Experimental analysis of exhaust emissions using catalytic converter

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Abstract. Emissions from the automobile contribute to major air pollution problems in cities as well as villages along with industrialised areas in developed and developing countries. Air pollution is one of the major factor that is the cause for global warming and the climate change problems. This paper focuses on mitigation using regular three way catalytic convertor to reduce the level of emissions of CO, NOx and HC along with a neem blend biodiesel. Since most of the transportation vehicles rely solely on Petrol and Diesel for their operation. This results in large amount of carbon monoxide (CO), unburnt hydrocarbons (HC), nitrogen oxides (NOx), and particulate matters. Hence, for the experimental analysis of the three way catalytic converter Neem-diesel blend will be used as alternatives of petrol and diesel. Nearly all (95%) of the world's transportation energy comes from petroleum-based fuels, largely gasoline and diesel. Thus an organized cultivation and methodical collection of Neem oil, is a potential bio-diesel substitute and will reduce the import burden of petroleum.

Keywords: Engine, Emissions, Catalytic Convertor, CO, NOx, HC

1. Introduction

Carbon monoxide is a poison that has high affinity toward haemoglobin. This reduces oxygen supply to the body leading to carbon monoxide poisoning. Long term exposure to HC and NOx leads to smog, which, in the presence of light from sun, would give rise to secondary pollutants like O3, NOx, which cause global environmental issues. The pollutants have negative impact human health that leads to stringent norms of pollutant emissions. As the emission standards were tightened, strategies were applied such as the BS IV (Bharat Stage IV) emission norms, Euro 6 norms, etc [1]. The aim is to reduce levels of exhaust emissions including NOx, CO, hydrocarbons, and particulate matter (PM) such as soot from diesel cars. Currently, the automobiles in India are close to BS 1V and by 2020, the automobile industry in India plan to achieve Euro 6 Norms. BS IV norms are emission control standards that are based on European regulations (Euro norms). They set limits for air pollutants release from equipments using IC engines [2,3]. In a recent survey report, of all the most polluting nations only India’s carbon emissions are rising, almost 5% in 2016. Carbon monoxide (CO) a colourless, odourless, tasteless, and toxic air is produced in the incomplete combustion of carbon-containing fuels, such as gasoline, natural gas, oil, coal, and wood. CO may be a week and direct greenhouse emission but it contributes to a majority of effects in heating of earth's surface. Motor vehicles turn out a considerable fraction of CO to the atmosphere along with
hydrocarbons which is a major part of oil, gas and pesticides. Hydrocarbons react in the presence of NO\textsubscript{x} and light from the sun to create ozone gas that irritates eyes, damages lungs, and aggravates metabolic process issues. It's our most widespread and proved exhausting to manage urban pollution drawbacks because several exhaust HC’s are also toxic, with potential to cause cancer. These substances contribute to the greenhouse effect and global warming, deplete the ozone, increase occurrences of cancer and metabolism disorders, scale back the photosynthetic capability of plant life and do much harm to ecosystems [4,5].

2. Experimental Setup

2.1. Engine
A single cylinder, water-cooled 5.2 kW direct injection CI was subjected to experimental investigations. To measure the exhaust emissions a gas analyzer of make AVL DiGas 444 was used. The mass flow rate of engine cooling water and its inlet temperature were maintained according to standards. Prior to the conduct of experimental trials, the engine was properly checked and the measuring instruments were subjected to calibration. The standard test procedure was adopted for all the fuels tested. The engine emission was studied at different loads for diesel, neem oil blend and with activated carbon, by operating the engine at an average speed of 1500 rpm.

2.2. Catalytic Converter
A catalytic convertor is an emission control device that is used to convert harmful gases and pollutants in exhaust from an IC engine into less harmful gases by catalyzing a redox reaction. The convertors are used along with IC engine which is fueled by either diesel or petrol. A three way catalytic convertor is used for the experimental analysis. As of the current scenario in the automobile industry, a three way catalytic convertor is used widely to reduce HC, CO and NO\textsubscript{x} emissions which are formed during the combustion process. A three way catalyst runs three tasks simultaneously with each other. One catalyst is responsible for the reduction of nitrogen oxide to both oxygen and nitrogen while the other catalyst is responsible for oxidation of carbon monoxide to carbon dioxide and using unburned HC’s and oxidizing them to H\textsubscript{2}O and CO\textsubscript{2}.

