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Copper Plate Catalytic Converter: An Emission Control Technique

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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. Perforated copper plate catalytic converter is designed and developed for a volume of 1000 cm^3. The experiment is carried out on four-stroke single cylinder CI engine. The optimum values of exhaust emissions found at full load are HC (35.2 ppm), CO (0.1 %) and NO_x (87 ppm). The conversion efficiency of the catalytic converter is calculated and it is found that it is increasing with increase in number of copper plates. The total numbers of copper baffle plates tried inside the converter shell are 28 out of which 20 numbers of plates found to give optimum results with maximum conversion efficiency for HC (55.44 %), CO (62.96 %) and NO_x (40.41 %) emission at full load. With increasing the number of copper plates beyond 20 does not show any improvement in emission reduction hence it is concluded that the 20 numbers of copper plates are optimum for emission reduction.

Thus though not a noble metal, copper works as a catalyst for the conversion of pollutants in exhaust but in a limited proportion. Increased in exposed area doesn't provide 100% conversion. Exposed area of copper catalyst is about 3800 cm^2 for 1000 cc capacity of a converter. Backpressure increases that affects in reduction in brake thermal efficiency. It is therefore concluded that the design and development of perforated copper plate catalytic converter is feasible since it gave satisfactory results for given operating conditions and reduction of HC, CO and NO_x emissions.

KEYWORDS

Catalytic Converter, Non-Noble Metal, Conversion Efficiency, Perforated Copper Plates Etc

INTRODUCTION

Internal Combustion Engines generate undesirable emissions during the combustion process. In this, both SI and CI engines are equally responsible. The major causes for these emissions are non-stoichiometric combustion, dissociation of nitrogen and impurities in the fuel and air. The exhaust gas sent into the atmosphere by the engine contains hydrocarbon (HC), carbon monoxide (CO) and nitrogen oxide for air pollution. These pollutants are known to cause global warming, acid rain, smog and respiratory and other health hazards. Therefore, there are laws on emission standards, which limit the amount of each pollutant in the exhaust gas emitted by an automobile engine.Engine emission can be classified broadly into two categories viz. exhaust emissions and non-exhaust emissions. Major exhaust emissions are unburnt hydrocarbon (HC), oxides of carbon (CO and CO_2), oxides of nitrogen (NO and NO_x), oxides of sulphur (SO_2 and SO_3), particulates and soot and smoke. And the sources of non-exhaust emission are fuel tank, carburetor and crankcase. The main non-exhaust emission is the unburnt hydrocarbons. The present work is focused upon the reduction of exhaust emission only using non-noble metal copper as a catalyst in catalytic converter [1, 2].

LITERATURE REVIEW

Devices developed for after treatment of exhaust emissions includes thermal converters or reactors, traps or filters for particulate matters and catalytic converters. The most effective after treatment for reducing engine emission is the catalytic converter found on most automobiles and other modern engines of medium or large size. It is basically a chemical chamber mounted in the flow system through which the exhaust gases pass. This chamber contains catalytic material and it is intended to convert harmful combustion byproducts from an engine cylinder into harmless products. In presence of catalytic material the rate of chemical reaction increases because catalyst helps to oxidize the material at comparatively low oxidation temperature level. Converter oxidizes harmful CO and HC emission to CO_2 and H_2O in the exhaust system and thus the emission is controlled. Catalytic converter uses precious noble metals such as platinum, palladium and rhodium as catalyst. Generally, catalytic converters are called as three-way converter because they are used to reduce the concentration of three emission gases CO, HC and NOx in the exhaust [1, 2].

NEED FOR REPLACING NOBLE METAL BASED CATALYTIC CONVERTER

There are several types of problems associated with noble-metal based catalytic converter. The failure of catalytic converter may be due to following factors (i)Converter meltdown(ii)Carbon deposit(iii)Catalyst fracture (iv)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. Either way, it doesn't work much any more, even though it may look good on the outside. The car drives fine, but the emissions aren't quite clean enough to pass a smog test [1, 2].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 [3].

NON-NOBLE METAL COPPER AS A CATALYST

Catalytic reduction of NOx from diesel engine exhaust by the reduction of saturated hydrocarbon, or diesel fuel has been demonstrated using a newly developed copper containing catalyst system. Fundamental interactions between NOx, oxygen and hydrocarbons over the copper based catalysts have been studied in relation to NO_x reduction by hydrocarbon additions with respect to hydrocarbon oxidation. The different NO_x reduction characteristics of various hydrocarbons were revealed. Based on this, the catalyst system and the hydrocarbon spray system have been designed to effectively reduce NO_x over a wide exhaust temperature range. The newly developed catalyst system combined with a diesel fuel or heavy saturated hydrocarbon spray system effectively reduces NO_x by 20% over an exhaust temperature range of 350^0C to 550^0C.

