Development and Performance Analysis of Catalytic Converter Based on Ferric Oxide for Four Stroke Diesel Engine

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Abstract— Reduction of toxic substances emission from combustion engines can be achieved in automotive exhaust after treatment process is applied based on oxidation and reduction processes which are takes place in catalytic converter. Exhaust emissions of much concern are Hydrocarbon (HC), Carbon Monoxide (CO) and Nitrogen Oxide (NOx) from the automotive vehicles. Catalytic converter oxidizes harmful CO and HC emission to CO2 and H2O in the exhaust system and thus the emission is controlled. Generally catalytic converter uses platinum group of metals like Pt, Pd and Rh. There are several types of problems and higher cost of noble metals associated with this noble metal based catalytic converter. The present work is aimed at using ferric oxide as a catalyst for catalytic converter. Wire mesh of ferric oxide catalytic converter is developed by metal vapour vaccum arc process. The experiment is carried out on four stroke four cylinder CI engine. By using ferric oxide based catalytic converter it is found that HC is reduced by 30%, CO by 24% and NOx by 16% at high load condition.

Key words: Exhaust Emission, Catalytic Converter, OEM Catco, Modified Ferric oxide Catco, Diesel Engine

I. INTRODUCTION

Air pollution created by vehicles is a major problem of general interest. Vehicle population is projected to grow close to 1300 million by the year 2030. Due to incomplete combustion in the engine, there are a number of incomplete combustion products CO, HC, NO_x, particulate matters etc. Most vehicular transportation relies on combustion of gasoline, diesel and jet fuels with large amount of emission of carbon monoxide (CO), unburned hydrocarbons (HC), nitrogen oxides (NOx) and particulates matter (PM) are especially concern. HC and CO occur because the combustion efficiency is less than 100%. The NO*x* is formed during the very high temperatures (>1500 °C) of the combustion process resulting in thermal fixation of the nitrogen in the air which forms NO*x*.[1]

Typical exhaust gas composition at the normal engine operating conditions are: carbon monoxide (CO, 0.5 vol.%), unburned hydrocarbons (HC, 350 vppm), nitrogen oxides (NO*x*, 900 vppm) hydrogen (H2, 0.17 vol.%), water (H2O, 10 vol.%), carbon dioxide (CO2, 10 vol.%), oxygen (O2, 0.5 vol.%) [10].Carbon monoxide is a noted poison that has an affinity for hemoglobin in the blood 210 times greater than the oxygen affinity prolonged exposure to levels above 9 ppm can lead to reduce mental acuity for some individuals. HC and NOx lead to photochemical smog in presences of sunlight give secondary pollutants like ozone, nitrogen dioxide & peroxyacyl nitrate which cause also global environmental problems. As the emission standards were tightened, more advanced control strategies were applied that included modifications in engine design and fuel system, control of engine parameters and use of sophisticated exhaust after treatment devices. Reduction of toxic substances emission from combustion engines can be achieved by primary (inside engine) measure and secondary (outside engine) measures[1].

As primary measures many different possibilities and technical methods of reducing exhaust gas emission are used e.g. combustion of lean air fuel mixture, multistage injection fuel, exhaust gas recirculation, fuel gas after burning, loading of additional water into cylinder volume. Nowadays secondary measures, in automotive exhaust after treatment processes a range of advanced technology is applied based on oxidation and three-way catalyst adsorption storage and filtration process. This enables reduction of the carbon monoxide (CO), hydrocarbons (HC), nitrogen oxide (NOx) and particulate emissions from a gasoline or diesel engine to meet the demands of current and future exhaust emission regulations. This review paper discusses automotive exhaust emissions and its impact, automotive exhaust emission control by platinum (noble) group metal based catalyst in catalytic converter, types of catalytic convertor, different materials of catalytic convertor and also achievements of catalytic convertor.