The oxidation and reduction reaction takes place in the honeycomb monolithic structure. The role of the honeycomb structure of the substrate is to increase the surface area covered by the catalyst layer exposed to the exhaust gases. Ceramic monoliths structure are abundantly used in automotive catalysts which has many channels of small hydraulic diameter of 1 mm and with a cross section with cell densities varying between 31-93 cells/cm\textsuperscript{2}. The monolithic structure is concealed with a thin layer of Rhodium as reduction catalyst and Palladium as oxidation catalyst. Platinum is also present in traces which helps both oxidation and reduction reactions. The reactions happen on the metal catalyst surface. Hence greater the surface area, maximum conversion efficiency will be achieved because the oxidation reactions depend on the surface on which species can absorb and react.

2.3 Test Fuel (Neem Blend B20)
Natural neem oil is a dark brown, a strong odored and bitter tasting plant. Neem is Indian specie found in Burma and other Asian countries and the entire tree is useful for medicine, organic manure and pesticide. It can conveniently grow on rocky, dry and shallow soils [6,7]. Neem trees are capable of tolerating extreme heat, annual rainfall of less than 35 cm. Matured trees of 10 years old can provide an average yield of 5.2 tonnes per hectare. The average percentage of oil yield and efficiency of oil extraction are 27% and 93% respectively. Based on the energy index of 1.64, biodiesel from neem proved to be one of the few promising renewable sources of fuel from environmental protection point of view. The main
element of neem oil is Azadirachtin with varying proportion of 300 to 2500 ppm based on the extraction method and crushed oil seed quality. The oil has pungent odor due to the presence of sulfur and is considered less clean burn as compared to other vegetable oils [8,9]. The properties of the test fuel used were given in Table 1.

Table 1. Comparison of properties of Neem Blend with Diesel.

| Properties                  | Diesel | Neem Oil | Neem Oil Blend (B20) |
|-----------------------------|--------|----------|----------------------|
| Density (g/cm³)             | 0.8358 | 0.943    | 0.8465               |
| Calorific Value (kJ/kg)     | 44600  | 39842    | 44124                |
| Kinematic Viscosity (Cst)   | 2-3    | 38.3     | 5.96                 |
| Flash Point (°C)            | 75     | 201      | 88                   |
| Cetane Index                | 51     | 55       | 51                   |

3. Methodology
A suitable catalyst is chosen which accelerates a chemical reaction. It doesn’t take part in the reaction and hence works indefinitely unless degraded by heating, aging or by contamination. The catalyst materials most used are Platinum, Palladium, and Rhodium. Platinum plays an especially active role in the hydrocarbon reaction. A catalytic converter is selected in such a manner so as to accommodate the catalytic material which promotes the oxidation of emission contained in the exhaust flow. The catalyst aids in the reaction of Carbon monoxide and Hydrocarbons with the remaining oxygen in the exhaust. The efficiency of the catalyst is very much dependent on temperature. It is seen that when a converter in good working condition is operated at a fully warmed temperature of 400°C or above. It is desirable that the catalytic converter has an effective life span as they tend to lose their efficiency with age due to thermal degrading and poisoning of the catalyst material. An appropriate equivalence ratio must be chosen to get higher converter efficiency. The catalytic converter should be operated hot to be efficient, but not hotter as serious thermal degradation may occur in the temperature range of 500-900°C.

Figure 1. A view of the catalytic converter setup.
4. Results and Discussion
The influence of Catalytic converter and neem blend on various exhaust gases has been experimentally investigated in this study. Experimental readings pertaining to engine performance and exhaust emission were recorded in different trials and tabulated. An analysis is carried out with the average of the trial values.

