International Journal of Research in Advent Technology (E-ISSN: 2321-9637) Special Issue
2nd International Online Conference on Advent Trends in Engineering, Science and Technology "ICATEST 2016", 03 April 2016

Minimization of CO CO_2 from Vehicle Exhaust by Catalytic Convertor

Vijay R.Hamand[1],Dikshatai S.Hatwar[2], Ekta R.Jadhav[3] , Lalitkumar D.Burde[4]
[1] *Student ,JDIET Yavatmal,vijay.hamand@gmail.com, 9175304845*
[2] *Student ,JDIET Yavatmal, dikshahatwar81gmail.com, 9975995194*
[3] *Student ,JDIET Yavatmal, ekta.jadhav25@gmail.com, 8482889114*
[4] *Student ,JDIET Yavatmal, lalitburde85@gmail.com, 9503123528*

Abstract: Air pollution generated from mobile sources is a 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_2, CO, HC, NOx, particulate matters etc. These 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. Among all the types of technologies developed so far, use of catalytic converters based on platinum rhodium palladium (noble) group metal is the best way to control automotive exhaust emissions.

Keywords: Vehicle population, Pollutant emission, catalytic converter, incomplete combustion.

1. INTRODUCTION:

Exhaust gases from internal combustion engines contain chemical substances and compounds components in gaseous phase like carbon monoxide nitrogen oxides hydrocarbons sulphur oxides as well as solid particles like black and condensed hydrocarbons which have an adverse impact on our

environment in the form of acidification, ozone formation, carcinogenic emissions, etc. Motor vehicles operation contributes considerably to the total toxic substances emission, particularly carbon monoxide, nitrogen oxides, hydrocarbons sulphur oxides. Carbon dioxide emissions are the common type of gas emitted from the burning of fossil fuels. When this CO_2 is released in to the atmosphere it remains there until it is absorbed in some form. 50% of CO_2 emission released in to the atmosphere is absorbed by oceans the ocean absorbs half of all carbon released into the atmosphere. CO_2, like all greenhouse gases does not absorb light waves from the sun where it absorbs heat waves because they have longer wave lengths than sun light does, thus stopping the heat from being reflected into space. This is called the "greenhouse effect" and has been linked by scientists to global climate change. **[1]**

If we reduce CO_2 emissions the air we breathe will be cleaner and that has got to be good for everyone. Global concentrations of CO_2 in the atmosphere have been increased from pre-industrialization levels of approximately 280 parts per million by volume in around 1860 to approximately 316 in 1958 and rapidly to approximately 369 today. Global CO_2 concentration is predicted to rise to above 750 by 2100. If no action is taken to address the current situation.CO_2 emissions have an impact on global climate change. Government is compelled to minimize motor-vehicle pollution problems with more stringent emission standards for reducing pollution related chemicals and improving air quality. **[2]**

1.1 History behind the catalytic converter for co_2 minimization:

The catalytic converter was invented by Eugene Houdry, a French mechanical engineer and expert in catalytic oil refining, who moved to the United States in 1930. When the results of early studies of smog in Los Angeles were published, Houdry became concerned about the role of smoke stack exhaust and automobile exhaust in air pollution and founded a company, Oxy-Catalyst. Houdry first developed catalytic converters for smoke stacks called "cats" for short. Then he developed catalytic converters for warehouse forklifts that used low grade non-leaded gasoline. Then in the mid-1950s. He began research to develop catalytic converters for gasoline engines used on cars. He was awarded United States Patent 2742437 for his work.

Widespread adoption of catalytic converters didn't occur until more stringent emission control regulations forced the removal of the anti-knock agent tetraethyl lead from most gasoline. Lead is a 'catalyst poison' and would effectively disable a catalytic converter by forming a coating on the catalyst's surface. Catalytic converters were further developed by a series of engineers including John J. Mooney and Carl D. Keith at the Engelhard Corporation, creating the first production catalytic converter in 1973. Dr. William C. Pfefferle developed a catalytic combustor for gas turbines in the early 1970s, allowing combustion without significant formation of nitrogen oxides and carbon monoxide. **[2]**

