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EFFECTIVENESS OF VARIOUS MATERIALS AS AN AUTOCATALYST IN A CATALYTIC CONVERTER

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Abstract - *A major cause of air pollution is the emission from vehicles and this cause has turned out to be a major concern as the population of vehicles on the road is increasing rapidly, hence it is predicted that the level of pollutants present in the air will escalate in the future as the incomplete combustion process of fossil fuels leads to the production of products like carbon monoxide, oxides of nitrogen, hydrogen carbon and particulate matter which further leads to increment in the level of emissions. To control the emission level for reducing air pollution, various methods are applied and one of them brings the use of catalytic converter, which involves the use of various materials like platinum, palladium, rhodium, copper, cobalt oxide, titanium dioxide and iron-exchange zeolite which act as an auto catalyst to reduce harmful emissions to a certain level. The effectiveness of different types of catalytic converters has a major impact on the level of emission.*

Key Words: Catalytic Converter, Catalyst, Emissions, Effectiveness, Noble Group.

1. INTRODUCTION

Over the past decade or two, there has been a significant increment in the number of vehicles present on the roads, which in return makes them a major cause of deterioration of the air quality, so further cuts in pollution per vehicle are needed to keep improving the air quality, as around 1/3 of the contamination of the air is from automobile fleet[1]. So here the use of catalytic converters comes in the picture. A catalytic converter is an exhaust emission control device that reduces toxic gases and pollutants in exhaust gas from an internal combustion engine into less toxic pollutants by catalyzing a redox reaction [2]. The process of catalyzing is performed with the application of various materials like platinum, rhodium, palladium, copper, cobalt oxide, etc which act as an autocatalyst resulting in a significant drop in the levels of pollutants emitted by vehicles which in return leads to improvement in the air quality. Usually, noble group metals like platinum, palladium, and rhodium are used as autocatalyst because of their superiority in the ability to work as a reducing or oxidizing agent for the conversion of toxic pollutants like nitrogen oxide, carbon monoxide, etc into less harmful gases like nitrogen and carbon dioxide. But the cost of production of a catalytic converter that incorporates the use of noble group metals is high so as an alternative option, materials like oxides of copper, titanium, and cobalt are used as they are inexpensive and readily available

2. NEED OF CATALYTIC CONVERTER

The catalytic converter is the best device to meet the strict exhaust emission limits as it converts the hydrocarbon, carbon monoxide, and oxides of nitrogen into less harmful gases by using a catalyst [3]. An alternative method for emission reduction is to increase the combustion temperature which ensures more complete burning takes place, but this increment leads to the formation of the third major pollutant, oxides of nitrogen. The converter forms a chamber for catalytic material in the exhaust system through which when the exhaust gas passes in the presence of oxygen the HC and CO compounds combine with oxygen giving rise to harmless by-products.

3. TYPES OF CATALYTIC CONVERTER

Two Way Catalytic Converter- A two-way catalytic converter performs two tasks simultaneously, oxidation of carbon monoxide to carbon dioxide and oxidation of hydrocarbons to carbon dioxide and water, as shown in figure 1. It has two separate elements one for nitrogen oxide and other for hydrocarbons/carbon monoxide. The converter has an axial flow and secondary air is injected ahead of the first element.

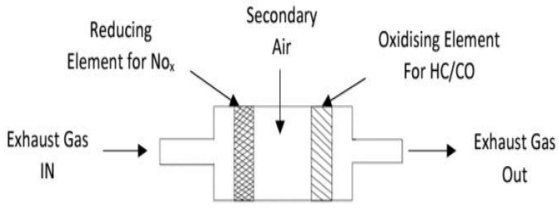

Figure 1: Two Way Catalytic Converter

4 HC + 5 O_2 -> 4 CO_2 + 2 H_2O (Oxidation of hydrocarbon)

2 CO + O_2 -> 2 CO_2 (Oxidation of carbon monoxide)

Three Way Catalytic Converter-Three-way catalytic converters have the advantage of regulating the emissions of oxides of nitrogen. A three-way catalytic converter performs simultaneous tasks, reduction of nitrogen oxides to nitrogen, oxidation of carbon monoxide to carbon dioxide and oxidation of unburnt hydrocarbons to carbon dioxide and

molecules of water. In this type of converter, the front inlet treated with platinum and rhodium, and the rear end is coated with palladium and termed as oxidizing agent [4].

