An Experimental Investigation On Emissions Of Neat Mahua Biodiesel Using Urea-SCR

Himangshu Sekhar Brahma, Dr. A Veeresh Babu

Abstract: The use of biodiesel is rapidly expanding around the world, making it imperative to fully understand the impacts of biodiesel on the diesel engine combustion process and pollutant formation. Biodiesel derived from non-edible feed stocks such as mahua (MadhucaIndica) are reported to be one of the feasible choices for developing countries including India. But one discomforting aspect is its emissions coming out of it. Emission control is one of the biggest challenges in today's automotive industry. Emission control can be achieved either by controlling combustion or by treating the exhaust gas. The latter is comparatively easier since there is less or no need to modify the engine. One such after treatment method is the use of catalytic converter. This paper is more concerned with an experimental investigation to study the diesel engine emission characteristics using Mahua biodiesel (mahua oil methyl ester) with the help of a Three Way Catalytic converter (TWC) with DEF (Diesel Exhaust Fluid) by running the engine in steady state conditions. The various exhaust parameters such as CO, HC and NO_X emissions were recorded and were found out to be comparatively very less when TWC converter was connected at the end of the exhaust tail pipe. Almost 90% NO_X emissions got reduced and the emission values recorded were much less when compared to Bharat stage- IV Norms for selected engine at all operated loads with retrofit arranged.

Keywords: Emission, Diesel engine, Mahua biodiesel, Three Way CatalyticConverter, Diesel Exhaust Fluid, SCR

1. Introduction

The world today is in need of alternate fuel sources because of fuel depletion and increase of fuel demand. The yearly reports in pollutants of atmosphere are also in increasing trend, the need is to develop the eco- friendly fuel to meet the fossil fuel depletion.These reasons increase the attention towards vegetable oil as an alternate fuel source. Biodiesel is the name of clean burning fuel, produced from domestic renewable resources. It contains no petroleum but it can be blended at any level with petroleum diesel to greater biodiesel blend. It can be used in CI engine with no major modifications. It is simple to use, bio degradable, non-toxic and essentially free of sulphur and aromatics. The choice of vegetable oil as engine fuel naturally depends upon the local conditions prevalent availability of a particular vegetable oil in excess amount. There are various oils which are being considered worldwide for use in the engines. But Mahua biodiesel is one of the most promising biodiesel options among these. Mahua (Madhuca Indica) is one of the forest-based tree-borne non-edible oils with large production potential of about 60 million tons per annum in India [1]. Many researchers investigated the effects of diesel-biodiesel blends on performance and emission characteristics in diesel engine and concluded that partial or full replacement of diesel with biodiesel is feasible [1-10].The major properties of Mahua biodiesel include calorific value, diesel index, flash point, fire point, cloud point, pour point, specific gravity, and kinematic viscosity. The various physicochemical properties of diesel and Mahua biodiesel are measured and listed in Table 1 for comparison.

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Table. 1: Comparison of properties between Mahua biodiesel and diesel

Fuel properly	Unit	Diesel	Mahua biodiesel
Kinematic viscosity at 40°C	cSt.	4.56	5.58
Specific gravity at 15°C		0.8668	0.8812
Flash point	°C	72	174
Fire point	°C	80	185
Pour point	°C	−18	4
Cloud point	°C	−3	12
Diesel index		50.6	51.4
Calorific value	kJ/kg	42850	42293