1.2 Actual need of co_2 minimization in vehicle exhaust:

According to a report from the car industries (Volkswagen and Audi), N2, CO2, H2O and O2, are the major components of vehicle exhaust emissions The toxic exhaust components, the terms which used repeatedly are: CO, NOX, SO2, O3, heavy metals, HC and Diesel PM. These pollutants have very serious and irreversible impacts on both human health and the environment in which we live the pollutants with various human health effects were highlighted in the table given below: **[3]**

Pollutants and their effects on human health

Name of pollutant	Symbol	Effects on human health
Carbon dioxide	Co_2	Light headeness, warmth, and confusion immediately prior to unconsciousness.
Carbon monoxide	Co	effect on the oxygen delivery to the body's organs
Nitrogen dioxides	NOx	Linked to a wide range of respiratory problems; cough and sore throat.
Ozone	O_3	Can cause chest pain, coughing & shortness of breath
Heavy metals	Pb	Exposure will lead to irreversible damage to brain
Particulate matter	PM	Exposure may cause death, decreased lung function.
Hydrocarbons	HC	irritation to eye and damage lungs

Table No.1 Pollutants and their effects on human health

- **Carbon dioxide (CO_2) :**

CO2 is the most important greenhouse gas. It is mainly produced by the combustion of fossil fuels. The discussions about global warming and CO2 effect have increased people's awareness on the subject of CO2 emissions. As a GHG, CO2 absorbs the emitted heat, and heats in the atmosphere, causing widespread climate change. After industrial revolution, the concentration of CO2 in the world has risen by over 30% In 2005, the transport contributed to 25% of all the world anthropogenic CO2 emissions released into the atmosphere. Approximately 80% of those emissions are from road transport, of which 60% is from automobiles, SUVs and pick-up trucks**. [3]**

1.3 Literature review:

Since 1970, vehicle's exhaust pollutions have received increasing attention as a Source of air pollution at both local (human health concerns) and global (global Warming) scales. This study mainly discusses diesel and gasoline vehicles because, today, over 90% of vehicles on the road use gasoline and diesel fuels. The major Concerns of gasoline exhaust contaminants are carbon monoxide hydrocarbon, carbon dioxide and polycyclic aromatic hydrocarbons; the major Concerns of diesel exhaust emissions contaminants are nitrogen oxides and Particulate matter. The aim of this study is mainly to compare gasoline and Diesel fuels, and to determine which fuel and its developed forms are less harmful to Humans, and which are most suitable for the natural environment at both a local and global level. The results show that burning gasoline fuels will emit less Particulate matter and emissions than burning diesel fuels, but it will generate about 50% more CO_2 than diesel fuels, and it also emit about ten times more, Polycyclic Aromatic Hydrocarbons; and around five times more hydrocarbon than diesel fuels; burning diesel fuels will produce less CO_2 emissions than Gasoline fuels, but will emit around ten times more Nitrogen Oxides, and Particulate matter than gasoline fuels. Consequently using a gasoline car in urban areas might help to reduce the human health effects; using a diesel car on motorways or in rural areas might help to reduce the greenhouse gas Green House Gas emissions and minimize the global warming effects. Biofuels, biodiesel and ethanol, have the potential to minimize the vehicle exhaust emissions and adverse effects. Nonetheless, there are still many debatable issues around biodiesel, such as insufficient fuel supply and health concerns especially, ultrafine particles Ultrafine Particles In the future, there remains a need to continue the further Studies of vehicle exhaust emissions, and to improve the understanding of all vehicles Exhaust emissions and all of their impacts, especially the vehicle exhaust health research. **[4]**

2. Catalytic Convertor Used in vehicle exhaust to minimize CO_2:

- **There are two types of catalytic convertor:**

Two way converter:
This type of catalytic converter is widely used on diesel engines to reduce hydrocarbon and carbon monoxide emissions.

Three way converter:
Since 1981, three-way catalytic converters have been used in vehicle emission control systems in North America and many other countries on road going vehicles.