Reduction of NOx is observed using copper base catalysts and by changing the copper content under the synthetic gas stream composed of NO, propane and oxygen with a nitrogen balance. The result shows that NO_x is reduced over a narrow temperature range and that copper content can control temperature. From the results, two types of the catalysts, which effectively reduce NOx at lower and higher temperature, were selected. Hence it can be concluded from this study and experiment carried by G. Muramatsu et. al. that non-noble metal copper can effectively be used as catalyst for catalytic converter [3,4].

Catalytic converter based on non-noble metal catalyst has been developed for 2-stroke application. In this study a modified and thermally stable alumina wash coat has been developed for application of non-noble metal catalyst. A number of prototypes based on alumina wash coat were prepared and tested for mass conversion efficiency with respect to CO, HC and NO_x. The result reveals the confirmation of performance of converter for Euro-I emission norms, which are presently applicable in India for 2-stroke [4].

BACK PRESSURE EFFECT ON ENGINE PERFORMANCE

Internal combustion Engines loose a small amount of work due to exhausting of burnt gases from the cylinder and the admission of fresh charge into the cylinder. This loss of power due to gas exchange process is due to pumping gas from lower inlet pressure to higher exhaust pressure. The gas exchange processes affects the volumetric efficiency of the engine. The performance of the engine, to a great deal, depends on the volumetric efficiency. During the exhaust stroke when the piston moves from bottom dead centre to top dead centre, pressure rises and gases are pushed into exhaust pipe. Thus the power required to drive the exhaust gases is called the exhaust stroke loss and increase in speed increases the exhaust stroke loss.

Therefore it is clear from the above discussion that the net work output per cycle from the engine is dependent on the pumping work consumed, which is directly proportional to the backpressure. To minimize the pumping work, the backpressure must be as low as possible for obtaining the maximum output from the engine. The backpressure is directly proportional to the pressure drop across the catalytic converter or design of complete exhaust system components causing the back pressure. Therefore exhaust system components and devices such as catalytic converter, in this case must be designed for minimum backpressure so that it should not disturb the engine as well as other subsystems operation. The present work therefore is an attempt to reduce exhaust emissions using copper as a catalyst without affecting engine performance. [5].

DEVELOPMENT OF CATALYTIC CONVERTER

To develop the catalytic converter, the volume of the converter is decided from the fact that the converter volume must be equal to the volume of engine cylinder and the space velocity must be in the range of 18,000 to

108000 hr^{-1}(hour inverse). The total converter volume to be maintained is 1000 cm^3. The shape of catalytic converter to be developed consists of three parts viz. the central cylindrical shell (housing), the diverging inlet cone and converging outlet cone. To provide the maximum area for catalytic reaction, the volume of central shell is assumed as 700 cm^3 and 150 cm^3 each for diverging inlet and converging outlet cone and thus maintaining the total converter as 1000 cm^3 . Schematic of assembly of converter is as shown in the Figure 1 [7].

A perforated copper plate of thickness 1 mm, and 170 holes of 0.5 mm diameter per $cm^{2,}$ is used. This plate gives total surface area that is exposed to the exhaust gas in a converter as 4.00 cm^2 per sq. cm of plate. The diameter of the plate to be accommodated in converter shell is 7.8 cm as such a plate gives total exposed area of 191 cm^2. These plates were assembled on a long bolt of 14.7 cm by putting spacers of appropriate length and inserted in the converter.

RESULTS AND DISCUSSION

The proposed work basically aims to find out the feasibility of alternative material as a catalyst for conventional noble metal catalytic converter. Therefore it has been attempted to prepare a catalyst system with different number of perforated copper plates as to vary exposed area of copper based catalyst that can reduce the exhaust emission without affecting the engine performance in any other way. Engine testing is carried out on Four-stroke single cylinder CI engine. The performance is observed for various areas of catalyst in converter shell and results are compared with and without converter. The parameters such as air-fuel ratio, brake power, brake thermal efficiency is calculated based on testing carried out on engine. Observations are taken by varying load in steps of 5.0 N-m and up to full load and overload. The results are presented in following section with the help of graphs. Different parameters are selected and compared for varying exposed catalyst area and optimum exposed area with corresponding numbers of plates are selected.

