

Experimental Investigation of Emission Control on CI Engine Using Gold Base Catalytic Converter

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ABSTRACT: in the last years, the world has been confronted with an energy crisis. The most use fuel and petroleum are becoming scarce and its use is associated with the increase of environmental problems. The concerns about clean environment driving forces for the research on catalytic converter which use for reduce the harmful exhaust emission from C.I. engine which are the NO_x, CO, HC and CO₂. Researcher's focuses the work by installing catalytic converter based on the use of platinum, palladium and rhodium play a major role in the cleaning of automobile emissions. But the annual global supply of platinum is only about 210 tones. Therefore increases prices of platinum. So there is need to change the catalyst of catalytic converter and implemented new catalyst. Gold nano particles are used in automotive catalytic converter for selective oxidations of CO and hydrocarbon. Gold has been considered as an active catalyst only when suitable techniques of preparation provided high metal dispersion. Major developments in Nanotechnology have taken place across the world over the last few years. The transition from micro-particles to nano-particles can lead to substantial changes in the properties of materials. These properties can be very helpful in prevention of automobile pollution which has become a grave problem today. The major contributors towards automobile pollution are automobiles. In this paper the control strategies and achievements in automotive pollution control are discussed. Attention is focused on the recent development in the field of the three way type catalytic converter.

KEYWORDS: Exhaust emission, design of catalytic converter, gold catalyst with TiO₂ & CoO support, diesel engine.

1. INTRODUCTION

In 2014, 82.8 million vehicles were playing on Indian roads. According to statistics provided by the Ministry of Road Transport & Highways, Government of India, the annual rate of growth of motor vehicle population in India has been about 10 percent during the last decade. The basic problem is not the number of vehicles in the country but their concentration in a few selected cities, particularly in metropolitan cities. Automobiles are the primary sources of air pollution in India's major cities. In India, transport sector emits an estimated 261 Tg of CO₂, of which 94.5% was contributed by road transport. In Delhi, the data show that out of total 300 metric tons of pollutants belched out every day, close to two third (66 %) is from vehicles. Similarly, the contribution of vehicles to urban Air pollution is 52 % in Bombay & close to one third in Calcutta. The transport sector in India consumes about 17 % of total energy & is responsible for 60 % of the Green House gas from various activities [31]. The pollution from vehicles is due to discharge like CO, unburnt HC, PM, NO₂ & suspended particulate matter mainly from tail pipes. This emission problem can be controlled by using catalytic converter. Catalytic converter is an exhaust after treatment, emission control device. It is intended to convert harmful combustion byproducts from an engine cylinder into harmless products, by increasing the rate of reactions, with the use of catalytic reaction at comparatively lower temperature levels. A catalyst is an element or compound that promotes a chemical reaction without being affected by the reaction. The purpose of using catalytic converter in compression ignition engines is to convert the harmful combustion by products into harmless products. Compression ignition engines burn with lean air-fuel mixtures of less than 20:1 that produce exhaust temperatures of 100⁰C to 400⁰C. This exhaust contains significant amount of particulate and pollute

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gases, that may require an after treatment device such as catalytic converter, in order to meet current requirements. To meet the environmental legislations, it is essential to reduce the amount of NO_x in the exhaust gases. In catalytic converter the catalyst used are platinum (Pt) palladium (Pd) and rhodium (Rh). It is also called as a noble metal, but we know the cost of this noble metal is more and its supply is less. There is one problem also resolved by equipping diesel vehicles with filters and two-way catalytic converters. Two-way catalytic converters require a higher loading of platinum than the three-way converters for gasoline vehicles [2]. Therefore, increased demand for platinum is a side effect of improving fuel efficiency by promoting diesel (and bio-diesel) vehicles. The platinum loading in a catalytic converter depends on engine type and size and emissions standards. It ranges from one to two grams for a small car in a lightly regulated environment to 12–15 g for a big truck with stringent regulations. The world's PGM resources are highly concentrated. Cerium, iron, manganese, nickel, gold, silver and copper are also used as a catalyst, although each has certain limitation. Nickel is not legal for use in European Union because of its reaction with carbon monoxide it converts into toxic nickel tetra carbonyl. Copper can be used everywhere except North America where its use is illegal because of the formation of toxic dioxin. But when gold is dispersed as a fine particle it demonstrated excellent activity to control the exhaust emission of compression ignition engine. Some important consideration in the application of nano size gold (Au) catalyst for emission control, including low temperature activity and thermal stability and possible approaches towards overcoming its inherent limitation are highlighted. Hence for the present work gold catalyst is selected as a catalyst in catalytic converter [7] & [8].