4.1. Emission characteristics
4.1.1. CO emission variations
Figure 2, depicts the changes in carbon monoxide emission with respect to brake power. These graphs show that CO emission increases with increase in engine load. The emission of CO for neat neem oil blend decreases by 45.67% in presence of converter on comparison when converter isn’t present. Whereas when diesel is used with the catalytic converter it reduces diesel emissions by 65.51%.

![BP vs CO](chart.png)

Figure 2. Changes in CO emissions with Brake Power.
4.1.2. Comparison of HC emissions

**Figure 3.** Changes of HC emissions with Brake power

Partially burnt or unburnt HC’s come out from the exhaust in vapor form. The emission of unburnt HC’s is responsible for the formation of smog, photochemical reactive species and also carcinogens [10,11]. Figure 3 depicts the changes in Hydrocarbon emissions with respect to brake power. The emission of HC for neem oil blend decreases by 2.32% in presence of converter on comparison when converter isn't present. Whereas when diesel is used with the catalytic converter it reduces diesel emissions by 9.83%.

4.1.3. Comparison of NOx in exhaust emissions

**Figure 4.** Comparison of NOx emissions with Brake Power.

Figure 4 depicts the changes in NOx emission with respect to brake power. The results show that NOx emission increases with increase in engine load due to higher combustion temperature [12,13,14]. The emission of NOx for neat neem oil blend decreases by 38.77% in presence of
converter on comparison when converter isn’t present. Whereas when diesel is used with the catalytic converter it reduces NO\textsubscript{x} diesel emissions by 51.70%.

4.1.4 Comparison of CO\textsubscript{2} in exhaust emissions

![BP vs CO2](image)

**Figure 5.** Comparison of CO\textsubscript{2} emissions with Brake Power.

Figure 4 depicts the changes in CO\textsubscript{2} emission with respect to BP. The emission of CO\textsubscript{2} for neem oil blend increases by 47.41% in presence of converter on comparison when converter isn’t present. Whereas when diesel is used with the catalytic converter it increases diesel emissions by 42.10%. Also on comparison to diesel the CO\textsubscript{2} emissions of neem blend with converter rises by 1.75%.

4.1.5 Comparison of Brake Thermal Efficiency in exhaust emissions

Figure 6 depicts the changes in Brake Thermal Efficiency with respect to brake power. The Brake Thermal Efficiency for neem oil blend decreases by 2.62% in presence of converter on comparison when converter isn't present. Whereas when diesel is used with the catalytic converter it reduces diesel emissions by 2.09%. Also on comparison to diesel the BTE of neem blend with converter falls by 2.92%. In all the remaining loads when coupled with catalytic converter neem blend has better brake thermal efficiency than diesel.
5. Conclusions

The performance and emission characteristics of neem oil blend fuelled Compression Ignition engine with a Catalytic converter system were studied and analysed. Based on the results derived from the experimental investigation, conclusions were drawn as summarized below.

1. The emission of NOx for neat neem oil blend decreases by 38.77% in presence of converter.
2. The emission of CO for neem oil blend decreased by 45.67% in presence of converter on comparison when converter isn’t present.
3. The Brake Thermal Efficiency for neem oil blend decreases by 2.14% in presence of converter on comparison when converter isn’t present. Also on comparison to diesel the BTE of neem blend with converter falls by 3.15%. In all the remaining loads when coupled with catalytic converter neem blend has better brake thermal efficiency than diesel.
4. The emission of HC for neem oil blend decreases by 2.32% in presence of converter.
5. The emission of CO2 for neem oil blend increases by 47.41% when converter is placed. Also on comparison to diesel the CO2 emissions of neem blend with converter rises by 1.75%

Based on the present experimental investigation, it is observed that Neem Blend and a coupled catalytic Converter absorb a significant amount of CO emission along with a slight reduction in emissions unburnt HC & NOx. This simple and reliable method of mitigation could be employed in large scale in industries for environmental protection.

Acknowledgement

We would like to thank management of SRMIST for providing the laboratory facilities for performing the experimental investigations.

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