It can be noted that the calorific value of Mahua biodiesel is 3% less than that of diesel. This might be due to the presence of oxygen atoms in the fuel molecule of Mahua biodiesel. The specific gravity and kinematic viscosity are, respectively, 1.66% and 22.36% greater in the case of Mahuabiodiesels than that for diesel. The higher specific gravity of Mahua biodiesel makes the fuel spray narrow and its penetration deeper. The higher viscosity of Mahua biodiesel could potentially have an impact on the combustion characteristics because the high viscosity affects its atomization quality slightly. The higher diesel index value of Mahua biodiesel is conducive to low engine operating noise and good starting characteristics. The pour and cloud points of Mahua biodiesel are not favourable. However, the flash and fire points of Mahua biodiesel are much higher than that of diesel, which make Mahua biodiesel safer than diesel from ignition due to accidental fuel spills during handling. It can be seen that the properties of Mahua biodiesel are found to be within the limits of biodiesel specifications of different countries. Neat Mahua oil as biodiesel or Mahua oil methyl Ester (MME) have been experimented in diesel engines and its performance and emissions were investigated [11]. One notable thing that can be derived from those experiments is the high amount of NO_X emissions coming out of the exhaust while using Mahua oil methyl ester. Air pollution generated from mobile sources is a problem of general interest. The environmental concern originated by mobile sources is due to the fact that the majority of engines employ combustion of fuels derived from crude oil as a source of energy. Burning of hydrocarbon (HC) ideally leads to the formation of water and carbon dioxide, however, due to non-perfect combustion control and the high temperatures reached in the combustion chamber, the exhaust contains significant amounts of pollutants which need to be transformed into harmless compounds. In case of neat Mahua oil as biodiesel the various emission parameters such as CO, HC and NO_X are considerably higher [13].Hence it is very much important to take necessary steps in reducing these harmful gases coming out of the diesel engine exhaust. There are two ways by which emission control can be achieved,i.e. either by controlling combustion or by treating the exhaust gas. The latter is comparatively easier since there is less or no need to modify the engine itself. One such after treatment method is the use of TWC (Three Way Catalytic) converter. The diesel engine cycle is the most efficient of the internal combustion power plants. NO_X and PM are two of the major pollutants in CI engines. The biggest steps, toward a cleaner engine,have been achieved by optimization of the injection system with the electronic control of injection and use of turbocharger and after-cooler technology. The recent developments of exhaust gas recirculation and variable turbo charging are other promising steps to cut down engine out emissions. Though it is very good if we remove them at their production stage itself (engine modification, EGR, injection timing alteration etc), they affect the efficiency and performance of the engine. But, the after treatment processes such as SCR can be e better trade of between better efficiency and reduced emissions. Exhaust after-treatment on diesel vehicles will be introduced and become mandatory in the coming years. Various modelling of SCR-Exhaust aftertreatment have been done [14].Therefore the engine can be operated fuel efficiently, and the SCR (Selective Catalytic Reduction) system can reduce the emitted NO_X in most cases enough to meet legislation. However, NO_X concentration must be measured without delay from exhaustmanifold to control amounts of urea solution i.e. DEF (Diesel Exhaust Fluid). DEF (Diesel Exhaust Fluid) is a high purity aqueous Urea solution containing a 32.5% solution by weight of Urea in water. Urea is a commodity, produced in largescaleworldwide (130 million tons/year). Productstandards and distribution is oriented to serve the majorconsumers, such as food processing and fertilizerindustries. An industry standard for urea quality for Urea-SCR applications is under development. A specificationfor the urea used in this study is shown Table 2.

Table 2: Specification of Aqueous Urea Solution (DEF)

Chemical Formula	$(NH_2)_2CO \bullet H_2O$
Molecular Weight	60.06 g/mol
Urea concentration in solution	32.5 % ± 0.5 %
Density (at 15 °C)	1.085 kg/ltr.
pH-value	9-11
Appearance	Colourless