II. EMISSION CHARACTERISTIC AND CONTROL STRATEGIES

Engine exhausts consists of a complex mixture, the composition depending on a variety of factor such as type of engine (two or four stroke, spark or compression ignited), size of engine (1 HP, 5 HP, 10 HP, 20 HP etc), driving condition, e.g. urban or rural, metro city, vehicle speed, acceleration & deceleration, etc. The exhaust contains principally three primary pollutants, 1 unburned or partially burned hydrocarbon (HCs), carbon monoxide (CO) and nitrogen oxides (NO_x), mostly NO, in addition to other compounds such as water, hydrogen, nitrogen, oxygen, etc. Given the different nature of the three classes of pollutants, i.e. reducing or oxidizing agents, it is necessary to simultaneously carry out both reduction and oxidation reactions over the exhaust catalyst, which can occur by a variety of reactions. In general, the emissions depend on air-to-fuel (A/F)ratio, as exemplified in Fig. 1. Tuning of the engine to rich feed gives the highest power output, which, however, occurs at expenses of high fuel consumption. Under lean conditions lower combustion temperatures lead to lower NO_x emissions, however, at very high A/F engine misfire occurs, leading again to high HC emissions. Under any A/F conditions catalytic abatement of pollutants is needed to comply with the legislation limits. Only at stoichiometric conditions are appropriate amounts of reducing and oxidizing agents present in the exhaust to carry out the catalytic reactions. Under such conditions TWCs effectively remove the pollutants [6].

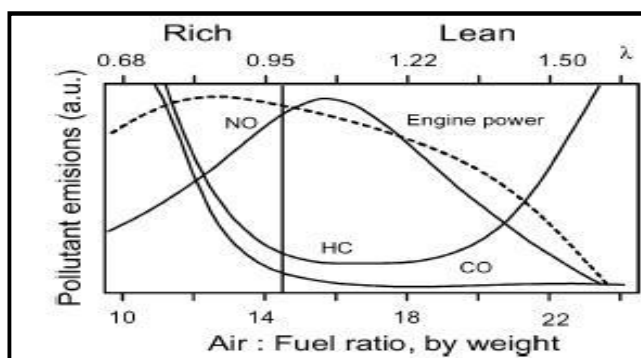


Fig.1. Effect of A/F ratio (w/w) on engine emissions and engine power

As for the exhausts originated by diesel, let us observe that even though diesel engines run in an excess of oxygen, typically 8.85 of O₂ is present in the exhausts compared to approximately 1% found in the engine fed at stoichiometric; the precise nature of the exhaust gases significantly differs between the two systems. In fact, diesel engine emit HC and

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NO_x at PPM levels (646–490 PPM) and large amounts of O₂ (8.82), at 1500 RPM and at full load. However, as far as the HCs are concerned, there is an important difference in that very low levels are emitted from the diesel engine (NO_x), which makes necessary addition of a reducing agent to the exhaust in order to achieve appreciable reduction of the emitted NO_x [5].

III. SYSTEM DESIGN CRITERIA

The design criteria for the exhaust emission control system for small engines were as follow

1. High CO and HC reduction.
2. NO_x reduction if the cost of the system is not prohibitive and if the system is not too complex.
3. No engine power loss.
4. High mechanical and thermal durability.
5. No increase in Noise pollution.
6. Simple installation and maintenance in new engine as well as easy retrofitting equipment.

Metallic catalyst support was chosen as opposed to the ceramic support due to its low exhaust back pressure. Low back pressure is an important design feature which eliminates any possible engine power loss.

