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Copper based catalytic converter

Chirag M. Amin
PG Student (ME Auto.)
Mechanical Engg. Department,
Govt. Engg. College, Bhuj.

Prof. Pravin P. Rathod
Asso. Professor
Mechanical Engg. Department,
Govt. Engg. College, Bhuj.

Prof. Jigish J. Goswami
Asst. Professor
Mechanical Engg. Department,
Govt. Engg. College, Bhuj.

Abstract

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 CO_2 and H_2O in the exhaust system and thus the emission is controlled. 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 copper as a catalyst, which may by proper improvements be able to show the desired activity and can also offer better durability characteristics due to its poison resistant nature.
The present work is aimed at using copper as a catalyst for catalytic converter. Wire mesh copper catalytic converter is developed for a volume of 1.54 m3. The experiment is carried out on 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.

1. Introduction

In internal combustion engines, the time available for combustion is limited by the engine's cycle to just a few milliseconds. There is incomplete combustion of the fuel and this leads to emissions of the partial oxidation product, carbon monoxide (CO), oxides of nitrogen (NOx) and a wide range of volatile organic compounds (VOC), including hydrocarbons (HC), aromatics and oxygenated species. These emissions are particularly high during both idling and deceleration, when insufficient air is taken in for complete combustion to occur.

Carbon monoxide is a product of a partial combustion of hydrocarbons in fuel. It is always present when there is a lack of oxygen during combustion and thus directly dependent on the applied engine air/fuel ratio. There are several paths that cause hydrocarbons in the exhaust. The most obvious is, as in the case of CO, a lack of oxygen when the air/fuel mixture is rich. The other reasons that can cause hydrocarbon emissions even with lean mixtures are crevices (piston top, threads around the spark plug), the quench layer (due to a lower temperature of the cylinders' walls), porous deposits, and absorption by oil. NOx is formed during combustion in the engine when oxygen reacts with nitrogen because of a high combustion temperature.

2. Exhaust Emission Control Technique

2.1. Exhaust gas recirculation (EGR)

In internal combustion engines, exhaust gas recirculation (EGR) is a nitrogen oxide (NOx) emissions reduction technique used in petrol/gasoline and diesel engines. EGR works by re-circulating a portion of an engine's exhaust gas back to the engine cylinders. In a gasoline engine, this inert exhaust displaces the amount of combustible matter in the cylinder. In a diesel engine, the exhaust gas replaces some of the excess oxygen in the pre-combustion mixture. Because NOx forms primarily when a mixture of nitrogen and oxygen is subjected to high temperature, the lower combustion chamber temperatures caused by EGR reduces the amount of NOx the combustion generates.

The exhaust gas, added to the fuel, oxygen, and combustion products, increases the specific heat capacity of the cylinder contents, which lowers the adiabatic flame temperature. In a typical automotive spark-ignited (SI) engine, 5 to 15 percentage of the exhaust gas is routed back to the intake as EGR. The maximum quantity is limited by the requirement of the mixture to sustain a contiguous flame front during the combustion event; excessive EGR in poorly set up applications can cause misfires and partial burns.

2.2. Positive Crankcase Ventilation (PCV)

During normal compression stroke, a small amount of gases in the combustion chamber escapes past the piston. Approximately 70% of these "blow by" gases are unburned fuel (HC) that can dilute and contaminate the engine oil, cause corrosion to critical parts, and contribute to sludge build up. At higher engine speeds, blow by gases increase crankcase pressure that can cause oil leakage from sealed engine surfaces.
The purpose of the Positive Crankcase Ventilation (PCV) system is to remove these harmful gases from the crankcase before damage occurs and combine

them with the engine's normal incoming air/fuel charge.

2.3. Catalytic converters

In chemistry, a catalyst is a substance that causes or accelerates a chemical reaction without itself being affected. Catalysts participate in the reactions, but are neither reactants nor products of the reaction. A catalytic converter reduces temperature at which CO & HC convert into CO_2 and H_2O. Generally catalytic converters uses platinum group of noble metals.