Spraying of aqueous urea solution in the upstream of the exhaust gas is an attractive solution. The aqueous urea dissociates into ammonia and carbon dioxide. The ammonia reacts with NO_X to produce harmless nitrogen gas and water vapour. But carrying another chemical on-board another problem. The SCR technology with urea as reducing agent has already been applied successfully to stationary applications and to mobile Diesel engines in applications such as ships andlocomotives [15]. Though, the SCR technology is three decades old, it is still an establishingtechnology. This method shows an excellent reduction in emissions and the reduction in efficiency of the engine is negligible.This paper reports a fully developed after-treatment process based on injection of urea in the upstream of the exhaust gas. The Urea-SCR system was developed to meet the demand for low NO_X emissions without compromising the engine efficiency from the existing diesel vehicles.The TWC (Three Way Catalytic) converter takes its name from controlling the three major emissions in an engine that are NO_X, VOCs and carbon monoxide. With the use of different advanced catalysts it has been possible to achieve high conversion of NO_X to NO_2 [16].The catalyst commonly contains an alumina wash coat supported on a honeycomb shape ceramic brick. Precious metals are coated onto the alumina. The active part of the catalyst is further divided into oxidation and the reduction catalyst sites. The platinum/rhodium components act as the active sites to carry out reduction reactions, while platinum/palladium acts as the active component for oxidation reactions.

2. Experimental Setup

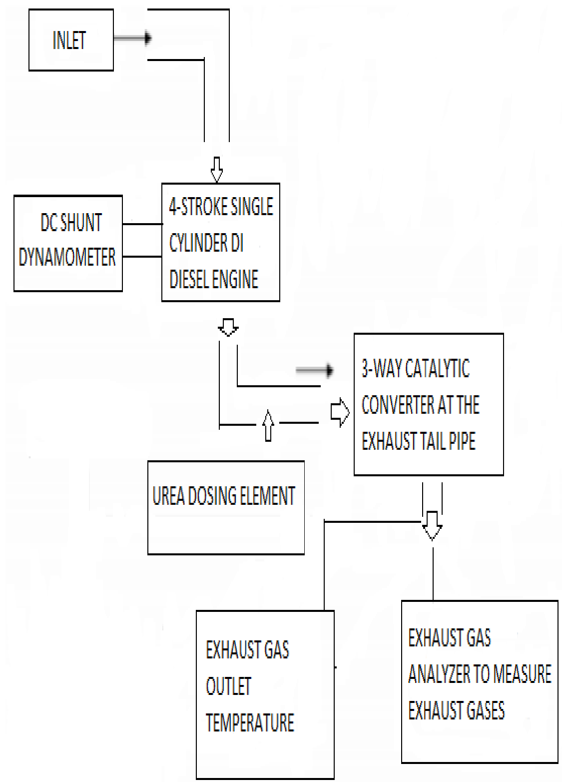
Experiments were conducted on a single cylinder, four-stroke, DI diesel engine at varying loads. Fuel used for testing was diesel and neat Mahua biodiesel .The major specifications of the engine are presented in Table 3.

Table 3: Specifications Of Test Rig

Item	Specification
Engine Type	Vertical, 4-Stroke Diesel Engine
	Make Kirloskar Oil Engines Ltd. ,India
Cooling	Water Cooled
BHP	5
Speed	1500
Compression Ratio	16.5:1
Bore/Stroke	80/110
Aspiration	Naturally Aspirated
Injection Pressure	200 kg/cm^2

For the application of load, engine was coupled to a DC Shunt dynamometer .The TWC (Three Way Catalytic) converter was connected at the end of the exhaust tail pipe of the engine. DEF (Diesel Exhaust Fluid) setup was connected with the engine test-rig. NO_X, HC and CO emissions were measured with a 5 gas analyzer. Initially the test engine was operated with base fuel-diesel for about 30 min to attain a normal working temperature condition after that base line data were generated and the corresponding results were obtained. The engine was then operated with neat Mahua biodiesel (MME). At every operation the engine speed was checked and maintained constant. The engine test was carried out at various loads with diesel and neat Mahua biodiesel using an experimental setup, as shown in Figure 1.