4 HC + 5 O_2 -> 4 CO_2 + 2 H_2O (Oxidation of hydrocarbon)

2 CO + O_2 -> 2 CO_2 (Oxidation of carbon monoxide)

2 NO_2 -> N_2 + 2 O_2 (Reduction of nitrogen oxide)

4. FACTORS AFFECTING PERFORMANCE OF A CATALYTIC CONVERTER

Various factors affect the ability of a catalytic converter to perform adequately so that it can meet all the requirements set by the regulatory bodies like there is a requirement that a catalytic converter should run perfectly for around 80,000kms without requiring any service.

Some of the main factors which affect the performance of a catalytic converter are-

1) **Engine Condition**- High-temperature levels can adversely affect the converter's life by damaging the core, as at higher temperatures the catalyst begins to break up. To prevent overheating proper maintenance of the engine is mandatory. Hence in some vehicles, temperature protection systems are provided. If the condition of an engine is poor the exhaust gases carry a greater amount of raw fuel, this exhaust gas with raw fuel makes the converter act as catalytic furnace, which may cause the internal temperature of the converter to rise rapidly. Long idling periods are considered to be one of the worst running conditions as a greater amount of heat is generated during this period when compared to driving at normal roads.

2) **Fuel Properties**- If leaded fuel is used in cars having a catalytic converter then, the lead and phosphorous additives present in leaded fuel considerably reduce the catalyst's efficiency as lead forms a coating over a catalytic surface hence, the exhaust gases are obstructed from coming in contact with the catalyst[5]. This causes the catalyst to lose its competence to promote oxidation of HC and CO. The working of a catalytic converter is found to be more efficient if the engine operates with a stoichiometric air-fuel ratio that is, when the value of equivalence ratio is close to unity which we can observe in Figure 2.

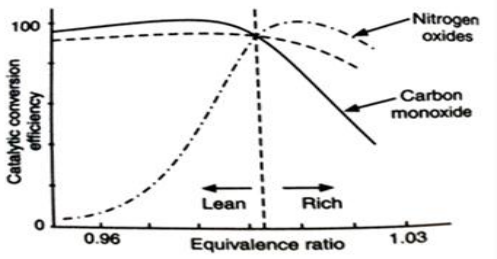

Figure 2: Effect of Equivalence Ratio on Conversion Efficiency

3) **Material of Catalyst**- Usually noble group metals such as platinum, rhodium, and palladium are used in catalytic converter as an autocatalyst [6]. The main function of the catalyst is to promote the rate of the oxidation process. The catalyst material is not consumed in the reaction, it just accelerates the chemical reaction by lowering the energy needed for a reaction to take place. There are several problems associated with the use of a noble metal-based catalytic converter like the cost of this type of catalytic converter is high as compared to their alternatives

Hence materials like copper oxide, cobalt oxide, titanium dioxide, etc are used as an alternative for these expensive catalytic materials, but their competence to perform is not comparable to that of platinum group metals.

The material used as a catalyst is divided into two categories, one being the noble group metals and being the nonnoble group materials-

Noble Group Materials

1) **Platinum**- The Auto industry uses around 33% of the world's platinum for the manufacturing of catalytic converters. Platinum is a good oxidation catalyst, oxidizes CO and HC resulting in the formation of carbon dioxide and water vapors [7]. Platinum works better in the condition where there is an excess of oxygen, so it is preferred that it should be used in diesel-powered vehicles. Platinum has an advantage over other metals that is, it does not have a high affinity for sulfur compounds.