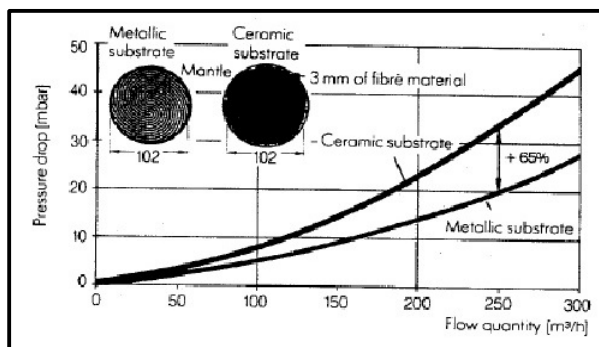


Fig.2. Exhaust back pressure of a metallic versus ceramic catalyst support of the same size

Table 1 shows geometrical and physical data of metallic and ceramic substrate [29]

Geometrical and physical data	Metallic substrate	Ceramic substrate
Wall thickness (mm uncoated)	0.05	0.2 - 0.15
Cell density (cps)	400	400
Clear cross section (% uncoated)	91.6	67.1- 76.0
Specific surface area (m ² /l)	3.2	2.4-2.8
Thermal conductivity (w/m-k)	14-22	1-0.8
Heat capacity (KJ/Kg-K)	0.5	1-0.5
Density (g/cm ³)	7.4	2.2
Thermal expansion (ΔL/L10 ⁰ /K)	15	1
Operating temperature (°C)	1500	1200

Low heat capacity and high thermal conductivity provide fast catalyst start-up so that exhaust purification can be achieved even during the engine cold start phase. A high % of clear cross section small geometrical size and high mechanical and thermal durability make the metallic catalyst support very suitable for the application in small engine powered equipment.

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Design Calculation of catalytic converter component.

$$\text{Space velocity} = \frac{\text{volume flow rate}}{\text{catalyst volume}}$$

Volume flow rate = swept volume \times Number of intake stroke

$$\begin{aligned} &= \frac{\pi}{4} \times d^2 \times L \times \frac{N}{2} \times 60 \\ &= \frac{\pi}{4} \times (0.080)^2 \times 0.110 \times \frac{1500}{2} \times 60 \\ &= 24.88 \text{ m}^3 \end{aligned}$$

$$\text{Catalyst volume} = \frac{\text{volume flow rate}}{\text{space velocity}}$$

Assuming that space velocity for a single cylinder diesel engine is 20000 hr⁻¹

$$\begin{aligned} \text{Catalyst volume} &= \frac{24.88}{20000} \\ &= 0.001244 \text{ m}^3 \\ &= 1244 \text{ ml} \end{aligned}$$

Shell dimension

$$L = 2d$$

$$\begin{aligned} \text{Catalyst volume} &= \frac{\pi}{4} \times d^2 \times L \\ 0.001244 &= \frac{\pi}{4} \times d^2 \times 2d \\ 0.001244 &= \frac{\pi}{4} \times d^3 \\ d^3 &= \frac{0.001244 \times 4}{\pi} \\ d &= 0.0925 \text{ m} \\ d &= 92.5 \text{ mm} \\ d &\cong 95 \text{ mm} \\ L &= 190 \text{ mm} \end{aligned}$$

Inlet cone and Outlet cone

Inlet cone is matched with exhaust pipe diameter

$$\begin{aligned} \text{Volume of cone} &= \pi \times \frac{h}{3} [(r_1)^2 + r_1 \times r_2 + (r_2)^2] \\ &= \pi \times \frac{100}{3} [(100)^2 + 100 \times 50 + (50)^2] \end{aligned}$$

$$\text{Volume of cone} = 1832.6 \text{ mm}^3$$

Catalyst loading

Catalyst loading was carried out by evaluating absolute mass of the components required to form the catalyst section during the reaction in the bed using the active component [22].

$$\text{Au/TiO}_2 \& \text{Na}_2\text{OSi} = C_1$$

$$\text{Co}_3\text{O}_4 \& \text{Na}_2\text{S}_2\text{O}_5 = C_2$$

$$W = \frac{v}{2} \times (C_1 + C_2)$$

$$= \frac{0.001244}{2} \times (0.550 \times 10^3 + 0.277 \times 10^3) \text{ kg}$$

$$W = 0.515 \text{ kg}$$

Mass of catalyst 0.515 kg

$$\text{Au/TiO}_2 = 0.240 \text{ kg (240 gram)}$$

$$\text{Co}_3\text{O}_4 \& \text{Na}_2\text{S}_2\text{O}_5 = 0.275 \text{ kg (275 gram)}$$

Spacer cylindrical spacer is located in between the circular housing containing wire meshing to reduce back pressure and restricting the movement of circular housing.