II. CATALYTIC CONVERTER

The pollutants have negative impact on air quality, environment and human health that leads in stringent norms of pollutant emission. Numbers of alternative technologies like improvement in engine design, fuel pretreatment, use of alternative fuels, fuel additives, exhaust treatment or better tuning of the combustion process etc. are being considered to reduce the emission levels of the engine. Out of various technologies available for automobile exhaust emission control a catalytic converter is found to best option to control CO, HC and NOx emissions from petrol driven vehicles while diesel particulate filter and oxidation catalysts converter or diesel oxidation catalyst have so far been the most potential option to control particulates emissions from diesel driven vehicle. A catalytic converter is placed inside the tailpipe through which deadly exhaust gases containing unburnt fuel, CO, NOx are emitted. The function of the catalytic convertor is to convert these gases into CO2, water, N2 and O2 and currently, it is compulsory for all automobiles plying on roads in US and Japan to have catalytic converters as they use unleaded petrol. In India, the government has made catalytic converters mandatory for registration of new cars.

Reactions in Catalytic Converter:-

Oxidation: $2CO + O_2 \rightarrow 2CO_2$

$HC + O_2 \rightarrow CO_2 + H_2O$

Reduction/3-way: $2CO + 2NO \rightarrow 2CO_2 + N_2$,

$$2HC + 2NO \rightarrow CO_2 + H_2O + N_2$$
$$2H_2 + 2NO \rightarrow 2H_2O + N_2$$

III. LITERATURE SURVEY

Narendrasinh R. Makwana et al present paper on development and performance analysis of nickel based catalytic converter. There are several types of problems associated with noble metal based catalytic converter. These factors encourage for the possible application of non-noble metal based material such as nickel as a catalyst. They have used Nickel as the oxidizing agent because of its non-poisonous nature, low cost and availability makes it preferred carrier in oxidation from the stationary pollution sources. Experimental tests were carried out on four cylinder four stroke diesel engine equipped with modified catalytic converter with using 30 mesh, 40 mesh and 50 mesh size of nickel coated wire mesh. It was found that most suitable for emission conversion rate is the 50 mesh size wire mesh. Because the surface area of 50 mesh size wire mesh is higher compare to 30 mesh size and 40 mesh size of wire mesh. By using nickel based modified catalytic converter, CO reduces up to 35% and HC reduces up to 40%. It was also found that the nickel is not effective for reducing the NOx content from exhaust emission. The price of nickel is approximately Rs. 900 per kg is very less as compared to platinum and palladium. Hence, nickel based catalytic converter is economically effective for diesel engine[5].

Chirag M. Amin et al present paper on copper based catalytic converter using four stroke single cylinder CI engine. . The optimum values of exhaust emissions found at full load are HC (130 ppm), CO (0.07 %). By using copper based catalytic converter it is found that HC is reduced by 38 % and CO by 33 % at full load. Though not a noble metal, copper works as a catalyst for the conversion of pollutants in exhaust but in a limited proportion. Experimental results shows that, by using copper based catalytic converter, HC reduces by 38% and CO reduces by 33%. It is therefore concluded that development of copper based catalytic converter is feasible since it gave satisfactory results for given operating conditions and reduction of HC and CO emissions. Thus the copper based catalyst system can be the effective approach in place of expensive noble metal based catalytic converter, but NOx emission is not measured in this research. The expenditure for fabricating a single catalytic converter is Rs. 2000 to Rs. 2500 but on mass production this cost can be reduced to economic range[6].

D. Reichert et al present paper on study of the reaction of NOx and soot on Fe_2O_3 catalyst in excess of O_2.This paper presents characteristics of a new catalytic converter based on ferric oxide (α- Fe_2O_3) in relation with NOx and soot reduction in emission. Experiments are performed with and without Fe_2O_3 catalyst using different gas mixture. Examinations show that the NOx reduction on the Fe_2O_3/soot mixture occurs on the soot surface without being directly affected by the catalyst. Furthermore, O_2 is considered to be crucial for the NO/soot reaction as it produces CC(O) complexes that decompose and lead to the formation of active carbon sites with suitable orientation of the atomic orbitals. Such appropriate surface configuration facilitates the dissociation of NO and formation of N_2. At these locations the oxygen is transferred to the soot, whereas the contact points maintain even up to high soot conversion levels. Thus, it is concluded that the catalyst affects the soot oxidation without intermission. Finally, our studies show that only surface and sub-surface oxygen of the Fe_2O_3 catalyst is involved in the oxygen transport. So, from this research paper it is concluded that Fe_2O_3catalyst may become more crucial for reduction of NOx in the exhaust emission of vehicles[7].

