Emission Analysis of CRDI Diesel Engine fueled with cotton seed oil biodiesel with multiple injection strategy

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Abstract : In commercial sectors diesel engines are used mostly to power the vehicles like busses and trucks due to their higher thermal efficiency and better fuel economy. The countries world over imposed stringent emission regulations to counter the harmful effects caused by the emissions from diesel engines. Due to heterogeneous combustion process, diesel engines generally emit higher NOx and smoke which are very much damaging the environment. HC and CO emissions are less from diesel engine because mostly it works on lean mixtures. At present lot of research work is diverted towards finding eco friendly and renewable alternative fuels to petro diesel and reducing the harmful emissions from diesel engines to comply with the regulations imposed upon. Biodiesel produced from non-edible feed stock is found to be a good alternative to petro diesel. 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 various multiple injection strategies with different injection timings and dwell periods. In this multiple injection strategy of three injection pulses the pilot fuel quantity is fixed as 10% of total fuel injected, post injection fuel quantity is fixed as 0.5 mg. The dwell between pilot and main was varied at different main injection timing. The post injection is closely coupled with main injection with a dwell of 3 CAD. The main injection timing along with pilot and post was retarded from the recommended 23^{o} bTDC in steps of 3 degrees. At all main injection timing the dwell of 10 CAD observed to be the best for smoke reduction, where as 20 CAD is better for NOx reduction. HC and CO emission observed to be reducing with multiple injection strategies.

***IndexTerms* - Pilot injection, post injection, Biodiesel, blends, transesterification, Emission.**

I. 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 continuously 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 [1].

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 [2].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 [3].

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 [4]. 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 [5]. 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 [6]. 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 [7,8].

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 [9]. 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.

II. 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. The injection timing of main injection is varied from 23 CAD to 2 CAD. Dwell between pilot and main is taken as 8, 10, 15, 20 CAD. 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.
- Characterisation of biodiesel.
- Preparation of B20 blend
- Testing the performance of CRDI diesel engine with B20 with multiple injection strategy varying injection timing and dwell.
- Comparing the emissions from various multiple injections and single injection

Fig 1. Preparation of biodiesel

Fig 2. Washing of Biodiesel

Fig 3. Cotton seed oil, biodiesel, B20

Engine setup

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

The set up 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.

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
Injection pressure	300 bar

Fig 4. Experimental setup

Fig 5. Common rail injection system

Fig 6. Emission measuring instruments (AVL 437C SMOKE METER, AVL DIGAS 444N)

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 0.5mg/cycle. 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 2^o bTDC. The influence of this retardation on NOx emission, HC, CO and CO_2 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 . The various harmful emissions with multiple injection strategies at 75% load are compared for various multiple injection strategies.

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III. RESULTS AND DISCUSSION

Biodiesel characteristics

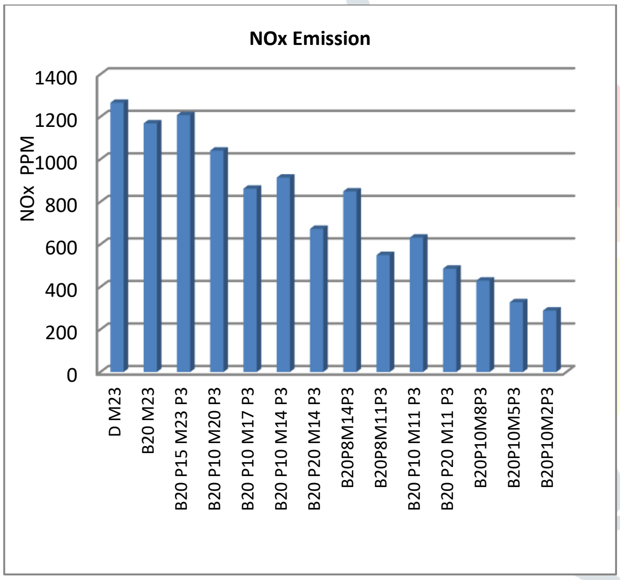
The properties of prepared cotton seed oil biodiesel is given in table 1, given below.

