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Emission Characteristics of Turbocharged Single Cylinder Diesel Engine

R. Vishnu Varthan and D. Senthil Kumar*

Department of Mechanical Engineering, Amrita School of Engineering, Amrita Vishwa Vidyapeetham, Amrita University, Coimbatore – 641112, Tamil Nadu, India; vishnurmech@gmail.com, d_senthilkumar@cb.amrita.edu

Abstract

Fossil fuel reserves are depleting at an alarming rate and may become extinct in few decades. To counteract this crisis much emphasis is laid out on usage of alternate fuels. Also techniques like turbocharging are used to increase the efficiency of the IC engines thereby reducing the fuel consumption. While opting for such alternate solutions like biodiesel and turbocharging, the exhaust emissions should be checked to ensure that these solutions don't pose a threat to the environment. So in this project the change in amount of component gases in the exhaust emissions were found out in four cases which are naturally aspirated with diesel, turbocharged with diesel, naturally aspirated with biodiesel and turbocharged with biodiesel. A single cylinder motorcycle diesel engine is used in this project. Emission characteristic tests were done in the naturally aspirated engine using diesel and biodiesel as fuels. Then a turbocharger designed for this engine is fitted to it and the same tests as above were conducted. Comparison in exhaust emissions which are NO_x, HC, CO and CO_2 was made for the above mentioned four cases. It was found that NO_x emissions has increased by the usage of biodiesel as fuel, while turbocharger has decreased the NO_x levels. This is a concern to be addressed while using biodiesel as alternate fuel. Biodiesel and turbocharger both had a positive effect on HC emissions, i.e. reduced the HC emissions. The impact of biodiesel and turbocharger on CO emissions was not so significant with the former increasing the emissions and the latter decreasing it by providing more oxygen. Though CO_2 is not categorised as toxic emissions like other emissions; it is important to compare the amount emitted in the different cases. Biodiesel increases the amount of less-toxic CO_2 whereas turbocharger has reduced the CO_2 emissions. This is because the excess oxygen provided by turbocharging is used for the formation of water vapour rather than CO_2. Thus the important four emissions were compared to appreciate the effect of biodiesel and turbocharger. In future work the problem of increase in NO_x by biodiesel fuel should be addressed and solution has to be formulated.

Keywords: Cotton Seed Methyl Ester, Diesel Engine Emission, Turbocharger

1. Introduction

The turbocharger works principally by employing the heat energy, which is usually exhausted to the atmosphere in case of a naturally aspirated engine, to drive a compressor by converting the heat energy into mechanical energy. This compressor, driven by the turbine, proved for increased volume of air and thereby more oxygen for the same amount of fuel injected and hence improved combustion of fuel and thereby directly reducing the emission caused by incomplete combustion like Carbon Monoxide (CO) and Hydrocarbons (HC). Almost all high capacity diesel engines used in recent times are turbocharged because of this advantage.

[1]Compared homogenous gasoline injection fuel system and stratified injection fuel system. The injection system is fitted with 3 cylinder and 4 cylinder turbocharged Gasoline Direct Injection (GDi) engine. The 3 cylinder turbocharged GDi engine reduces 22% of CO_2 when compared with 4 cylinder GDi engine and 18% of CO_2 emission is obtained at stoichiometricratio. 3 cylinder turbocharged GDi engine emits lesser NO_X and CO_2 and also gives more torque for better driveability. 3 cylinder engine requires 3-way catalytic converter to

* Author for correspondence

reduce major emission like CO_2 and NO_X. Other types of engine requires NO_x after treatment and Catalytic Reduction (SCR) system to reduce emissions.

[2]Concluded that the turbocharger improves the performance and reduces the CO_2 emission. In high load condition, higher torque engines with higher torque (engine size was large) are used to move the load. While using turbocharger, the same engine can move the higher load without changing its size. i.e. 2 liter with 141 hp natural aspirated diesel engine attains the speed of 60 miles/hr in 6.5 sec while 2 liter with 224 hp turbocharged engine diesel engine attains speed of 60 miles/hr in 2.8 sec. Turbocharger utilize the exhaust gas into useful work i.e. increases speed and torque of engine.