Figure 1:Experimental Setup

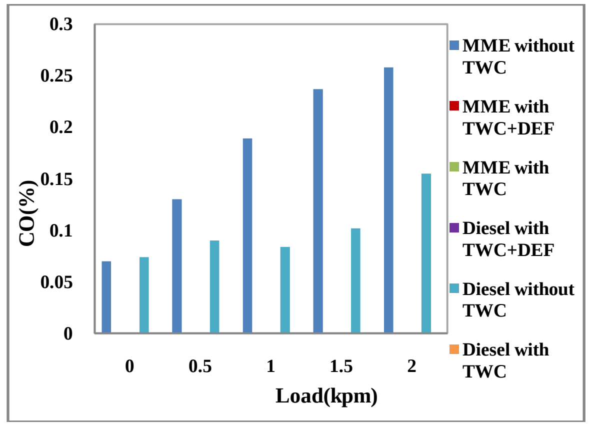


3. Results and Discussions

3.1 Carbon Monoxide Emission

Carbon monoxide emission is greatly reduced with the addition of Mahua oil methyl ester (MME) to diesel. But with neat Mahua biodiesel the emissions recorded were found out to be slightly higher than that of diesel. Higher Co emissions in the exhaust gas of the engine may be attributed to the polymerization that takes place at the core of the spray; this also caused concentration of the spray core and decreased the penetration rate [12]. Low volatility polymers affected the atomization process and mixing of air and fuel causing locally rich mixture, which leads to difficulty in atomization and vaporization of neat Mahua biodiesel due to improper spray pattern produced. This feature increases the incomplete combustion and hence higher Co emission. However with the use of TWC and DEF, the CO emissions can be reduced completely as shown in Figure 2.At maximum load,it is observed that the CO emissions using neat Mahua biodiesel (MME), without TWC+DEF, was found out to be 0.258 (% by vol.) whereas it is reduced to 0 (% by vol.) with TWC+DEF.

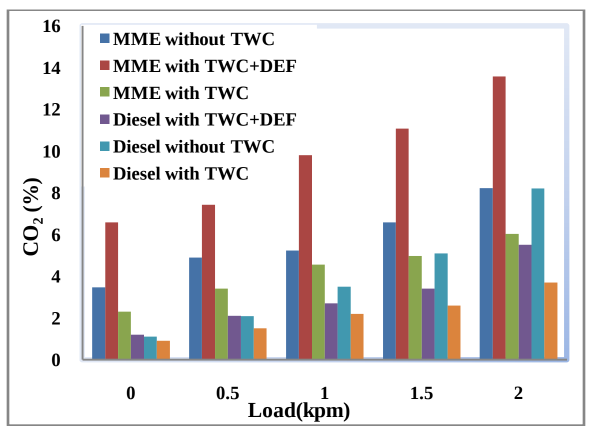
Fig 2:Load vs CO Emissions



3.2 Carbon Dioxide Emission

It is observed from the Figure 3.that the variation of CO_2 using neat Mahua biodiesel is in a increasing trend with the increase in load. This indicates that Mahua being an oxygenated biodiesel, leads to complete combustion of the fuel.The values of CO_2 can be seen undergoing a significant change while using TWC+DEF. The CO_2 emissions increases while using catalytic converter with DEF. This is because more CO_2 is formed as a result of the reduction process when DEF is injected in the exhaust. The value recorded using TWC at maximum load is 6.03 (% by vol.) whereas it is 13.58 (% by vol.) with TWC+DEF.