Table 1. Properties of biodiesel (Eta Laboratories)

Properties	B100
Density@15 ºC,(gm/cm^3	0.8865
Kinematics viscosity@40 ºC	4.85
Flash point, ºC	149
Fire Point, ºC	160
Cloud point, ºC	+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%

Properties are measured in ETA laboratory, Chennai as per standard ASTM methods. It is found that the characteristics of biodiesel produced are in conformity with biodiesel standards.

Emission Analysis



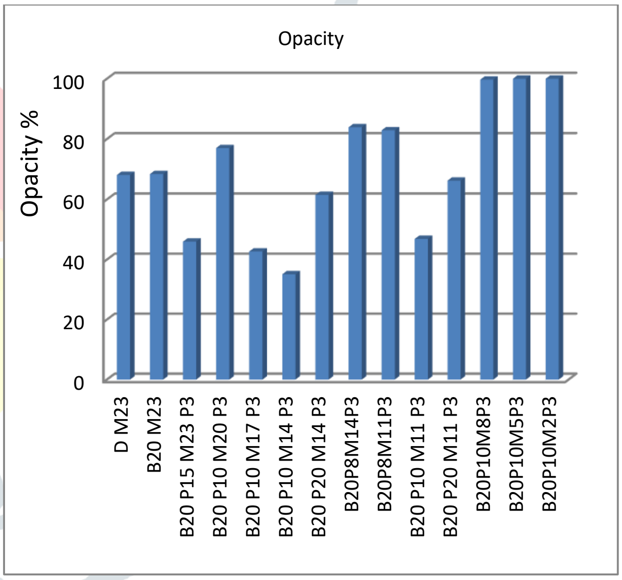
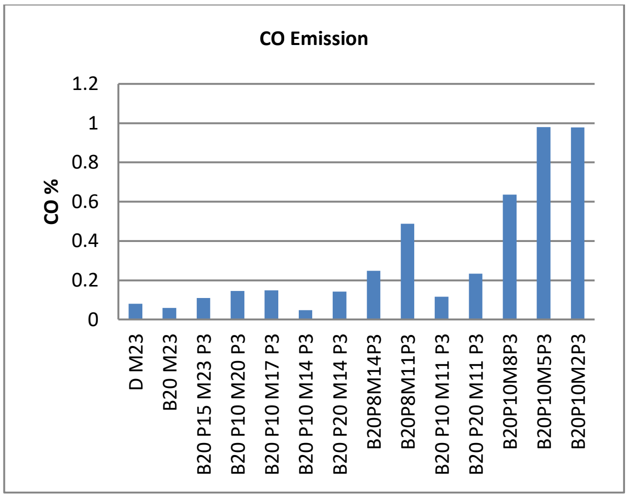


Fig 7. NOx emission in various multiple injection strategies. Fig 8. Smoke emission in various multiple injection strategies



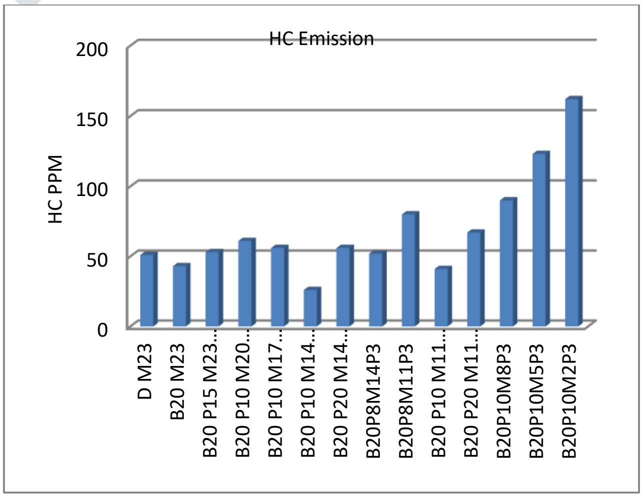


Fig 9. CO emission in various multiple injection strategies. Fig 10. HC emission in various multiple injection strategies