2.1 Construction of catalytic convertor:
The catalytic converter consists of following several components

1. **The Core or Substrate:**

The core is often a ceramic honeycomb in modern catalytic converters, but stainless steel foil honeycombs are used, too. The honey-comb surface increases the amount of surface area available to support the catalyst, and therefore is often called a "catalyst support". **[5]**

Specification of Engine

Table no 2. Specification of Engine

2. The Washcoat:

A washcoat is used to make converters more efficient, often as a mixture of silica and alumina. The washcoat, when added to the core, forms a rough, irregular surface, which has a far greater surface area than the flat core surfaces do, which then gives the converter core a larger surface area, and therefore more places for active precious metal sites. The catalyst is added to the washcoat (in suspension) before being applied to the core (in suspension) before being applied to the core. **[5]**

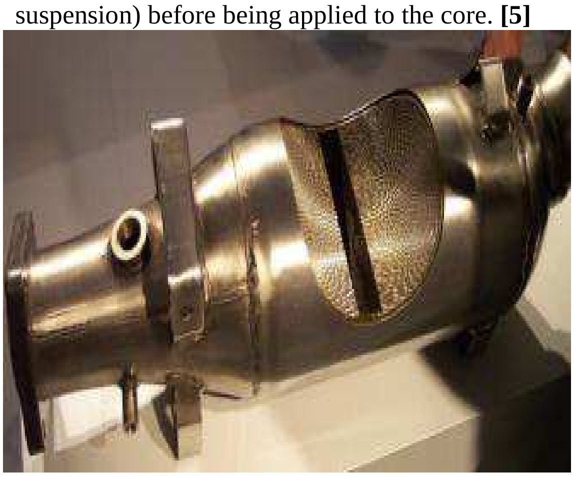
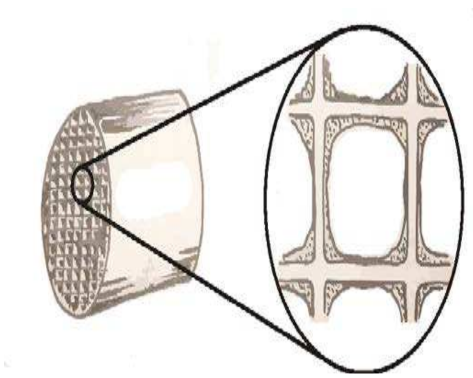


FIG.1: (a) Cutaway of a metal-core converter

FIG: (b) Ceramic -core converter

3. The Catalyst:
The catalyst itself is most often a precious metal. Platinum is the most active catalyst and is widely used. It is not suitable for all applications, however, because of unwanted additional reactions and/or cost. Palladium and rhodium are two other precious metals used. Platinum and rhodium are used as a reduction catalyst, while platinum and palladium are used as an oxidization catalyst. **[5]**



Features	Description
Type	Gasoline 1.3L, Straight 4 cylinder
Bore	73.0 mm
Stroke	77.4 mm
Displacement	1295cc 10 degree before TDC
Ignition timing (as per Haynes	5 degree before TDC @ 800rpm

FIG. 2 Schematic representations of Rh, Pt and Pd catalysts

Steps in a catalytic reaction
Diffusion from the bulk fluid to the external surface of the catalyst pellet
Diffusion of the reactant from the pore mouth through the catalyst pores to the immediately internal catalytic surface
Adsorption of reactant onto the catalyst surface
Reaction on the surface of the catalyst
Desorption of the product from the surface

Diffusion of the products from the interior pellet to the mouth at external surface

2.2 Catalytic Convertor mechanism:

2.2.1 Type of Reaction involved:

A two-way catalytic converter involved following reaction:

- **Oxidation of carbon monoxide to carbon dioxide:**

$2CO + O_2 \rightarrow 2CO_2 \quad \Delta H = -565.96$ KJ/mol

- **Oxidation of unburnt hydrocarbons (unburnt and partially-burnt fuel) to carbon dioxide and water:**

$C_xH_{2x+2} + 2xO_2 \rightarrow xCO_2 + 2xH_2O$ (a combustion reaction)

Fire is actually a combustion reaction and is exothermic in nature i.e. it liberates a lot of heat upon completion of the reaction. A three-way catalytic converter involved following reaction:

Reduction of nitrogen oxides to nitrogen and oxygen:

$$2NO_2 \rightarrow 2O_2 + N_2$$

Oxidation of carbon monoxide to carbon dioxide:

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

Oxidation of unburnt hydrocarbons to carbon dioxide and water:

$$C_xH_{(2x+2)} + 2xO_2 \rightarrow xCO_2 + 2xH_2O$$

2.2.2 Two-Way Catalytic Converter:

A two-way catalytic converter has two simultaneous tasks

Oxidation of carbon monoxide to carbon dioxide:

$2CO + O_2 \rightarrow 2CO_2$

Oxidation of unburnt hydrocarbons (unburnt and partially-burnt fuel) to carbon dioxide and water:

$$C_xH_{2x+2} + 2xO_2 \rightarrow xCO_2 + 2xH_2O$$

(a combustion reaction)

This type of catalytic converter is widely used on diesel engines to reduce hydrocarbon and carbon monoxide emissions.

2.2.3 Three-Way Catalytic Converter:

Since 1981, three-way catalytic converters have been used in vehicle emission control systems in North America and many other countries on road going vehicles. A three-way catalytic converter has three simultaneous tasks:

Reduction of nitrogen oxides to nitrogen and oxygen:

$$2NO_2 \rightarrow 2O_2 + N_2$$

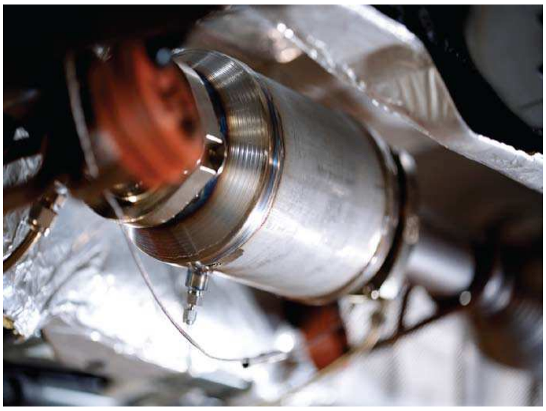
Oxidation of carbon monoxide to carbon dioxide:

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

Oxidation of unburnt hydrocarbons to carbon dioxide and water:

$$C_xH_{(2x+2)} + 2xO_2 \rightarrow xCO_2 + 2xH_2O$$

These three reactions occur most efficiently when the catalytic converter receives exhaust from an engine running slightly above the stoichiometric point. This is between 14.6 and 14.8 parts air to 1 part fuel, by weight, for gasoline. The ratio for LPG, natural gas and ethanol fuels is slightly different, requiring modified fuel system settings when using those fuels. Generally, engines fitted with 3-way catalytic converters are equipped with a computerized closed-loop feedback fuel injection system employing one or more oxygen sensors, though early in the deployment of 3-way converters, carburetors equipped for feedback mixture control were used. While a 3-way catalyst can be used in an open-loop system, NOx reduction efficiency is low. Within a narrow fuel/air ratio band surrounding stoichiometry, conversion of all three pollutants is nearly complete. However, outside of that band, conversion efficiency falls off very rapidly. When there is more oxygen than required, then the system is said to be running lean, and the system is in oxidizing condition. In that case, the converter's two oxidizing reactions (oxidation of Carbon monoxide and hydrocarbons) are favored, at the expense of the reducing reaction. When there is excessive fuel, then the engine is running rich. The reduction of NOx is favored, at the expense of Carbon monoxide and Hydrocarbon oxidation. Unwanted reactions can occur in the three-way catalyst, such as the formation of odiferous hydrogen sulfide and ammonia. Formation of each can be limited by modifications to the wash coat and precious metals used. It is very difficult to eliminate all these byproducts entirely. For example, when control of hydrogen sulfide emissions is desired, nickel or manganese is added to the wash coat. Both substances act to block the adsorption of sulfur by the wash coat. Hydrogen sulfide is formed when the wash coat has adsorbed sulfur during a low temperature part of the operating cycle, which is then released during the high temperature part of the cycle and the sulfur combines with hydrocarbon**. [6]**



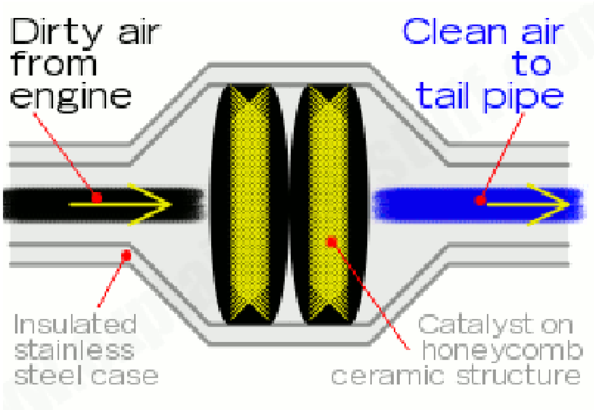


FIG 3. Schematic representation of Three-Way Catalytic Converter having Pt, Pd, Rh.

