than no 1
Acid value as mgof KOH/gm	0.063
Carbon Residue	0.041%
Sulphur	0.0043%

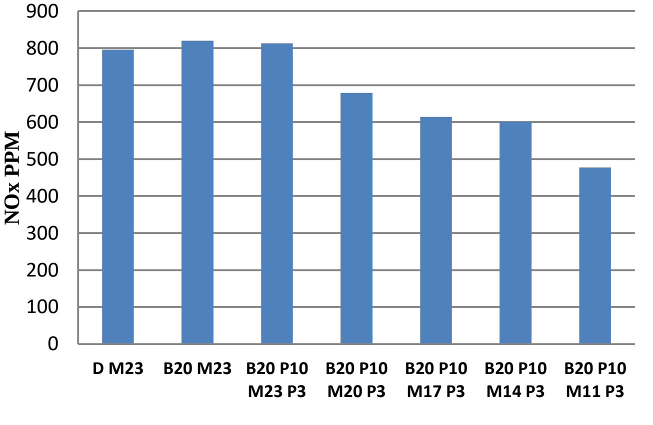

Figure 1. NOx emission at 25% load

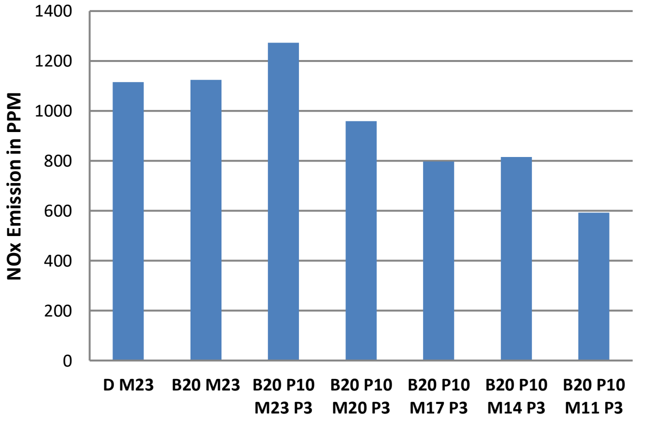

Figure 2. NOx emission at 50% load

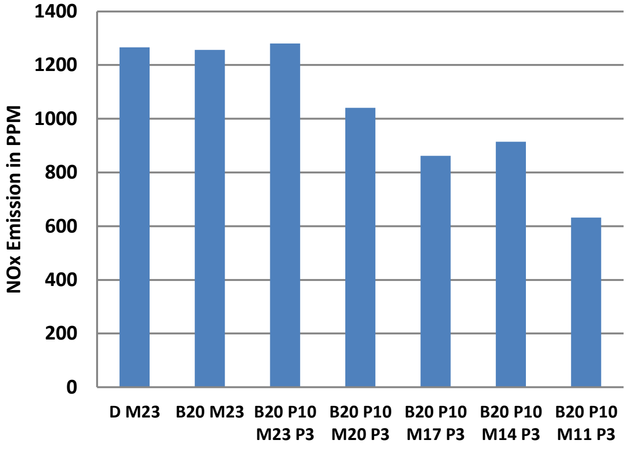

Figure 3. NOx emission at 75% load

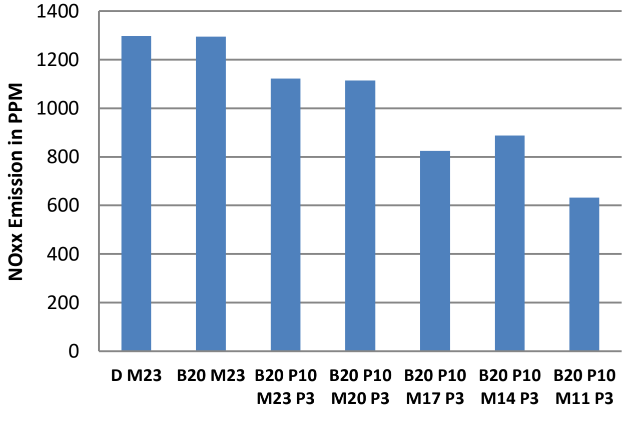

Figure 4. NOx emission at 100% load

It is observed that the retardation of multiple injection with main injection retardation from 23° bTDC to 11° bTDC, smoke emission is considerably affected (Figure 5). Smoke opacity reduced gradually up to main injection 14° and then starts increasing with further retardation. The reduction is 69.1%, 62.23%, 58.93%, 48.68%, and 18.29% with load of 0%, 25%, 50%, 75%, and 100% respectively at P10 M14 P3.

Reduction in smoke with multiple injections is more at lower loads than higher loads.

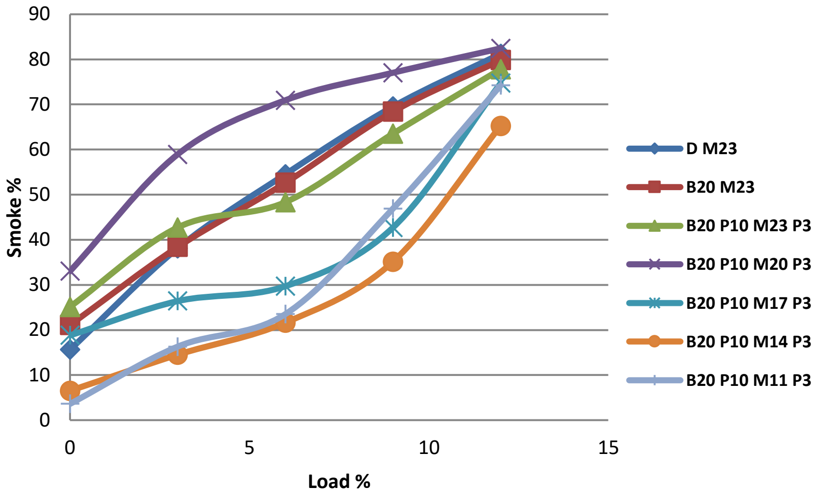

Figure 5. Smoke Emission with varying load

4. Conclusion

- Retardation of multiple injection up to M11 helped in reducing both NOx and smoke. Further retardation caused increment in smoke.
- B20P10M14P3 observed to be better for smoke. Smoke starts increasing with further retardation.
- NOx observed to be reducing continuously with retardation.
- P10 M11 P3 is better for smoke and NOx tradeoff
- Multiple injection is a good means of having tradeoff between smoke and NOx emissions.
- It is a very complex process. Numerous experiments are required to have thorough understanding of the influence of multiple injection.
- Dwell 10 is observed to be better
- Further combustion related analysis is required to understand completely the influence of multiple injection
- Multiple injection strategy seems to be more efficient than conventional in reducing emission due to their capability in controlling heat release rate and hence peak temperature.
- Multiple injection is better than single injection in optimising tradeoff between NOx and smoke due to their efficiency in reducing initial high temperatures and supporting combustion of late injection.

- Reduction in emissions was improved with multiple pre-main-post injection strategy, as pre injection supports main injection combustion and reduced delay while post combustion helped in oxidation of soot particles without impact on NOx.
- Proper dwell between injections was significant as small dwell led to situation of single injection while long reduced the effect of pre-mix combustion. For pilot injection dwell around 10 CAD observed to be better for reducing harmful emission efficiently.
- Around 21 CAD bTDC injection timing of first injection was observed to be optimum for simultaneous reduction of NOx and soot.
- Multiple injection strategy is more effective in reducing smoke emissions at lower loads.
- The rate of increase in smoke emission is high as load increases with multiple injection strategy.

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