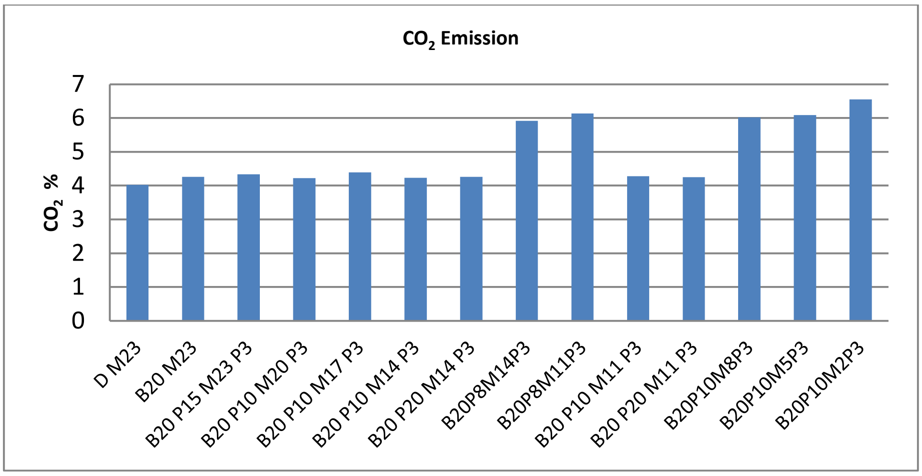


Fig 11. CO_2 emission in various multiple injection strategies

Fig. 7 shows variation of NOx emission with various multiple injection strategies. It clearly indicates as the injection timing of the main injection retards the NOx emission reduces. It is due to reduction of ignition delay reducing the premixed combustion which causes low peak temperatures in the cylinder. High Peak temperature is the main cause of NOx formation. Also it is observed that at a given main injection timing higher the dwell period between main and pilot injection lower the NOx emission. It is noted that at M11 the NOx emission is reducing as the dwell between pilot and main increasing from 10 CAD to 20 CAD. There is a maximum reduction of 56.91% with dwell of 20 CAD compared to single injection M23. At M14 also similar trend of reducing NOx emission with increase in the dwell period.

The variation of opacity with different multiple injection strategies is given in Fig 8.. It is observed that splitting the injection helps in reducing the smoke emission. With dwell of 10 CAD the smoke emission is less compared to other strategies. The smoke emission with dwell of 8 CAD is higher than the smoke emission with dwell of 10 CAD. B20P10M14P3 caused the least smoke emission compared to other strategies.

CO emission observed to be increasing with retardation of multiple injection strategy from the Fig.9. Multiple injections did not cause much increase in CO emission. B20P10M14P3 is found to be better with less CO emission compared to other multiple injection strategies. B20P10M11P3 is also reasonably good with less CO emission.

HC emission for B20P10M14P3 is observed to be less compared to other strategies as shown in Fig 10. B20P10M11P3 is also reasonably good with less CO emission. This shows the complete combustion process with the multiple injection strategies.

CO2 emission is almost same as shown in Fig 11 for multiple injections and single injection.