[3]Conducted an experiment on gas to liquid fuel with the help of 6 cylinder four stoke turbocharged intercooler direct injection diesel engine and the experiment is conducted at constant load (maximum load) by varying the engine speeds and fuel blends (GTL10, GTL20, GTL30, GTL50, GTL70, GTL100). From this experiment, speed and load influences more on emissions such as NO_X, CO and particulate matter. From the different fuel combination, GTL100 reduces the emission. With increase in toxicity of air at urban centers and uncertainty with the fossil fuel supply in future, there has been increasing focus on identifying a commercially viable alternative fuel especially the diesel fuel which is used almost in all large commercial vehicles. The various vegetable oils available in market like castor oil, soybean oil, cotton seed oil have been considered by various researchers and engineers as a replacement for diesel fuel in CI engines. The vegetable oils are already available in local market, they are cheap in comparison to fossil fuel and also their sources grown locally in comparison with the heavy bill of imported crude oil for diesel fuel. In addition to these advantages as the experiment concluded they are less polluting than diesel. But these vegetable oils cannot be used as fuels directly because of their low calorific value to be used in current IC engines, low atomization, flash and fire points and very high viscosity[4]. To overcome these drawbacks, various researchers have tried methods including pre heating the vegetable oils before introduction into combustion chamber, the vegetable oils blended with diesel fuel, using a vegetable oil alcohol emulsion as fuel and subjection of vegetable oil to transesterification. From the results obtained from these processes it is concluded that the most efficient method for improving the performance characteristics like atomization, volatility and density is transesterification. Methyl esters of vegetable oils have several advantages than several other alternative fuel types. For one compared to diesel fuels vegetable oils are more viscous[5].

[6]Conducted an experiment on naturally aspirated four stoke diesel engine using rape oil methyl ester as fuel and test carried out at full load for different speed between 1200 and 2400 rpm. On his test concludes that the brake thermal efficiency obtained by using biodiesel fuel was slightly higher than diesel but its output BHP and torque is lower and also CO emission will decrease with increase of $NO_{x.}$ These fuels produced via transesterification of the vegetable oils are called biodiesel. In most of the similar experiments conducted, it was concluded that the usage of biodiesel blended fuels in CI engine lead to decrease in Carbon Monoxide, Hydrocarbon and particulate emission but increase in NO_x emission at higher load condition on engine. But some reports contradict this statement mentioning the NO_x emission decreases with increasing output power, i.e. increasing load.

Transesterification is the process of using an alcohol (e.g. methanol, ethanol or butanol), in the presence of a catalyst, such as sodium hydroxide or potassium hydroxide, to break the molecule of the raw renewable oil chemically into methyl or ethyl esters of the renewable oil, with glycerol as a byproduct. The transesterification reaction proceeds with catalyst or without catalyst by using primary or secondary monohydric aliphatic alcohols having 1–8 carbon atoms as follows:

Triglycerides + Monohydric alcohol = Glycerine + Mono-alkyl esters[7].

Study was conducted to select among the various available vegetable oil, the one with least exhaust emission, better performance and the most economic. Sunflower oil and cottonseed oil methyl esters (biodiesels), blended with diesel fuels were taken up for study. The various experiments done by researchers concluded that the more the percentage of biodiesel in the biodiesel - diesel fuel blend, the better is the reduction in particulate and exhaust emission from engines. Rakopoulos concluded in his experiment that cotton biodiesel blended diesel fuel exhaust have lower soot than the Sunflower oil biodiesel – diesel blended fuel[8]. Also with cotton seeds being easily available in the local market and more economical than sunflower oil seeds, it was decided to use cotton seed oil in the transesterification process to produce biodiesel.

The experiment was conducted and exhaust of various fuels (diesel only and diesel - biodiesel blend) was analyzed at varying speeds of the CI engine under naturally aspirating condition and turbocharged condition. The Carbon Monoxide (CO) emission was reduced while using biodiesel blended diesel fuel. This reduction being inversely proportional to the percentage of biodiesel fuel in the blend. Also the CO emission was further reduced by employing turbocharger, due to improved volumetric efficiency. The HC emissions were slightly decreased by using biodiesel blended fuel with further reduction possible through using turbocharger[4].