3. How Catalytic Converter Works?

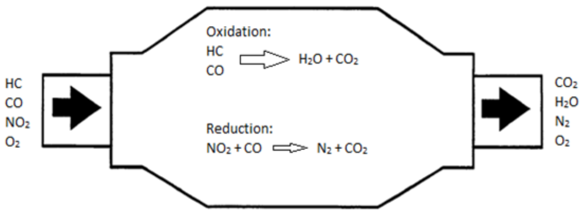
In the catalytic converter, there are two different types of catalyst at work, a reduction catalyst and an oxidation catalyst. Both types consist of a ceramic structure coated with a metal catalyst, usually platinum, rhodium and/or palladium. The idea is to create a structure that exposes the maximum surface area of catalyst to the exhaust stream.

The reduction catalyst is the first stage of the catalytic converter. It uses platinum and rhodium to help reduce the NOx emissions. When an NO or NO2 molecule contacts the catalyst, the catalyst rips the nitrogen atom out of the molecule and holds on to it, freeing the oxygen in the form of O2. The nitrogen atoms bond with other nitrogen atoms that are also stuck to the catalyst, forming N2. For example:

$$2NO \rightarrow N_2 + O_2$$

Or

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



The oxidation catalyst is the second stage of the catalytic converter. It reduces the unburned hydrocarbons and carbon monoxide by burning (oxidizing) them over a platinum and palladium catalyst. This catalyst aids the reaction of the CO and hydrocarbons with the remaining oxygen in the exhaust gas. For example:

$$2CO + O_2 \rightarrow 2CO_2$$
$$HC + O_2 \rightarrow CO_2 + H_2O$$

There are two main types of structures used in catalytic converters -- **honeycomb** and **ceramic beads**. Most cars today use a honeycomb structure.

3.1. Types of converter

3.1.1. Monolithic converters: The monolithic catalytic converter uses ceramic material made in a honeycomb pattern to control the exhaust gases flowing through it. The catalytic elements in the ceramic are enclosed in stainless steel. When ceramic beads are used instead of a honeycomb structure, the unit is known as a pellet catalytic converter.

3.1.2. Oxidation Converter / two-way catalytic converter: This type is also known as a two-way catalytic converter, because it can only operate with hydrocarbons (unburned fuel) and carbon monoxide (caused by partially-burned fuel). Oxidation converter elements are usually covered in platinum.

3.1.3. Reduction Converter / Three-way catalytic converter: Similar to the oxidation converter, the reduction catalytic converter helps eliminate hydrocarbons and carbon-monoxide emissions, plus oxides of nitrogen emissions, or NOx. NOx emissions are produced in the engine combustion chamber when it reaches extremely high temperatures more than 2,500 degrees Fahrenheit, approximately.

3.1.4. Dual-Bed Converter: This is perhaps one of the most efficient converters. The dual-bed uses a combination of two-and three way catalytic converters housed in a single unit. Both converters are connected through a chamber where incoming emissions are mixed. An air line plugs into the mixing chamber to force air into the chamber to react with the combined emissions and help reduce hydrocarbon and carbon-monoxide emissions.

3.2. Automobile exhaust catalysts

Conversion efficiency of a catalytic converter is low at low temperature and efficiency increases as exhaust temperature increase. It means that catalytic converter is less effective during cold starting, when pollution constituents in the exhaust gas are maximum. The technology race to develop suitable methods to control cold start HC's included both catalytic and some unique system approaches:

a. Close-coupled catalyst;
b. Electrically heated catalysed metal monolith;
c. Hydrocarbon trap;
d. Chemically heated catalyst;
e. Exhaust gas ignition;
f. Pre-heat burners;

The concept of using a catalyst near the engine manifold or in the vicinity of the vehicle firewall to reduce the heat-up time has been practiced. Electrically heated catalyst is used to overcome the cold temperatures during start-up & provide heat to the exhaust gas or the catalytic surface using resistive materials and a current/voltage source. Another approach investigated was the hydrocarbon adsorption trap in which the cold HC's are adsorbed and retained,on an adsorbent, until the catalyst reaches the light off temperature.All of these approaches contain under floor catalysts of various compositions. The chemically heated catalyst uses highly reactive specie, usually H_2, which is generated in a device onboard, the vehicle. Since this reacts at room temperature over the catalyst, the heat of reaction warms up the catalyst to react during cold start.The exhaust gas igniters involve placing an ignition source (e.g. glow plug) in between two catalysts. During cold start, the engine is run rich and a small amount of air is injected to make the mixture flammable. This is then ignited and heats the catalyst.The pre-heat burner uses the gasoline fuel in a small burner placed in front of the catalyst. The burner is turned 'on' during cold start and the heat generated warms up the catalyst. So, the catalyst is hot when the cold exhaust from the manifold reaches the catalyst.