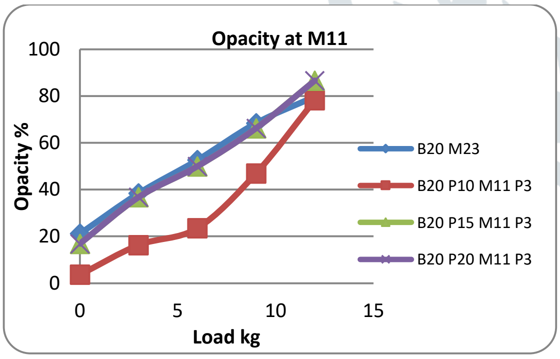


Fig 12. Opacity at M11 with varying dwell

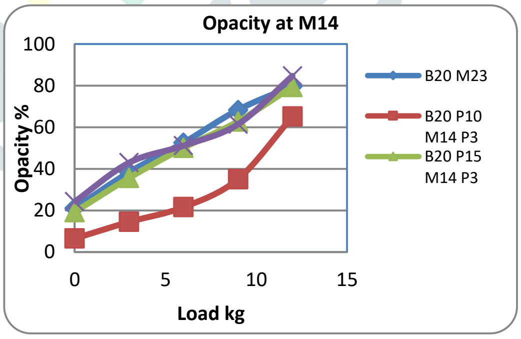


Fig 13. Opacity at M14 with varying dwell

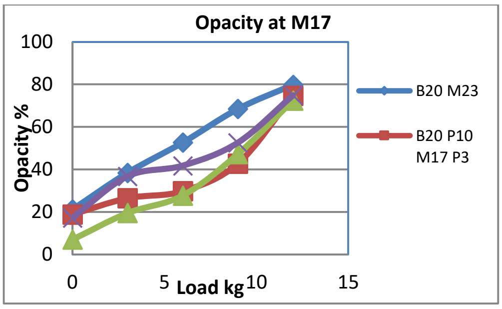


Fig 14. Opacity at M17 with varying dwell

From the above figures 12, 13, 14, it is observed that splitting the fuel injection has considerable effect on smoke emission. Maximum reduction of smoke is noted at M14 with dwell of 10 CAD with 6 kg load. At this condition the reduction in smoke is 58.93%. The reduction of smoke at M11 with a dwell of 10 CAD 55.32% with load of 6 kg.
It is observed that the engine is hesitating at higher load with higher dwells of 15 and 20 CAD at M23 and M20. At all main injection timing the dwell of 10 CAD observed to be the best.

The retardation of multiple injection with main injection retardation from 23° bTDC to 2° bTDC, smoke emission is considerably effected. 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%, 18.29% with load of 0%, 25%, 50%, 75%, 100% respectively at P10 M14 P3.

IV. CONCLUSIONS

- Multiple injection helps in reduction of both smoke and NOx.
- Retarding of multiple injection reduces the NOx emission.
- Smoke reduces with retardation upto M14 then starts increasing.
- P10 M11 P3 is better for smoke and NOx tradeoff
- Further experiments are required to understand the influence of multiple injection.
- At all main injection timing the dwell of 10 CAD observed to be the best for smoke reduction, where as 20 CAD is better for NOx reduction. In overall Dwell 10 CAD is better for trade off between NOx and Smoke.
- 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 helps 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 reduces emission efficiently.
- Around 21 CAD bTDC injection timing of first injection was observed to be optimum for simultaneous reduction of NOx and soot.

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REFERENCES

[1] YanuandriPutrasar, ArifinNur, AamMuharam, (2013), "Performance and emission characteristic on a two cylinder DI diesel engine fuelled with ethanol -diesel blends," *in International Conference on Sustainable Energy Engineering and Application[ICSEEA*] Energy Procedia 32 ,

[2] A.S.A.E.Atabani, (2013),"'Non-ediblevegetable oils: A critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production'," *Renewable and Sustainable Energy Reviews journal*,pp. 211-245.

[3] T. Pushparaj, S. Ramabalan,(2013),"'Green fuel design for diesel engine combustion,performance and emission analysis'," *in International Conference On DESIGN AND MANUFACTURING IConDM .research scholar*, Tamil Nadu, india , .

[4] Busca G., Lietti L., Ramis G., and Berti F., Chemical and mechanistic aspects of the selective catalytic reduction of NOx by ammonia over oxide catalysts: A review, Applied catalysts B: environmental, 18(1-2), 1998, 1-36

[5] H. Bosch, F. J. J. G. Janssen: Catalytic Reduction of Nitrogen Oxides: A Review on the Fundamentals and Technology, Catalysis Today, 2(369), 1988.

[6] Perry, R. A. and Siebers, D. L. Rapid reduction of nitrogen oxides in exhaust gas streams. Nature, 324, 1986, 657–658.

[7] Imarisio, R, et al.: " Multiple injection, a cost effective solution for emission reduction of common-rail DI Diesel Engines", Aachener Kolloquium Fahrzeug-und Motorentechnik, 9(2000), 1047-1062.

[8] Badami, M, et al.: " Influence of Multiple injection strategies on emissions, combustion noise and BSFC of a DI common rail diesel engine", SAE Tech. Ser., No.2002-01-0503, (2002)

[9] Gao Z and Schreiber W (2001), "The Effects of EGR and Split Fuel Injection on Diesel Engine Emission", *InternationalJournal of Automotive Technology*, Vol. 2, No. 4, pp. 123-133.