2. Experimental Setup

The test setup consists of diesel engine, turbocharger (Chevrolet beat), Mexa-Horiba emission analyzer as shown in the Figure 1. The engine which is used for the test is four stoke single cylinder naturally aspirated diesel engine and the technical specification of the engine is shown in the Table 1. Mexa-Horiba Emission analyzer is used to measure emission like CO, HC, CO_2, NO_X and O_2. The turbocharger is used to improve the mass of air inside the cylinder.

Table 1. Engine specifications

Make	Greaves
Number of Cylinders	Single
Bore	78 mm
Stoke	68 mm
Total Displacement	350 CC
Charging	Natural aspirated
Cycle	4 Stroke
Fuel System	Direct Injection
Compression Ratio	18 : 1
Cooling System	Air Cooled
Power	3.72 kW
Maximum torque	445 Nm@800rpm
Make	Greaves
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Figure 1. Experimental vehicle.

The biodiesel is prepared from the cotton seed oil. Cotton seed oil contains many impurities. In order to increase the density and reduce the viscosity of cotton seed oil, it is put in transesterification process with methanol. 900 ml of cotton seed oil is taken and it is mixed with 100 ml of methanol and 2.4 gram of Sodium Hydroxide (NaOH)[3] and mixing has done with the help of magnetic stirrer. The magnetic stirrer is a device which creates the rotating magnetic field and it rotates the stir bar at the speed of 600 rpm and the temperature is maintained at 60-70^0 C for 8 hours. Then beaker is placed in idle position for few hours for impurities to settle down after that cotton seed oil separated. Again separated oil is mixed with some amount of water and stirred for some time. Then beaker is placed in idle condition for separation of soap oil, glycerin and it is filtered with the help of filter paper. The technical specification of the diesel and cotton oil has shown in the Table 2. Pure cotton seed oil where stored on the separate fuel tank, then biodiesel is prepared by mixing 900 ml of the diesel and 100 ml of the cotton seed oil is taken and mix to form the biodiesel.

Table 2. Properties of fuel in the test[9]

	Diesel	Cotton seed oil
Formula	$C_{12}H_{23}$	$C_{18}H_{38}$
Density at 20^{0}C (kg/m^3)	837	910
Lower heating value (kJ/kg)	43000	36800
Kinematic viscosity at 40^{0}C (mm^2/s)	2.6	34
Cetane number	50	38
Flash point (^{0}C)	74	205
Latent heat of vaporization (kJ/kg)	250	210
Stoichiometric air-fuel ratio	15	12.5
Boiling temperature (^{0}C)	180-360	340-480

3. Experimental Procedure

The biodiesel (900 ml diesel + 100 ml cotton seed oil) and diesel fuels are taken in two separate tanks. The quantity of fuels coming out of the tanks is controlled through valves placed on each tank outlet. HORIBA emission analyzer has a suction unit of minimal pressure which draws in air (emission sample to be tested) into the test chamber. Once connected to the emission chamber, it must be ensured that the connection is secure and there is no leakage. HORIBA emission analyzer needs 120 seconds to calibrate and emission analyzer was shown in Figure 2. This is done by taking the emission readings of the atmospheric air in the surrounding and accuracy measurement of emission analyzer was shown in Table 3.

Figure 2. Emission analyzer.

The naturally aspirated engine is run in idle speed for period of time till it reaches steady state condition. The first set of data is taken on natural aspirated engine running on conventional diesel fuel for different speeds (800 rpm, 1800 rpm and 3600 rpm) with no load condition. The different emission parameters such as CO, CO_2, NO_x and HC are measured using Horiba emission gas analyzer. The same set of parameters are measured again with biodiesel as a fuel in same engine. Then turbocharger is fitted to the naturally aspirated engine. Again the same set of parameters are tested to the engine fitted with turbocharger using emission gas analyzer with diesel and biodiesel as a fuel. Then the values are compared and graph is plotted between the speed and emission parameters. Evaluation is done using the graph to find either the engine with turbocharger or without turbocharger has more efficiency in terms of fuel (diesel and biodiesel) used.