4. Why Catalytic Converter Based On Non-Noble Material?

Generally catalytic converter uses platinum group of metals like Pt, Pd and Rh. These noble metals are known to promote the oxidation processes.There are several types of problems associated with noble metal based catalytic converter. The failure of catalytic converter may be due to following factors:

a. Converter meltdown
b. Carbon deposit
c. Catalyst fracture
d. Poisoning

The converter becomes too hot and melts inside so that the small particles come apart on the inside. The broken pieces can move around and get in position to plug up the flow of exhaust through converter. This meltdown is caused by converter having too much work to do. There is too much HC or CO to clean up. The converter doesn't know how to stop; It keeps up its reactions. The inside chamber of the catalytic converter gets coated with some contamination, like carbon, oil, coolant or other stuff, or they are just melted enough and reduce surface area. Poor engine performance may happen as a result of a clogged or choked converter. Symptoms of clogged converter include loss of power at higher engine speeds, hard to start, poor acceleration and fuel economy. A red hot converter indicates exposure to raw fuel causing the substrate to overheat. A critical review of all these factors infers the following important facts: It is still difficult to achieve long term durability of converter under the conditions of normal vehicle use.

5. Copper Based Catalytic converter

5.1. Catalyst and substrate preparation

5.1.1. Catalytic converter chamber: 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.

5.1.2. Wash coat material: The stainless steel wire mesh pieces were coated with metal catalyst (copper) using electroplating before arranged onto a straight bar.

Fig. 1 Catalytic converter chamber

Fig. 2 Wire mesh coated with copper

5.2. Experimental setup and result:

The experimental study was conducted with the exhaust of a stationary, four stroke single cylinder, water-cooled, constant speed (1500 rpm) diesel engine with a power output of 3.5Kw.

As unburnt fuel (HC) and CO is imparted on the catalyst, they will be oxidized and converted in to CO_2 and H_2O in the presence of catalyst material.

$$2CO + O_2 \rightarrow 2CO_2$$
$$HC + O_2 \rightarrow CO_2 + H_2O$$

The exhaust gas temperature for an engine is maximumat the chemically correct mixture because at this pointthe fuel and oxygen are completely used. From theresults obtained, it can be observed that the

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exhaust gastemperature increases towards chemically correct air-fuelratio for CI engine. The efficiency of a catalyticconverter is very much dependent on temperature.When a converter in good working order is operating at afully warmed temperature of 300˚ C or above, it reduces HC by 38% and CO by 33%.

Since the after-treatment is applied by providing thecopper coated wire mesh placed in the path of exhaust flow, it wouldaffect the engine performance in terms of backpressureon the engine. But it is observed from the resultsobtained that back pressure created as a result ofcopper coated wire mesh placed in between is very small comparedto that is created on the engine without any convertermounted on it. No doubt, with increase in number ofplates inside the shell backpressure has found to beincreased but it is very small and hardly affects theoverall engine performance.

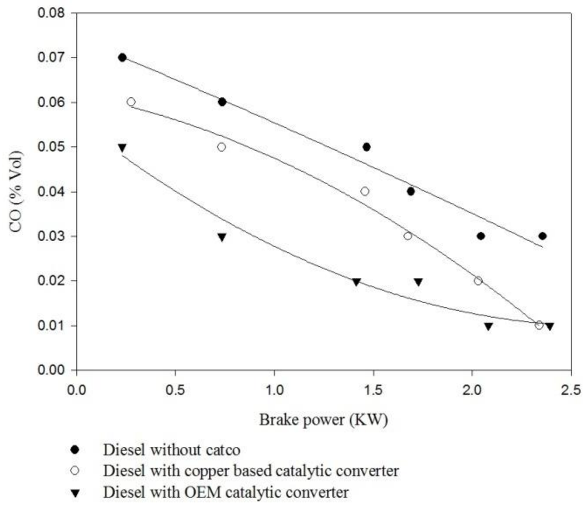

Fig. 3 CO vs BP

From fig. 3, it can be seen that as brake power of engine increases CO content also increases due to supply of rich mixture of air-fuel. Carbon monoxide contents are highest while diesel was used as fuel and catalytic converter is not mounted on the engine. Carbon monoxide content reduces by 33% at 5.2 Kg load, when copper based catalytic converter and OEM catalytic converter is attached on the engine.