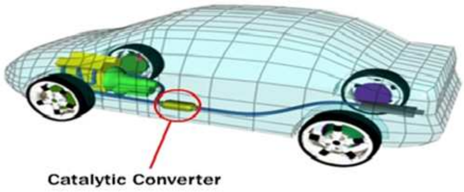


FIG 4 Schematic showing the position of catalytic convertor in car

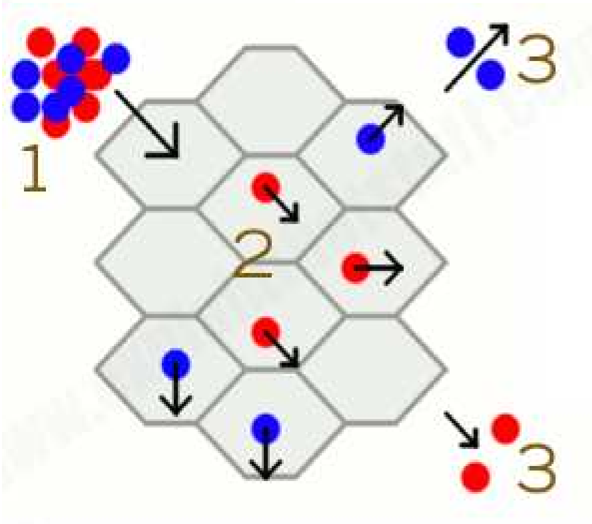


FIG 5 .Schematic representation of working of catalytic convertor

2.2.4. Working process of catalytic convertor:

Before catalytic converters were developed, waste gases made by a car engine blew straight down the exhaust tailpipe and into the atmosphere. The catalytic converter sits between the engine and the tailpipe, but it doesn't work like a simple filter: it changes the chemical composition of the exhaust gases by rearranging the atoms from which they're made:

1. Molecules of polluting gases are pumped from the engine past the honeycomb catalyst, made from platinum, palladium, or rhodium

.

3. The catalyst splits up their molecule into their atom

3. The atoms then recombine into molecules of relatively harmless substances such as carbon dioxide, nitrogen, and water, which blow out safely through the exhaust. **[7]**

2.2.5 Different catalyst converter implementations in cars and their cost:

The following gives the detail information about Different catalyst converter implementations in cars and their cost.

Name of	Application	Respective
Platinum,	Toyota A-90,	**RS 20250**
Monolithic	Audi , volkas	**RS 15800**
Thermal management convertor (TMC)	Ford	**RS 14500**

Table No 3 Different catalyst converter implementations in cars and their cost

3. Measurement of selected air pollutant in car exhaust:

Automobile emissions have a huge impact on human health and the well-being of our planet. Not only do they lead to elevated ozone levels, but the CO emitted by engines is toxic. Also, both CO2 and ozone are greenhouse gases. Automobile engines convert energy stored in chemical bonds into mechanical energy through the controlled combustion of gasoline (hydrocarbons, CxHy) in air:

$$CxHy + O2 \rightarrow CO2 + H2O + heat \quad (1)$$

When there is the correct balance of O2 and hydrocarbons in the combustion chamber (i.e., under "lean" conditions), complete combustion occurs and CO2 and H2O are emitted in the exhaust. When the mixture is not in balance, such as the case when there is too much fuel and not enough oxygen (i.e., under "rich" conditions), combustion is incomplete and the exhaust can contain CO and excess hydrocarbons. Since both nitrogen and oxygen are present in air used for combustion, the following reactions may also take place within the engine, especially when the combustion temperature is high:

$$O2 + heat \rightarrow 2O\cdot \quad (2)$$

$$O\cdot + N2 \rightarrow NO\cdot + N\cdot \quad (3)$$

$$N\cdot + O2 \rightarrow NO\cdot + O\cdot \quad (4)$$

$$2\,NO\cdot + O2 \rightarrow 2\,NO2 \quad (5)$$

As a result, nitrogen oxides (NOx = NO + NO2) are also present at high concentrations in car exhaust. Typical untreated car exhaust may contain CO concentrations of 1–2% by volume, unburned hydrocarbons levels between 500-1000 ppm and NOx levels between 100-3000 ppm. The unit of ppm, or parts-per-million, is called a mixing ratio. In fact, scientists prefer to measure the amount of trace pollutants such as NOx or ozone in the air in terms of ppm or even parts per billion (ppb), which are defined as follows:

1 ppm = 1 molecule reported per 1,000,000 molecules of other gases in air

1 ppb = 1 molecule reported per 1,000,000,000 molecules of other gases in air

The catalytic converter is located under the automobile between the engine and the muffler when the car is first started (i.e. "cold start"), the catalytic converter is cold and the catalyst does not efficiently remove NOx and CO from the exhaust. As the engine warms up, the exhaust warms the catalytic converter to a high enough temperature to initiate the catalytic reactions that remove pollutants. The catalytic reactions occur heterogeneously (i.e. when Gaseous combustion products adsorb onto the surface of a ceramic monolith and react with the various metal atoms present there) and convert toxic gases into less harmful chemicals.

The active components of catalytic converters are precious metals such as Pt, Pd, and Rh dispersed on the high surface area ceramic monolith that is shaped like a honeycomb The honeycomb support can be 10 inches in diameter, 7 inches long, have between 10-500cells per square inch, and is held inside a metal housing (you will have an opportunity in class to take a catalytic converter apart). The honeycomb structure means that exhaust gases travel through the converter at the fastest possible rate while at the same time hitting a lot of catalyst- covered surface on their way out. This design aims at maintaining fuel efficiency and preventing a loss of power that would happen if the exhaust gases build up pressure going through the converter**. [9]**

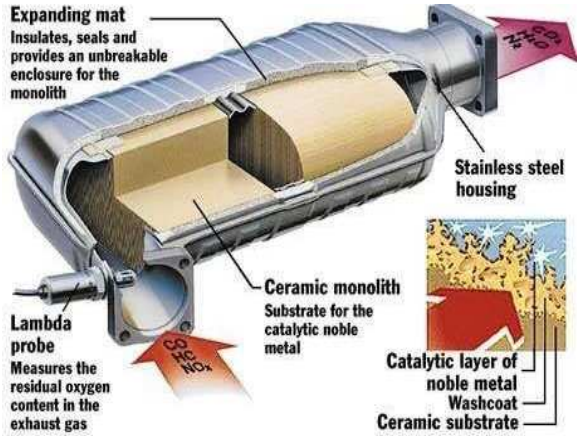


FIG 6. Schematic representation working of catalytic convertor in car exhaust

4. Performance Analysis:

1. Increment in the amount of preferable oxygen:

Figure 7 shows the effect of catalytic converter on the amount of oxygen emitted from the engine. It shows that the highest amount of oxygen (19.2%) is emitted from the engine when the speed is between 10-30 km/hr while the exhaust system is attached with catalytic converter. Again from this figure the amount of oxygen emitted from the engine is equipped with catalytic converter. has been reduced significantly with the absence of catalytic converter while the best possible amount of oxygen is 18.1% which occurred around 10km/hr of engine speed. The amount of oxygen emitted from engine stabilizes while the engine speed increases with the absence of catalytic converter but the amount is still lower than the condition while the exhaust system. **[8]**

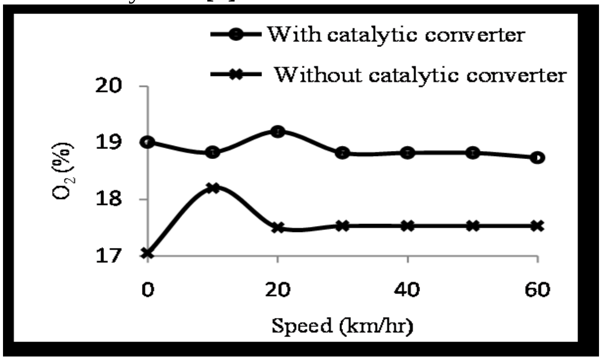


FIG 7. Schematic representation of Percentage of O2vs Speed (km/hr)