Wire mesh:-The circular shaped with 250 cells per circle inch and a thickness of 0.30 mm honeycomb monolith was employed in the current study

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The cell density N is defined as the Number of cells per unit of cross sectional area and is expressed in unit of cells per square inch (cpsi) or per square centimeter

$$N = \frac{1}{L^2} = \frac{1}{(200)^2} = 0.000025$$

The OFA is defined as a function of wall thickness cell spacing and cell density as shown in table

$$OFA = N (L-t)^2$$

Table2. Shows the configuration of wire mesh

Parameters	Dimension
Vertical diameter	1.27 MM
Horizontal diameter	1.27 MM
Cell length	200 MM
Cell density	400 cpsi

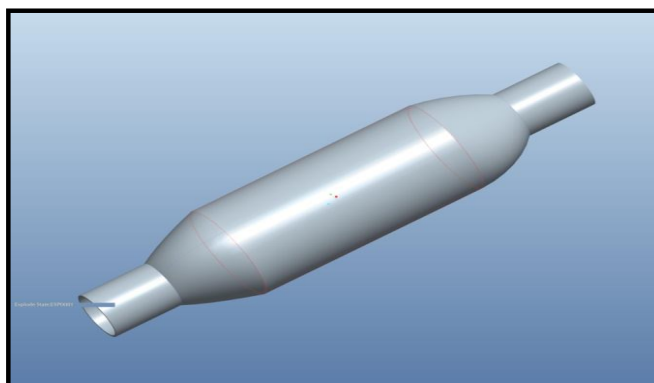


Fig.3. shows the full assembly of catalytic converter

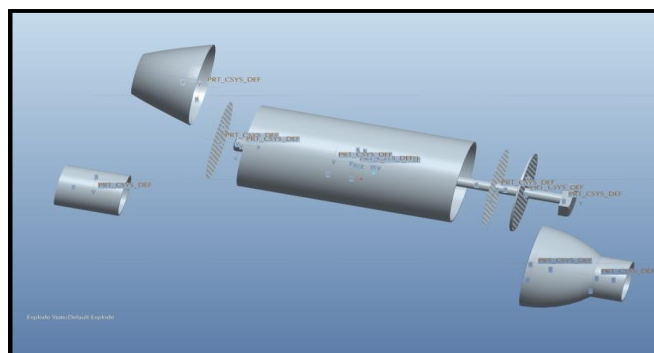


Fig.4.shows the explode view of catalytic converter.

From the reaction the space time was evaluated as the ratio of the reactor volume to that of the volumetric flow rate

$$T_S = \frac{V_R}{V_O}$$

V_R = converter volume

V_O = volumetric flow rate

= $2.22 \times 10^{-5} \text{ M}^3/\text{SL}^{-1}$ (measured)

T_S = space time

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$$T_s = \frac{0.001244}{2.22 \times 10^{-5}}$$
$$T_s = 56.03 \text{ sec}$$

Material Selection and Catalyst Preparation

Selecting raw material for catalyst is a stage in the production of catalyst for exhaust conversion. Preparation of the catalyst and its subsequent loading and application is a major factor in the control of exhaust conversion technology. There exist different ways and method of catalyst preparation especially through sedimentation, precipitation metal infusion, chemical vapour deposition, but for a catalyst to serve in exhaust converter, both the surface properties and the geometry are very important [15] & [16].

Material selection for catalyst

In this study, several stock solutions with different aqueous molar ratios and weight ratios were used. Gold supported Titanium dioxide (Au/TiO₂) and cobalt oxide (Co₃O₄) were used as a metal oxide catalyst. The Co₃O₄ is used as the reducing agent and Au/TiO₂ is the oxidizing agent. Its inertness to sulphate formation and surface properties makes it preferred carrier in selective catalytic reduction of NO_x from the stationary pollution sources [20].