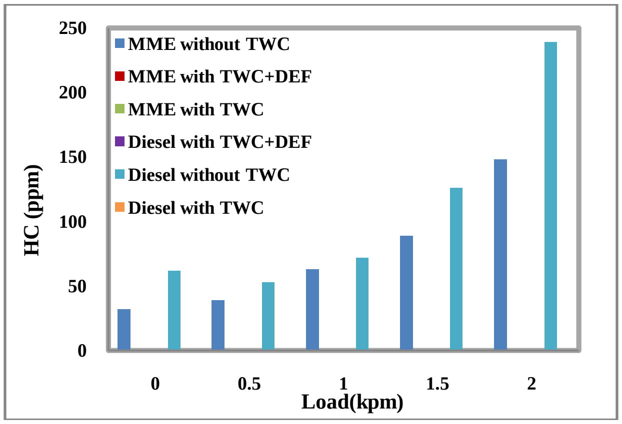
Fig 3: Load vsCO_2Emissions



3.3 Unburnt Hydrocarbon Emission

Hydrocarbon (HC) emission is reduced significantly with the use of TWC+DEF HC emissions increases with increasing load while using Mahua biodiesel (MME) but its emissions are much less than that of diesel. However it can be observed from the Fig.4 that the emissions of HC can be significantly reduced by using TWC+DEF. At maximum load the HC emission recorded with Diesel and neat Mahua biodiesel without using TWC is 239 ppm and 148 ppm respectively. But it was reduced to minimum while using TWC and TWC+DEF.

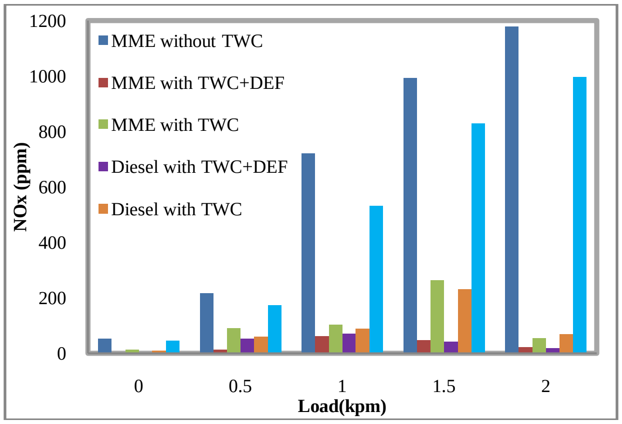
Fig 4: Load vs HC Emissions



3.4 Nitrogen Oxide Emission

The removal of NO_X is especially difficult because of the excess oxygen associated in the diesel engine operation.

Fig 5: Load vs NO_X Emissions



From the Fig 5.it can be noted that with the increase in load the NO_X emission increases. It is observed that oxygenated fuel such as Mahua biodiesel can result in increase in NO_X emission. It is of the fact that complete combustion causes higher combustion temperature which results in higher NO_X formation. The NO_X emission recorded using neat Mahua biodiesel is nearly 0.5% more than the emission recorded using Diesel. But it gets reduced significantly using TWC and TWC+DEF. Nearly 90% reduction is seen at maximum load using TWC+DEF.

Conclusion

Based on the values obtained for the tests conducted on single cylinder vertical type four stroke, water-cooled, and compression ignition engine, the following conclusions are made.

* CO emission is zero for TWC converter and TWC converter +DEF system connected at the end of exhaust tail pipe when compared withoutconnecting catalytic converter at the end of exhaust tail pipe. The CO emission is lower when compared to the Bharat stage IV Norms for selected engine at all operated loads with retrofit arranged.
* HC emission is zero for TWC converter and TWC converter +DEF system connected at the end of exhaust tail pipe when compared withoutconnecting catalytic converter at the end of exhaust tail pipe. The HC emission is lower when compared to the Bharat stage IV Norms for selected engine at all operated loads with retrofit arranged.
* Carbon dioxide emission is less for TWC converter and TWC converter +DEF system connected at the end of exhaust tail pipe when compared withoutconnecting catalytic converter at the end of exhaust tail pipe.
* Oxygen concentration is more for TWC converter system when compared to TWC converter +DEF system connected at the end of exhaust tail pipe. But it is less in concentration for withoutcatalytic converter system when compared to TWC converter +DEF system at the end of exhaust tail pipe.
* Nitrogen oxides / dioxides (NO_x) emission is less for TWC converter +DEF system and TWC converter connected at the end of exhaust tail pipe when compared withoutconnecting catalytic converter at the end of exhaust tail pipe. The NO_xemission is lower when compared to the Bharat stage IV Norms for selected engine at all operated loads with retrofit.

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