EXHAUST EMISSION REDUCTION

It is observed that the HC, CO and NOx emission from the engine increases with increase in load on the engine. This is because increase load demands more fuel while same amount of air is present in the engine hence HC emission increases due to insufficient availability of O_2 due to non-homogenous mixture. CO and NOx emission increased due to higher combustion temperatures. Therefore the soot formation is more in CI engines. Some HC particles condense onto the surface of the solid carbon soot that is generated during combustion. The HC components condensed on the surface of the carbon particles, in addition to the solid carbon particles themselves, contribute to the emissions of the engine. Further it is observed that emission of all pollutants decrease as number of plates (exposed area) goes on increasing up to a certain point and then remains constant. Conversion efficiency of converter with different areas is presented and summarized in a graphical presentation as shown in Figure 2, 3 and 4. The graph indicates that conversion efficiency is very poor for smaller areas; it rapidly increases for all loads up to certain area and then don't improve. This happens to all loads, it means for part load operation of the engine converter is equally effective and it can be concluded that maximum exposed effective area is about 3820 cm^2 beyond which increase in area has no effect [8].

PRESSURE DROP ACROSS THE CONVERTER

Since the aftertreatement is applied by providing the copper plates placed in the path of exhaust flow, it would affect the engine performance in terms of backpressure on the engine. But it is observed from the results obtained that back pressure created as a result of copper plates placed in between is very small compared to that is created on the engine without any converter mounted on it. No doubt, with increase in number of plates inside the shell backpressure has found to be increased but it is very small and hardly affects the overall engine performance. The optimum exposed area of copper based catalyst that gave good results for emission reduction without affecting the engine performance is found to be 3800 cm^2 as shown in Figure 5. At this exposed area minimum emission reduction is reported.

The exhaust gas temperature for an engine is maximum at the chemically correct mixture because at this point the fuel and oxygen are completely used. From the results obtained it can be observed that the exhaust gas temperature increases towards chemically correct air-fuel ratio for CI engine. The efficiency of a catalytic converter is very much dependent on temperature. When a converter in good working order is operating at a fully warmed temperature of 400 ^0C or above, it will remove 98-99% 0f CO, 95% of NO_x and more than 95% of HC from exhaust flow emissions. The maximum temperature up to which the engine operated is 476 ^0C and gave optimum emission reduction for exposed area of 3820 cm^2 [8].

CONCLUSIONS

Though not a noble metal, copper works as a catalyst for the conversion of pollutants in exhaust but in a limited proportion. Increased in exposed area doesn't provide 100% conversion. Exposed area of copper catalyst is about 3800 cm^2 for 1000 cc capacity of a converter. Perforated copper plate catalytic converter is designed and developed for a volume of 1000 cm^3. The cross check is made by calculating the space velocity and it is found within the specified range recommended for an engine. Hence the assumed volume of 1000 cm^3 is considered feasible. It can therefore be concluded that the assumed design and fabricated model of catalytic converter is feasible since it gave satisfactory results for exhaust emission reduction. The conversion efficiency of the catalytic converter is calculated and it is found that it is increasing with increase in number of copper plates. The total numbers of plates tried inside the converter shell are 28 out of which 20 numbers of plates found to give optimum results with maximum conversion efficiency for HC (55.44 %), CO (62.96 %) and NO_x (40.41 %) emission at full load. With increasing the number of plates beyond 20 does not show any improvement in emission reduction hence it can be concluded that the 20 numbers of copper plates are optimum for emission reduction.

It is therefore concluded that the design and development of perforated copper plate catalytic converter is feasible since it gave satisfactory results for given operating conditions and reduction of HC, CO and NOx 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 Rs. 1800/- but on mass production this cost can be reduced to economic range.Future scope of this work is that the feasibility of the system of this kind can be checked by increasing the volume of catalytic converter to get increase in conversion efficiency. To reduce the cost of copper baffle plates of cheaper metals with copper plating can be tried. Installation of catalytic converter can be varied with respect to its position from engine outlet and its optimum position can be found out. Flow analysis can also be performed.