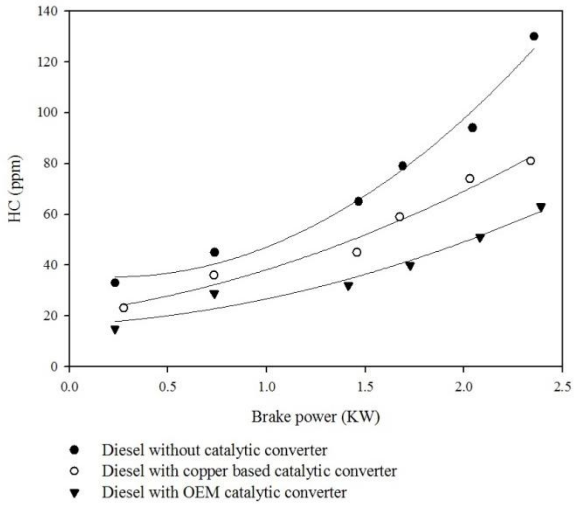

Fig. 4 HC vs BP

The variation of HC with the brake power of theengine with and without trap & converter is shown in Fig. 4. It is seen that HC increases with increasing load. This is due to theincrease in air-fuel supply inside the cylinder as the loadincreases.

Performance comparison of copper based catalytic converterwith OEM (original engine manufacture) catalytic converter can be seen in fig. 3 & 4.

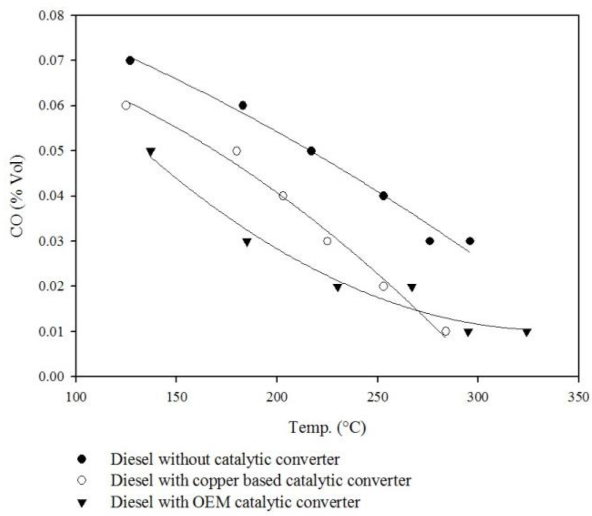

Fig. 5 CO vs Temp.

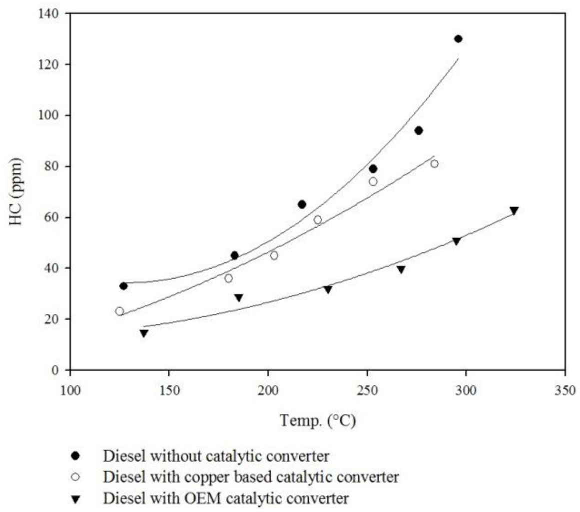

Fig. 6 HC vs Temp.

From fig. 5&6 it can be seen that as temperature of catalyst increases, its ability to convert CO and HC into H_2O and CO_2 increases or simply we can say that its conversion efficiency increases.

When exhaust gases come in contact with copper plated wire mesh, catalysis process occurs and in the presence of copper, HC and CO will be converted into H_2O and CO_2.

$$2CO + O_2 \xrightarrow{Cu} 2CO_2$$
$$HC + O_2 \xrightarrow{Cu} CO_2 + H_2O$$

When conversion efficiency of catalytic converter reaches up to 50% that temperature is known as light-off temperature. From above diagrams it can be seen that light of temperature of copper based catalytic converter is 230°C to 250°C.

6. Conclusion

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. The expenditure for fabricating a single catalytic converter is □2000 to □2500 but on mass production this cost can be reduced to economic range.

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