The procedure is repeated for biodiesel emission values taken once with turbocharger and in naturally aspiring conditions at the different speed conditions as mentioned above. The values of different pollutant emission, i.e. CO, CO_2, HC and NO_x are tabulated and plotted in graph to compare and conclude the results.

Table 3. Accuracy of measurements

Sensor	Range	Accuracy
HC	0-2000 ppm	4ppm
CO	0-10%	0.06%
CO_2	0-20%	0.3%
O_2	0-25%	0.01%
NO_x	0-5000 ppm	25 ppm

4. Results and Discussion

4.1 Nitrogen oxides (NO_X) Emissions

The NO emissions are formed when there is high combustion temperature[10] in the cylinder which is usually attained when the reactants burn at stoichiometric conditions. NO is a colorless gas that makes harm full effects to humans[11].

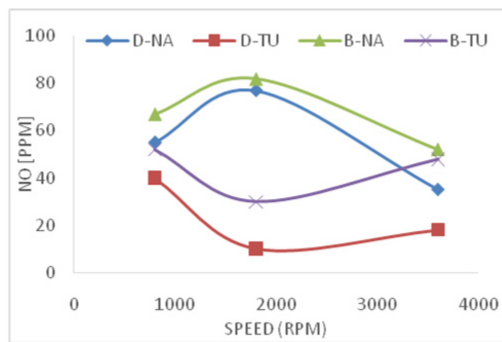

Figure 4.1. Speed vs. NO.

In naturally aspirated engine with both diesel and biodiesel as fuels NO emissions at idle speed of 800 rpm is found to be less. As the speed increases the equivalence ratio reaches near 1 therefore the NO emissions reach highest value as the combustion temperature reaches a peak value.

Turbocharged engines do not reach the stoichiometric conditions due to the excess mass of air present in the cylinder and the mixture is mostly lean. The increased mass flow of air decreases the combustion temperature, therefore the NO emission is less at half-throttle (1800 rpm). The NO emission increases at maximum speed as the temperature reaches a high value as there is inadequate time for the accumulated heat to be dissipated to the surroundings.

The NO emission for biodiesel fuel is higher than with diesel fuel as biodiesel has higher cetane number and therefore less ignition delay. The combustion takes place immediately after ignition and maximum combustion temperature is high for the same cycle time as diesel.

4.2 Hydrocarbon (HC) Emissions

HC emissions are formed in engines due to the following reasons:

- When the air-fuel ratio is above the stoichiometric ratio, i.e. rich mixture with equivalence ratio more than 1. This condition occur during starting especially in cold conditions, sudden acceleration and loading[12].
- Due to inadequate time for combustion during quick strokes of the piston at higher rotational speeds.
- Unburned fuel or partially burned fuel entrapped in the crevice volumes of the cylinder wall.

It is observed that the HC emissions for biodiesel blend is lesser than their diesel counterparts. This is because of the low ignition delay of biodiesel and hence more fuel is burnt for the same time period resulting in less HC[17]. The turbocharger ensures more mixing of air and fuel leading to a homogeneous mixture which burns cleaner. This reduces the HC emission by a small extent by usage of turbocharger.

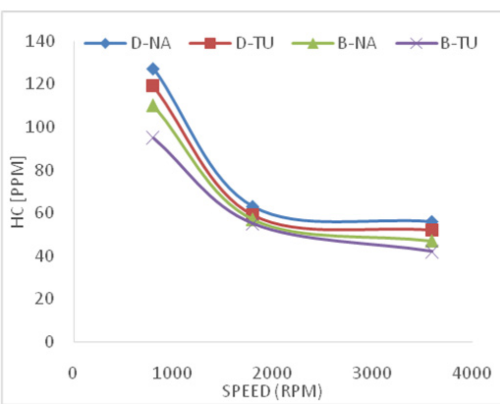

Figure 4.2. Speed vs. HC.

Hence the HC emission for biodiesel with turbocharger is the least in all speeds (800 rpm, 1800 rpm and 3600 rpm) because of turbocharger send more volume of air in less time and fuel air ratio gets enough time mix. Biodiesel have more cetane number it helps to increase ignition delay so that naturally aspirated engine with diesel fuel emitted more HC when comparing natural aspirated engine with biodiesel fuel.