Catalyst slurry preparation

By using deposition precipitation method 2% Wt of NaOH was suspended in 50 ml of ammonia and the PH was adjusted to 7 to 9 by adding HCL (0.1 Mol⁻¹) drop wise. Then 2 ml of an aqueous solution of HAuCl₄ and 20% Wt of TiO₂ was diluted with 50 ml of ammonia while stirring 500 rpm at 50^oC for 1 hour. After ageing for 1 hour the precipitate was washed with ultra pure water to remove chlorine ions, and then dried at 110^oC and calcined for 3 hours at 600^oC.

Sodium silicate solution and sodium Meta bisulphate were used in wash coat material to increase the coating strength to surface of woven Aluminum substrate. Hundred grams of sodium silicate solution was added into 30% Wt of Au/TiO₂ to get 30% Au/TiO₂ slurry. The slurry was then stirred at 5000 rpm for 30 minutes, and 6% Wt of Co₃O₄ and 4% Wt of sodium Meta bisulphate were gradually added. To ensure homogenization, it was milled for around 1:0 hours by using ball mill at 5000 rpm and then dried frozen at temperature 100^oC for 24 hours.

Material selection for substrate

The substrate material is Aluminum, 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 aluminum wire mesh was cut to a circular shape with a diameter of 95 mm prior to catalyst coating [13].

Treatment of wire mesh substrate

The wire mesh substrates were immersed into a preparation of 10% HCl solution for 30 minutes to remove all the impurities. It was then rinsed in distilled water before being dried in an oven at temperature of 100^oC. The drying process takes about 1 h before coating it with catalyst.

Wash coat material

Titanium dioxide, TiO₂ served dual functions: a reduction catalyst and a titanium substance for the wash coat. Rutile form of TiO₂ was chosen because of its thermal stability from 500^oC and high durability. This property is suitable for catalyst embedment [17] & [18].

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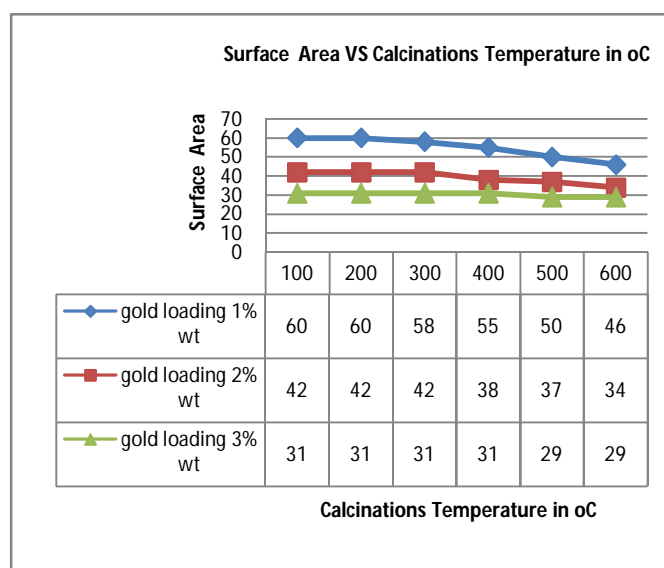


Fig.5. Surface properties of the gold loading Vs Calcinations Temperature

Substrate coating

The aluminum wire mesh was then coated with the metal catalyst via dipping technique. Figure 4 shows coated wire meshes that are calcined. In this process aluminum wire mesh was immersed into prepared catalyst slurry for the duration of 5.0 minutes. Then the coated wire mesh was removed from catalyst slurry to be blowed using air at the speed of 1.0 l/min until the unwanted residual catalyst was evaded from the surface of the aluminum wire mesh. After blowed process, coated aluminum wire mesh was dried in an oven at temperature 100°C for 10.0 hours before being calcined in a muffle furnace. Calcinations is a process in which a material is heated to a high temperature without fusing, so that hydrates, carbonates, or other compounds are decomposed and the volatile material is expelled. Calcinations take 6.0 hours at a temperature of 550°C. After the calcinations process the aluminum wire mesh were arranged into straight bar to become a substrate for use as a catalytic converter.

IV. EXPERIMENTAL SET-UP

In the present work, tests were conducted on a single cylinder, water cooled, four strokes, vertical, naturally aspirated, stationary, D.I diesel engine with a displacement volume of 661.5 cc, compression ratio of 17.5:1, developing 53.7 kW of power at 1500 rpm. The detailed technical specifications of the engine are given in table 3.