Steffen Wagloehner et al present paper on study on the mechanism of the oxidation of soot on Fe_2O_3 catalyst. For the removal of soot from the exhaust of diesel engines so called diesel particulate filters (DPF) are currently applied. These filters operate with high efficiency by forcing the exhaust to flow through their porous walls. paper we conclude a scheme of global reactions describing the mechanism of the catalytic soot oxidation on Fe_2O_3. According to this scheme illustrated in oxygen is transferred from the catalyst surface to the soot by contact points. The resulting oxygen defects of the catalyst surface are refilled either by surface migration and final re-oxidation by gas-phase oxygen, respectively, or by diffusing bulk oxygen. The oxygen deficiency of the lattice is balanced by migration of oxygen from the surface or sub-surface to the bulk of the catalyst. Furthermore, the heat capacity of the catalyst reveals strong effect on the heat evolution upon soot oxidation thus affecting the local temperature and the rate of soot oxidation. Hence, for maximum soot oxidation rate an optimum mass of catalyst is required. Additionally, high catalytic activity is closely related to a sufficient amount of contact points between Fe_2O_3 and soot[8].

IV. CATALYST AND SUBSTRATE PREPARATION

A. Material Selection for Catalyst:

Ferric oxide is used as the reducing agent. Its non-poisonous nature, low cost, and availability makes it preferred carrier in reduction from the stationary pollution sources.

B. Material Selection for Substrate:

The substrate material is stainless steel, as it is widely used in the automotive exhaust system not only due to its advantages in mechanical and physical properties but also low-cost. The stainless steel wire mesh was cut to a circular shape prior to catalyst coating.

C. Treatment for Wire Meshes Substrate:

Stainless steel wire mesh pieces were coated with metal catalyst (Ferric Oxide) before arranged onto a straight bar.

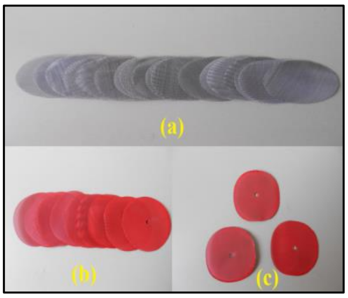

Fig. 1: Various Views of Wire Mesh

(a) 30*30 mesh/inch2 size of S.S. wire mesh before coating
(b) Ferric oxide coated wire mesh
(c) Wire mesh of Ferric oxide after coating

Following procedure is carried out for Ferric Oxide coating on substrate:

1) Ttitanium was implanted onto 304 stainless steel by a metal vapour vacuum arc (MEVVA) ion source followed with annealing treatment in air at 450 °C.
2) 2. Iron oxide (Fe_2O_3) was formed combining with TiO_2 on the annealing Ti implanted stainless steel surface. Thickness of Ferric Oxide coating on wire mesh was 50-60 micron.

The fabrication of catalytic converter consists of few components, namely the converter chamber, substrate and insulator. The catalytic converter casing and chamber remain as same as originally installed into the vehicle system. The same outer dimensions were purposely fixed in order to avoid redesign of the existing exhaust system, which then required further thermal optimization and design validation studies. Holes are drilled and provision is provided on converter chamber to mount thermocouple as well as manometer.

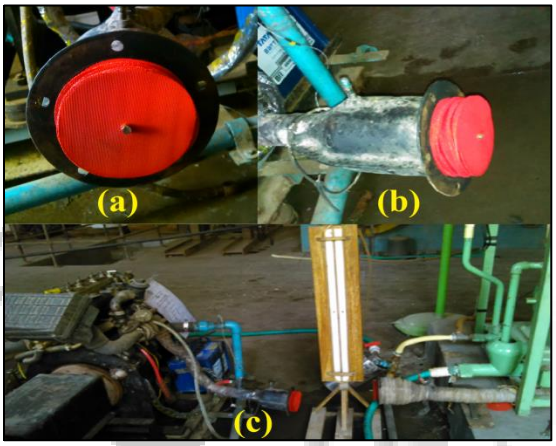

Fig. 2: Developed CATCO Assembly

(a) Coated wire mesh mounted in modified CATCO
(b) Wire mesh inserted in modified CATCO
(c) Developed CATCO mounted on engine setup