2) **Palladium**- Demand of palladium is increasing in the industry even when we are heading towards electrical vehicles, which has led to increment in the cost of palladium. It is more effective in petrol-powered vehicles as there is a balance between reductants and oxidants in the exhaust gas. Like platinum, palladium neutralizes the toxic pollutants and converts them into nontoxic by-products. The catalytic convertor's effectiveness may decrease by time and will require replacement, so this shows that the demand for palladium will increase in the future.

3) **Rhodium**- It is considered as the most precious and highly valuable metal far ahead than gold or silver. Rhodium is corrosion and oxidation resistant, the main use in the

catalytic converter is to reduce the oxides of nitrogen present in the exhaust gas. Also, it is a great oxidizing agent that efficiently oxides HC and CO.

Non-Noble Group Materials

1) Metal Oxides- Usually oxides of metals like Cobalt, Copper Titanium, etc are used as an alternative to the conventional catalyst that consists of the use of noble group metals. Metal oxides are present in thermodynamically stable forms and this factor makes them capable of working efficiently at high temperatures, also we can vary the composition of these oxides to a certain extent which in return provides more flexibility for enhancing the performance of the catalytic converter. As compared to other catalysts based on metal oxides, copper oxide is found to be most effective in lowering the emissions having hydrocarbons and carbon monoxide, also it leads to enhancement in the value of brake thermal efficiency of an engine.

2) Zeolites- Zeolites are also one of the alternative materials that can be used to replace a noble group as an autocatalyst. They are crystalline solids that are made up of alumina and silica. Zeolites have different crystalline structures which have a greater number of open pores, these pores make them suitable to be used as a catalyst and their abundance is one of many other factors that make them a better choice as compared to other materials [8]. One of the types of zeolite that can be used as a replacement is iron-exchange zeolite as it can degrade organic pollutants via a Fenton like reaction.

5. EFFECTIVENESS OF VARIOUS MATERIALS

The process of selection of catalytic material that is best suitable for use in a certain type of catalytic converter, out of all the options mentioned above the selection highly depends upon the result that a manufacturer wants to achieve and price to performance ratio is also considered as an important factor because materials like Pd, Pt, Rh are less abundant as compared to other alternatives like different metal oxides and zeolites. But the effectiveness of these alternative materials is far less when compared to platinum materials is far less when compared to platinum.

Table 1: Result of Practical Experiment

POLLUTANTS	Palladium Catalytic Converter	Metal Oxide Catalytic Converter	Without Catalytic Converter
Measured CO	0.64	1.04	2.12
Measured HC	214	578	1274

A.K.M. Mohiuddin et al. presented the outcomes having a comparison of relative activities of noble group metals and base metal catalysts. The results were as follows, For Pd, the relative activity was 500, For Pt, it was 100, For Co2O3 it was 80, For CuO, it was 45, For MnO2 it was 4.4 and for Au, the value was 15 [8], all of these values were calculated for reactants having a concentration of 1%. It can be observed from this data that the relative activities of Pd, Pt are superior to that of metal oxides like CuO, CO2O3 etc.

For obtaining practical results we performed an experiment on Two-wheeler engines for examining the level of HC and CO in the exhaust emissions and the result obtained[Table 1] suggested that performance of noble group materials was better as compared to its alternatives, which was also the case in the experiment performed by A.K.M. Mohiuddin.

6. CONCLUSIONS

In this paper, we have considered various factors that affect the ability of a catalytic converter under different circumstances, also we have performed a practical experiment to get an idea of how effectively metal oxides or zeolites can perform as a catalyst. The result of this experiment suggested that the competence of noble group materials is superior to metal oxides and zeolites, but if we take into consideration the cost to performance ratio it can be observed that non-noble group materials can be a good option as an alternative to the conventional catalyst materials that are used in catalytic converters.

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