The test facility includes the following arrangements/ instruments/ analyzers:

1. Test engine coupled to an alternator and an electrical loading device.
2. Diesel flow measurement using a burette and stopwatch arrangement.
3. Piezo-electric pressure pick up for in -cylinder pressure measurement.
4. Thermocouples for the measurement of temperature of exhaust gases, cooling water, EGR system and intake charge.
5. Computer based digital data acquisition system for analyzing the pressure crank angle data and to obtain the heat release rate.
6. Smoke meter for measuring the exhaust smoke.
7. Exhaust gas analyzer for measuring HC, CO, NOX, and CO2 emissions
8. Flow meter for maintaining EGR flow rates

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Table3 Shows Specifications Of Kirloskar Diesel Engine

1	BHP/KW	53.7
2	RPM	1500
3	TYPE/SR.NO.	VRC1/10557
4	FUEL	H.S.D.OIL
5	LUBRICATION OIL	SAE-30/40
6	S.F.C.	25g/Kwhr
7	GOVT.NO.	B1



Fig.6.shows Photographic view of the experimental setup

V. RESULT AND DISCUSSION

5.1 Specific fuel consumption

The variation of specific fuel consumption with brake power for with and without converter is depicted in fig 7. It is observed that the specific fuel consumption without catalytic converter is higher when compared to that of with catalytic converter. This is due to low heating value and high viscosity of diesel without catalytic converter that result in making more heterogeneity in air fuel mixture resulting in increase in specific fuel consumption. However this can be offset by increasing the fuel injection pressure.

5.2. Break thermal efficiency

The variation of break thermal efficiency with brake power for with and without converter is depicted in fig 8. With catalytic converter it increased with increase in break power. This was due to reduction in heat loss and increase in power with increase in load. It is observed that, the operating conditions of average injection pressure test at each fuel, without converter thermal efficiency decreases gradually compared with catalytic converter for pure diesel. The higher injection pressure increases the atomization of diesel using 3-hole nozzle & spray characteristics (fine spray), and higher oxygen content

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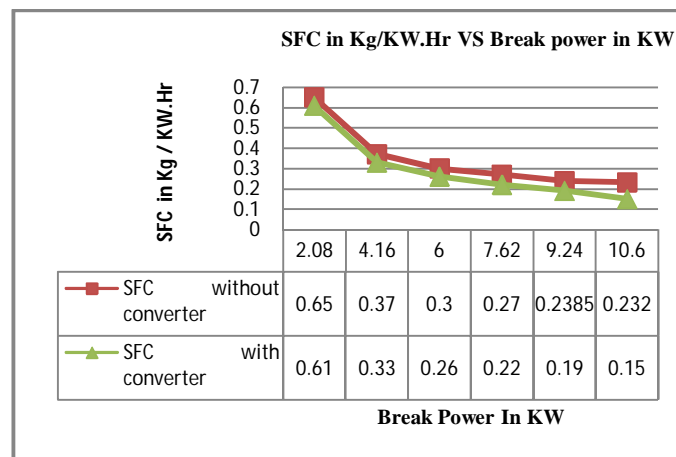


Fig.7. – shows the specific fuel consumption in Kg/KW-Hr versus Break power in KW.

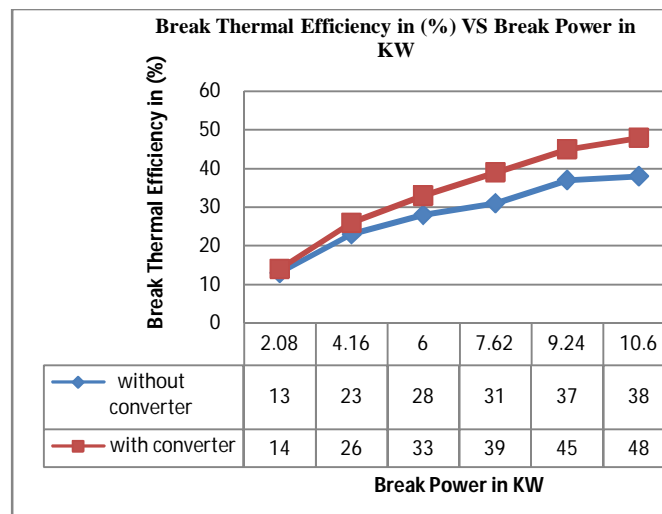
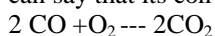


Fig. 8.-shows Break Thermal Efficiency in % versus break power in KW.