2. Significant reduction in the amount of CO_2:

From figure 8, CO2 emitted from the engine is always less than 7ppm while the minimum amount of CO2 emission from engine without catalytic converter is greater than 7ppm. This implies a significant improvement in reduction of CO2 presented in the exhaust gas. In both the cases the amount of CO2 increases constantly with increase in speed. Highest speed causes to emit the highest amount of CO2 from the engine exhaust. **[8]**

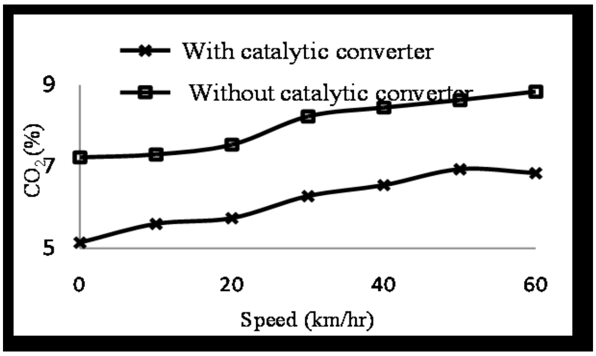


FIG 8.Schematic representation of Percentage of CO_2vs Speed (km/hr)

3. CO Increases Linearly With the Engine Speed:
The figure 9 shows the linear characteristic of CO emission with the change of engine speed. In both the cases the amount of CO increases with the engine speed. But with the use of catalytic converter it is possible to lower the amount except the peak point of emission which occurs around the speed of 30km/hr. **[8]**

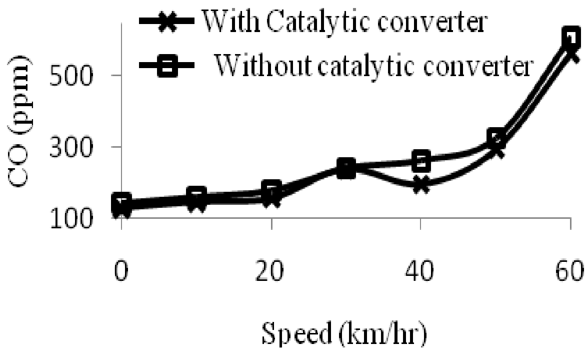


FIG 9. Schematic representation of CO (ppm) vs Speed (km/hr)

4.1 Reasons for failure of catalytic convertor:

Catalyst poisoning occurs when the catalytic converter is exposed to exhaust containing substances that coat the working surfaces, so that they cannot contact and react with the exhaust. The most notable contaminant is lead, so vehicles equipped with catalytic converters can be run only on unleaded fuels. Other common catalyst poisons include fuel sulfur, manganese (originating primarily from the gasoline additive MMT), and silicon, which can enter the exhaust stream if the engine has a leak that allows coolant into the combustion chamber. Phosphorus is another catalyst contaminant. Although phosphorus is no longer used in gasoline, it (and zinc, another low-level catalyst contaminant) was until recently widely used in engine oil anti wear additives such as zinc dithiophosphate (ZDDP). Beginning in 2004, a limit of phosphorus concentration in engine oils was adopted in the API SM and ILSAC GF-4 specifications.

Depending on the contaminant, catalyst poisoning can sometimes be reversed by running the engine under a very heavy load for an extended period of time. The increased exhaust temperature can sometimes vaporize or sublimate the contaminant, removing it from the catalytic surface. However, removal of lead deposits in this manner is usually not possible because of lead's high boiling point. Any condition that causes abnormally high levels of unburned hydrocarbons raw or partially burnt fuel to reach the converter will tend to significantly elevate its temperature, bringing the risk of a meltdown of the substrate and resultant catalytic deactivation and severe exhaust restriction. Vehicles equipped with OBD-II diagnostic systems are designed to alert the driver to a misfire condition by means of flashing the "check engine" light on the dashboard.