V. EXPERIMENTAL WORK AND METHODOLOGY

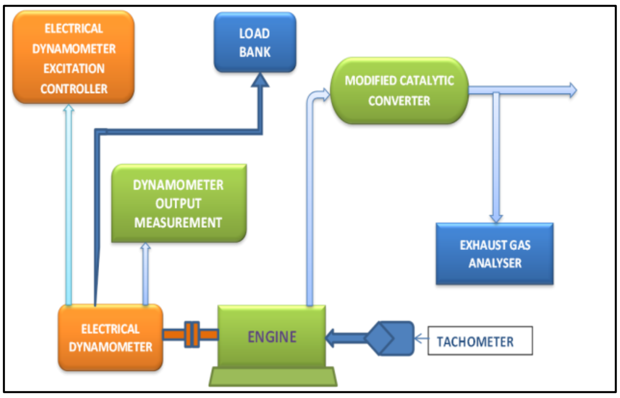

Fig. 3: Layout of Experimental Setup

A four cylinder four stroke diesel engine coupled with electrical dynamometer was used for data collection by using digital voltmeter and ameter. The engine is a water cooled, naturally aspirated and DI diesel engine. The main specifications are given in table 4.1. The engine is a completely self-contained test bed incorporating electrical dynamometer, with panel board consists of ammeter and voltmeter fuse carries.

Four stroke four cylinder Diesel engine is coupled with The electrical dynamometer which is capable for 30 hp at 2000 rpm. Power produced by engine will be supplied to generator by means of coupling joint to produce electrical power. Amount of power generates into the generator will be supplied to load bank which has heaters which will consume that power.

VI. RESULT AND DISCUSSION

A. *CO Vs Brake Power:*

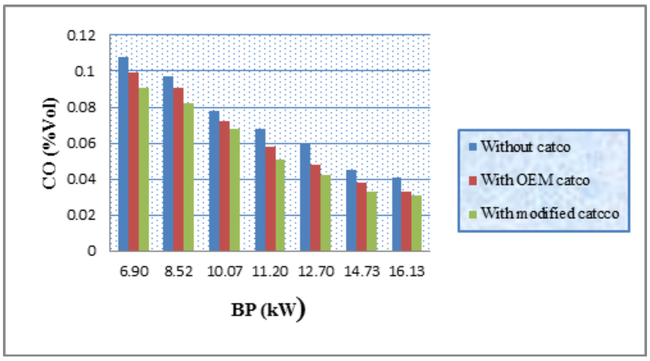

Fig. 4

It has been seen from figure that when brake power increases amount of CO decreases with respect to load. Because of CO emission is observed to be decreasing due to increased rate of complete conversion of Carbon to Carbon dioxide (CO_2). The CO emission when considered with respect to modified catco is much lesser than without catco. While comparing with not mounting catalytic converter, with catalytic converter gives less emission of CO and further decrement of CO occur when modified catalytic converter is used. At higher brake power for modified catalytic converter CO is reduced to 30% than without catalytic converter at 12.7 kW brake power.

B. *HC Vs Brake Power:*

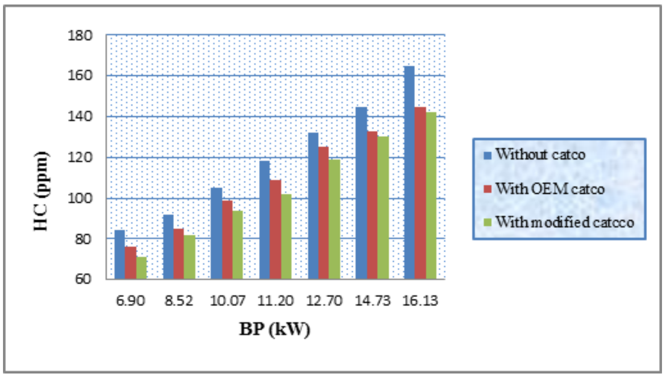

Fig. 5: HC Vs Brake Power:

Hydrocarbon contents are highest while diesel was used as fuel and catalytic converter is not mounted on the engine. From the above figure, it has been seen that hydrocarbon content reduces by 18% and 24% at power 16.13 kW, when OEM catalytic converter and modified catalytic converter is attached on the engine respectively.