5.3. Carbon Monoxide

From experimental data following analysis it can be carried out when diesel is used a fuel. During starting of diesel engine carbon monoxide are highest in the exhaust because starting of diesel engine rich air fuel ratio is supplied to the engine and also because of incomplete combustion of fuel. When the air fuel ratio is too rich there is insufficient air for complete combustion or some fuel will not burnt or only at least partially burnt. Since hydrogen has a greater affinity for oxygen, hydrogen will take all the oxygen with a deficiency of oxygen. As a result of shortage of oxygen percentage carbon will be converted into carbon monoxide. As a load on engine increases, more amount of air supplied compared to fuel and carbon monoxide reduces because of complete combustion of fuel it can be seen in fig 9. When the more load is increases on engine the fuel is supplied more compare to air and again percentage of carbon monoxide increases.

From the below figure it can be concluded that when the break power of engine increases the temperature also increases and when the temperature of catalyst increases its ability to convert CO into CO₂ also increases, or simply we can say that its conversion efficiency increases.



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From the below figure we can say that the conversion efficiency of gold based modified converter and traditional platinum base converter are nearly equal.

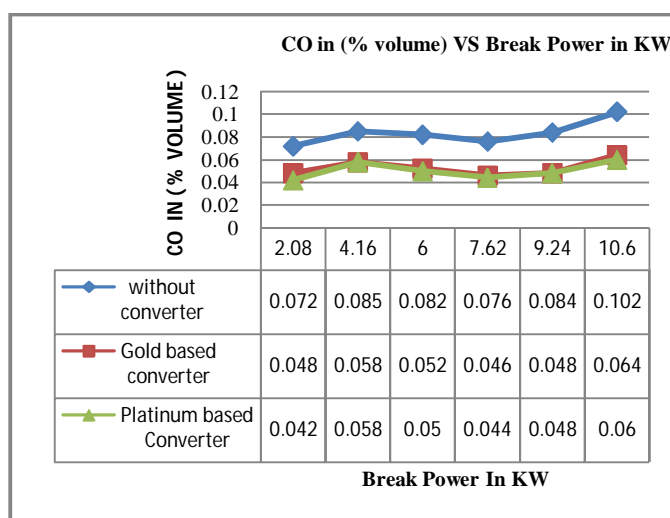
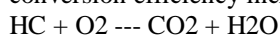


Fig.9.–Shows Carbon monoxide in % Volume versus break power in KW.

5.4. Hydrocarbon

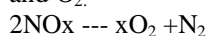
From figure 10 it can be say that when the break power of engine increases hydrocarbon content also increases, because of increase of fuel consumption. Generally hydrocarbon produces due to incomplete combustion of fuel. Due to existence of local very rich mixture pockets at lower temperature than combustion chamber, unburnt hydrocarbon will appear in the exhaust. The hydrocarbon also appears due to flame quenching near the metallic walls. From the below figure it can be concluded that when the break power of engine increases the temperature also increases and when the temperature of catalyst increases its ability to convert HC into H₂O & CO₂ also increases, or simply we can say that its conversion efficiency increases.



From the below figure we can say that the conversion efficiency of gold based modified converter and traditional platinum base converter are nearly equal at the low temperature level. When the break power increases the temperature also increases and at high temperature the efficiency of conversion of gold based catalytic converter reduces because it is suitable for only at low temperature level, because of their thermal stability.

5.5. Nitrogen oxides

Figure shows the NO_x emissions versus break power from 2.08 to 10.63 KW without converter, with modified converter and with platinum based converter. The test was conducted on a diesel engine. It was found that the gold based modified catalytic converter produces level of NO_x emission with an average of 412 PPM all over the break power, followed by platinum based traditional catalytic converter produces level of NO_x emission with an average of 389 PPM. Without catalytic converter produces NO_x emission with an average of 705 PPM. It can be calculated that the conversion efficiency of gold based and platinum based catalytic converter is 41.83% and 44.82% respectively. This conversion efficiency is due to the effect of metal oxide such as Au/TiO₂ and Pt/TiO₂. The Rutile phase of TiO₂ is suitable at high temperature level at catalyze the decomposition of NO to N₂ and O₂. In addition, the lowest period to reach light of temperature obtained by the TiO₂/CoO catalyst leads to increase the conversion efficiency of NO to N₂ and O₂.