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FIGURES

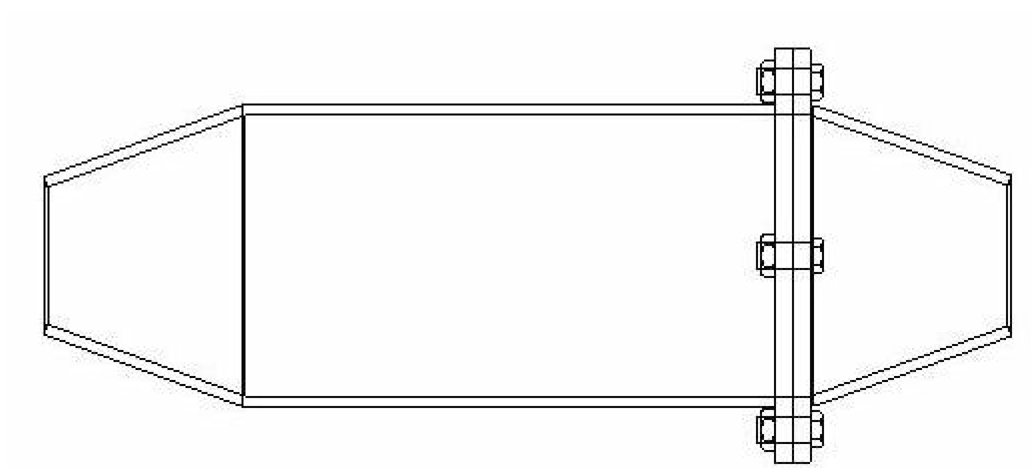

Figure 1. Schematic of assembly of catalytic converter

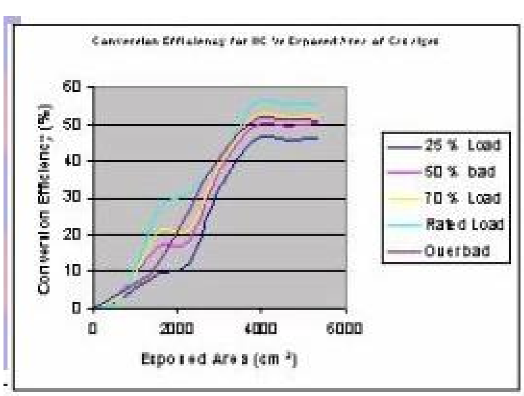

Figure2. Conversion Efficiency for HC Emission

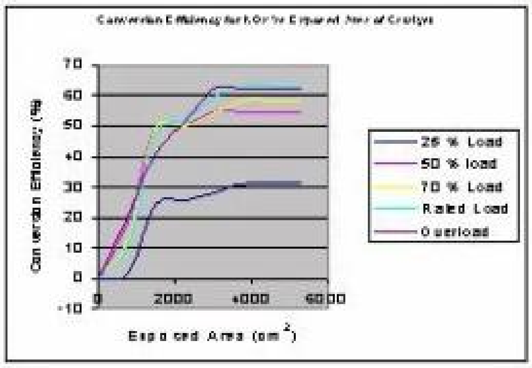

Figure 4. Conversion Efficiency for NOx Emission

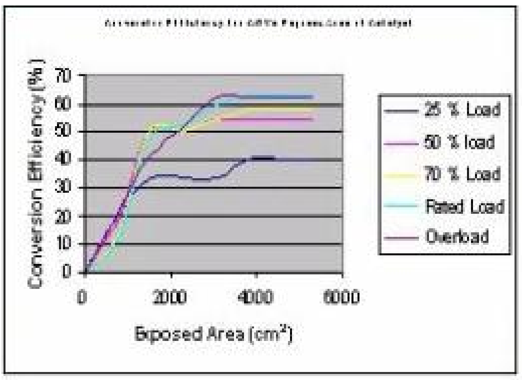

Figure 3. Conversion Efficiency for CO Emission

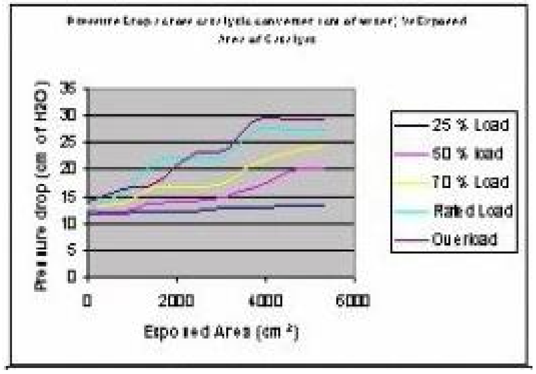

Figure 5. Effect of back pressure