C. *NO_x Vs Brake Power:*

It is seen that NO_x emission always higher at higher power was generated by engine. Amount of NO_x emission is in direct proportion with temperature. So as brake power increases temperature of combustion also increases, as NO_x

increases. Here NO_x contents are highest while catalytic converter is not mounted on the engine. Here Modified catalytic converter is much effective for reduction of NO_x emission at higher brake power condition. NOx reduces up to 16 % at 14.73 kW brake power.

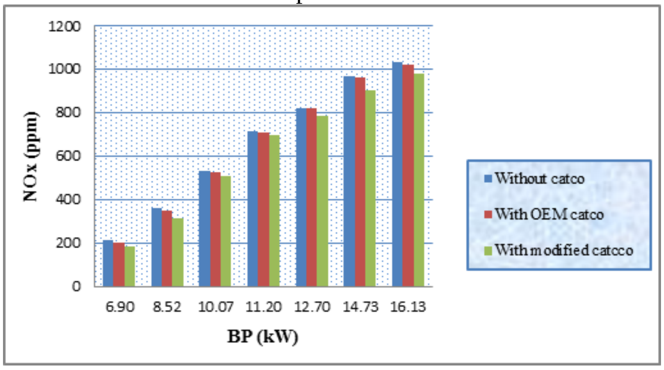

Fig. 6: NOx Vs Brake Power

D. CO_2 Vs Brake Power:

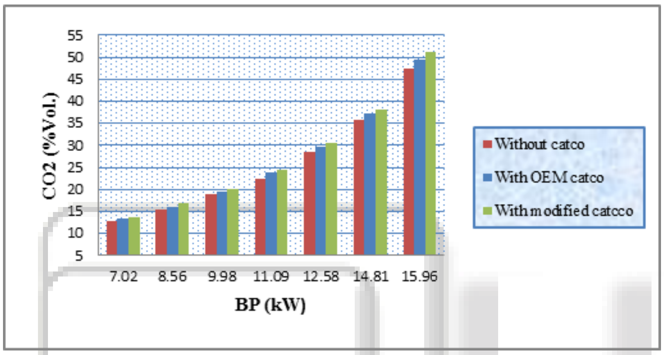

Fig. 7: CO_2 Vs Brake Power

From figure, it has been seen that as brake power of engine increases CO2 content also increases due to the fact that more amount of air-fuel mixture is inducted in to the engine at higher load. As more amount of air-fuel is supplied, it produces more amount of CO2. When catalytic converter is not attached with engine it produces less amount of CO2.When OEM catalytic converter and modified catalytic converter is attached with the engine, amount of CO2 increases by 15%, and 22% respectively.

E. Back Pressure Vs Brake Power:

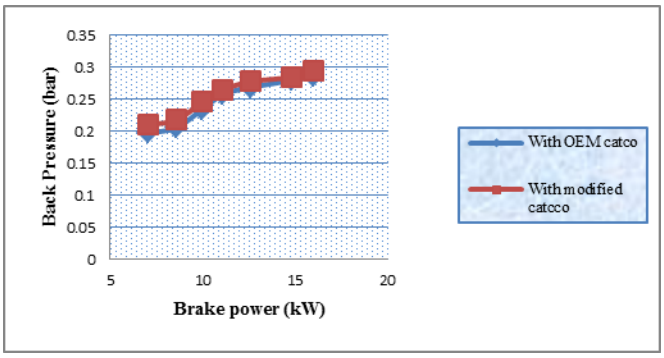

Fig. 8: Back Pressure Vs Brake Power:

At low engine speed the back pressure has no significant effect on engine performance with various load conditions. At medium and high engine speed the performance constant up-to a certain back pressure (0.228 bar) and then decreased. From the fig. 6.5, it is observed that when ferric oxide coated wire mesh is placed than the back pressure is slightly higher than the OEM catalytic converter, and the maximum back pressure is generated at highest brake power which is 15.96 kW.

VII. CONCLUSION

From above graphs of emissions it is concluded that, by using ferric oxide as catalyst leads to reduction in emission of Hydrocarbon (HC) and Carbon Monoxide (CO) by 30% and 24% respectively. It also reduces NO_x by 16%. Experimental analysis on Copper and Nickel based catalytic converter has been done so far, but not much effect analysed in reduction of Nitrogen Oxide (NO_x).So, Ferric Oxide (Fe_2O_3) can be much effective as catalyst for effective reduction of Nitrogen Oxide (NO_x).

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