From the below figure we can say that the conversion efficiency of gold based modified converter is 33.02% and traditional platinum base converter is 35.82% are nearly equal.

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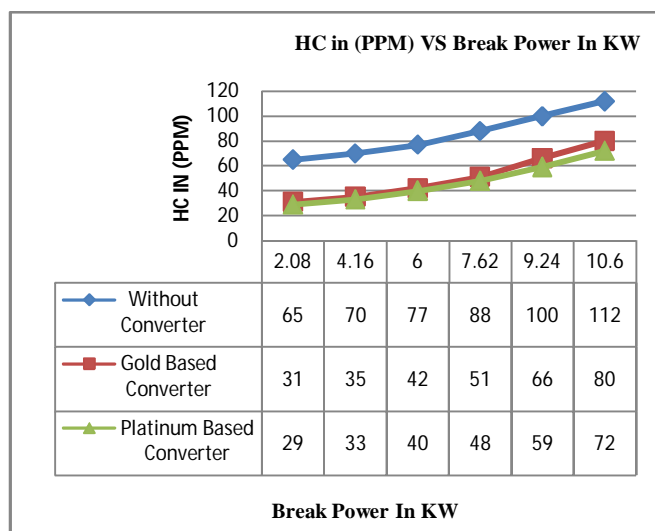


Fig.10. –shows Hydrocarbon in PPM versus break power in KW.

5.6. Carbon dioxide

As a load on engine increases, more amount of air supplied compared to fuel then complete combustion takes place and increases the carbon dioxide. Vice versa as a load on engine decreases more amount of fuel supplied compared to air then incomplete combustion of fuel takes place and increases the carbon monoxide and decreases the carbon dioxide it can be seen in the below figure.

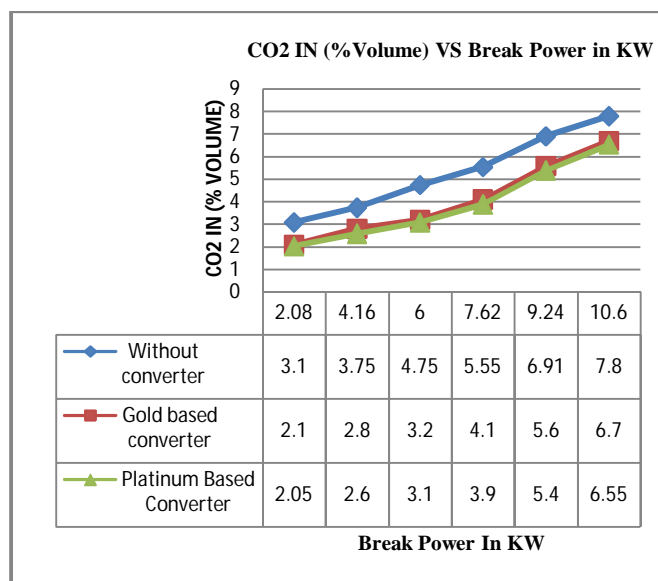


Fig.11.figure shows carbon dioxide in % volume versus Break power in KW

VI. CONCLUSION

This work introduces a simple low cost; non noble metal (gold) based catalytic converter manufacture with a wire mesh technology is used to reduce the diesel engine exhaust emission. Though not a noble metal, gold with titanium dioxide

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(TiO₂) and cobalt oxide work as a supportive catalyst for the conversion of pollutant in exhaust but in limited proportions. By using gold based modified converter, Carbon monoxide (CO) reduces by 36.92%, Hydrocarbon (HC) reduces by 41.45%, Nitrogen oxides (NO_x) reduces by 33.02% and Carbon dioxide (CO₂) reduces by 23.10%. Also improve the thermal efficiency of the engine. The conversion is done better at a low temperature level. But as the Break power increases temperature also increases and its conversion efficiency reduces. So conclude that gold with supportive oxides catalyst can be effective approach in a place of expensive noble metal based catalytic converter at a low temperature level.

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