Sulphur in gasoline and diesel fuel has a major negative impact on catalyst performance and also contributes to the mass of particulate matter. The effect of sulphur on catalyst performance becomes more critical as lower tailpipe emissions are targeted and the loss of catalyst efficiency caused by sulphur in the fuel has a greater impact at the very low emissions levels required in the most advanced emissions regulations. In addition, as catalyst is poisoned by lead, catalytic converters on vehicles helped bring about elimination of lead containing gasoline additives were hazardous. **[10]**

5. Application catalytic convertor:

1. The Catalytic Converter burns off the unburned fuel gases from the engine. This highly reduces the amount of toxins that would enter our atmosphere. By having a more complete burn-off, we all enjoy cleaner air and a better life.

2. The increasing use of catalytic converters required the introduction of more sophisticated engine control technologies.

3. These have allowed automobile manufacturers to design engines for higher fuel efficiency, promoting a continuous rise in fuel economy which will continue to be important as manufacturers strive to meet more demanding fuel economy and CO_2 regulations.

4. Higher flow catalytic converters are useful for large or oversized vehicles like heavy duty trucks. When a vehicle has a larger engine, a higher flow catalytic converter can help provide adequate processing for the exhaust that comes out.

5. Catalytic converters have also been developed for construction equipment lawn and garden equipment marine engines and other non-road engines.

6. Catalytic convertor is also used to reduce emission from alternative fuel vehicles powered by natural gas, methanol, ethanol and propane.

7. To date more than 500 million vehicles equipped with catalytic converters have been sold worldwide over 90 percent of new cars sold had a catalyst. **[10]**

5.1 Global effects:

On a global scale, people are more concerned about air pollution and global climate change which are contributed to by vehicle exhausts. Combustion engines contribute to greenhouse gas accumulation in the atmosphere. There are many climate researchers who support the view that emissions of heat trapping gases into the atmosphere, particularly CO2, from the combustion of fossil fuel, cause global warming. The concentration of CO2 are currently rising by 2 ppm (parts per million) annually. Transport contributed to an estimated 19% of global GHG (greenhouse gas) emissions in 1971, but rose to 25% in 2006. Reductions of CO2 emissions from transport can be achieved by using energy saving vehicle technologies, which relies on cleanly produced Biofuels, such as biodiesel and ethanol**. [7]**

6. Conclusion:

The presence of catalytic converter in the exhaust system is essential to reduces the pollutant content to a great extent except for sulphur dioxide the amount of which increases with the increase in speed even with the presence of catalytic converter. Although more study can be done with the latest designed catalytic converter along with other emission control devices. The graphical representation actually indicates the reduction of carbon dioxide, hydrocarbon and other harmful contents with the attachment of catalytic converter.

REFERENCES

[1] A. Bera, and M. S. Hegde, "Recent advances in auto exhaust catalysis", Journal of the Indian Institute of Science, vol. 90:2, pp. 299-325, 2010.

[2] John m. Sullivan and Michael sivak "Carbon capture in vehicles" A review of general support, available mechanisms, and consumer acceptance issues Feb-2012 pp145-150.

[3] HEI (Health Effects Institute). January 2010. Traffic-related air pollution: A critical Review of the literature on emissions, exposure, and health effects. Special Report 17.PP. 145-180.

[4] Bergvall, C., Westerholm, R. 2009.Determination of highly carcinogenic Dibenzopyrene isomers in particulate emissions from two diesel and two gasolines fuelled light-duty vehicles. Atmospheric Environment. 43(2009) 3883-3890.

[5] Brandt, Erich; Wang, Yanying; Grizzle, Jessy "Dynamic Behavior of a Three Way Catalyst for SI Engine Exhaust Emission Control", IEEE Transaction On Control Systems Technology 8 (5): 767-776, ISSN 1063-6536, (September 2000).

[6] M. Shelef, and R.W. McCabe, "Twenty-five years after introduction of automotive catalysts: What next?", Catalysis Today, vol. 62, pp. 35- 50, Dec 2000.

[7] R. M. Heck and R. J. Farrauto, "Catalytic Air Pollution Control: Commercial Technology", Van Nostrand Reinhold, New York, 1995.

[8] Catalytic Converters, International Platinum Group Metals Association. Retrieved January 10, 2011.