4.3 Carbon Dioxide (CO_2) Emission

Moderate levels of carbon-dioxide are not considered as a major air pollutant since it can be observed by plants during photosynthesis. But at higher concentration it is an important greenhouse gas and is a major contributor to global warming. Carbon-dioxide is a major component of vehicle exhaust.

The products of complete combustion are water vapor and carbon-dioxide alone. If more fuel is burnt more CO_2 emissions are observed in the exhaust. Usage of biodiesel increases the CO_2 emissions a little since more fuel is burnt due to less ignition delay[13]. Turbocharger has proved to reduce the CO_2 emission since the excess of oxygen is used for the formation of water vapor (H_20) rather than CO_2.

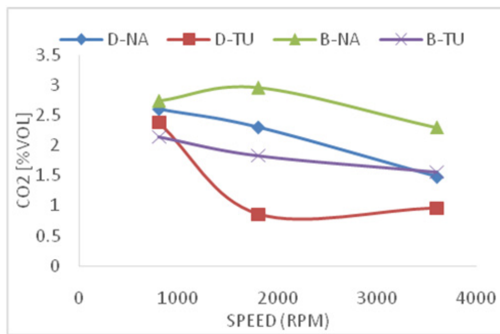

Figure 4.3. Speed vs. CO_2.

4.4 Carbon Monoxide (CO) Emission

CO emission are formed on when engine is operated by rich fuel rich equivalence ratio due to inadequate oxygen to form carbon-dioxide from carbon[14]. CO is a colorless, odorless gas which is also poisonous when inhaled continuously. In CI engines the CO emissions are far lesser than SI engines due to presence of lean mixture present[15].

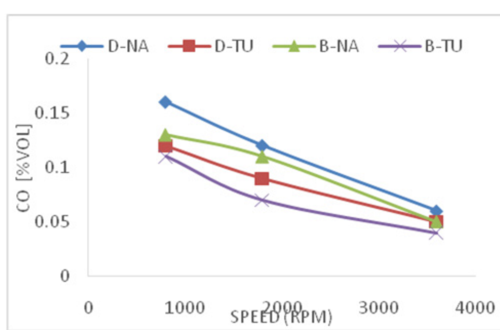

Figure 4.4. Speed vs. CO.

CO emission is less in turbocharged diesel engine when compared to the natural aspirated diesel engine. CO emission reduced due to turbocharger as more oxygen is available for conversion of carbon to CO_2.

In turbocharged engine run via biodiesel and it produced less CO emission due to biodiesel have more cetane number it helps to increase ignition delay[11,18] and makes proper combustion when compared to turbocharged diesel engine.

5. Conclusion

The emission tests were conducted on the 350 CC single cylinder diesel engines by changing the method of air induction (turbocharger) and the type of fuel (diesel and biodiesel). The following conclusions can be made from the results obtained from the tests:

- The NO_X emissions had increased while using biodiesel due to higher combustion temperature attained by less ignition delay. The turbocharger helped in reduction of NO_x emission by lowering the temperature by more induction of air.
- The HC emissions decreased by the usage of biodiesel and turbocharger. Using biodiesel ensures unburnt fuel was less by more time for combustion.
- The CO_2 emissions increase by the usage of biodiesel as more fuel was burnt for the same cycle. More fuel combusted had increased the CO_2 emission. While turbocharger decreased the CO_2 emissions as the excess oxygen was used for formation of water vapor instead of CO_2.
- CO emission showed little variations by using biodiesel and turbocharger. Turbocharger reduced the emission of CO by providing more oxygen for oxidizing CO to CO_2. Biodiesel had very little effect on CO emission, i.e. biodiesel reduced CO by small extent.

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Nomenclature

CI	Compression Ignition
DI	Direct injection
GTL	Gas to liquid fuel
GDi	Gasoline direct engine
HC	Hydrocarbon
CO	Carbon monoxide
NOx	Oxides of nitrogen
NO	Nitrogen oxide
CO_2	Carbon dioxide
PM	Particulate matter
NDIR	Non dispersive infrared
ppm	Parts per million
rpm	Revolution per minute
CC	Cubic centimeter