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Photocatalytic Converter

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ABSTRACT

The concept of Photo catalysis is being incorporated into catalytic converter to increase the efficiency as well as to reduce the production cost. Conventional converters make use of surface catalyst process using noble metals like palladium and rhodium. Our concept works based on photo catalytic reactions by Titanium dioxide and Zinc oxide thereby reducing the NO_x emissions and CO emissions. Development of this proposal will reduce the fabrication cost of catalytic converter as well as lay seeds of foundation for the future of photocatalytic converters.

Index Terms— Photocatalytic Converters, Photo catalysis, UV Light, TiO_2, ZnO, Catalytic converters, Wire Mesh, Dip Coating, Drop Casting, Reflux method–Preparation of ZnO, Nanoparticles

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I. INTRODUCTION

A catalytic converter is an emissions control device that converts toxic pollutants in exhaust gas to less toxic pollutants by catalyzing a redox reaction (oxidation or reduction). Catalytic converters are used with internal combustion engines fueled by either petrol (gasoline) or diesel—including lean-burn engines as well as kerosene heaters and stoves. The first widespread introduction of catalytic converters was in the United States automobile market. To comply with the U.S. Environmental Protection Agency's stricter regulation of exhaust emissions, gasoline-powered vehicles starting with the 1975 model year must be equipped with catalytic converters. These "two-way" converters combined oxygen with carbon monoxide (CO) and unburned hydrocarbons (HC) to produce carbon dioxide (CO_2) and water (H_2O). In 1981, two-way catalytic converters were rendered obsolete by "three-way" converters that also reduce oxides of nitrogen (NO_x); However, two-way converters are still used for lean-burn engines. Although catalytic converters are most commonly applied to exhaust systems in automobiles, they are also used on electrical generators, forklifts, mining equipment, trucks, buses, locomotives and motorcycles. They are also used on some wood stoves to control emissions. This is usually in response to government regulation, either through direct environmental regulation or through health and safety regulations. Though conventional catalytic converters have their own advantages, it has its own drawbacks of being temperature dependent, with the catalytic action being good only at higher temperatures. It is prone to theft due to presence of noble metals which are very expensive. We look forward to eliminate these disadvantages with the development of a highly cost friendly converter. This project deals with use of photo catalytic reaction in catalytic converters to improve the efficiency as well as to reduce the production cost drastically by delimiting the use of noble metals.

II. TRADITIONAL CATALYTIC CONVERTER

An internal combustion engine creates heat energy by igniting a mixture of gasoline and atmospheric oxygen with a high-voltage spark. Unfortunately, a residual quantity of hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NO_X) are left over after combustion. Consequently, a catalytic converter uses precious metals like platinum as a catalyst to convert harmful pollutants like HC, CO and NO_X into harmless gases like oxygen (O_2), carbon dioxide (CO_2) and water (H_2O). Since a catalyst will accelerate a chemical reaction without being consumed by the process itself, the catalytic converter will theoretically last forever. In reality, catalytic converters eventually succumb to contaminants from coolant and engine oil additives and heat stress.

Platinum, palladium, rhodium and cerium store oxygen in the converter during periods of lean operation or by an external air source. The oxygen is used to oxidize hydrocarbons and toxic gases during periods of “rich” operation. This oxidation changes harmful carbon monoxide (CO) into carbon dioxide (CO_2). It will also oxidize hydrocarbon or fuel by turning it into inert carbon products and water (H_2O). This is called reduction in chemistry and breaks down molecules into smaller parts. The precious metals act as catalysts in the process and are not changed, they just store and use oxygen to breakdown combustion products.

According to Johnson Matthey, a leading refiner of precious metals, industrial uses excluding catalytic converters make up about 30% of total platinum demand. Catalytic converters for the auto industry use 33% of the world's platinum while jewelry accounts for 29%. The remaining 8% is made up of platinum coins, bars and ingots used for investment purposes. Drawbacks to palladium include its sensitivity to poisons. Rhodium, currently the most expensive of the three, has by far the highest activity for the removal of NO_x from the exhaust. In addition, it has significant activity for the oxidation of HC and CO and very good resistance to the poisons present in the exhaust stream. With its primary drawback is its high cost. However, they can't breakdown or oxidize some chemicals in the exhaust stream. If the catalyst is blocked by carbon, silica or phosphorus, the converter will fail to work.

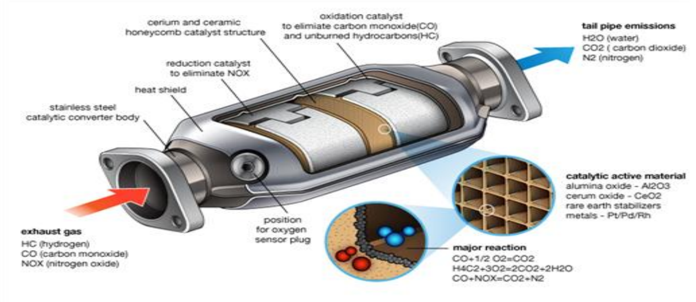

Figure 1. Cut section of exsisting catalytic converter

III. PROPOSED DESIGN

The photocatalytic converter has an outer cuboid casing, made up of sheet metal forming. The substrate for photocatalytic metal oxides is a wire mesh made up of galvanized iron trimmed in

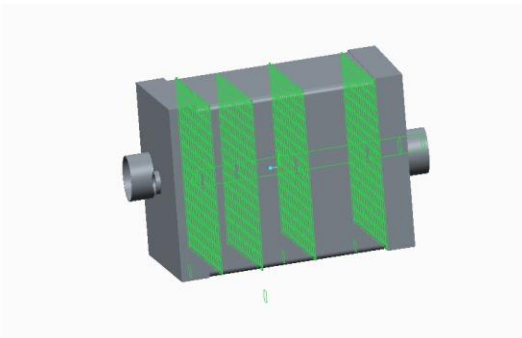

Figure 2. Isometric view of the prototype photocatalytic converter

such a way that it fits perfectly inside the photocatalytic converters body. The wire mesh substrate is provided with a center circular hole to allow UV bulb positioning. the photocatalytic metal oxides are coated on the wire mesh by the process of dip coating and drop casting. Here in this photocatalytic converter titanium

Figure3. Mesh and bulb arrangement inside the prototype

dioxide and zinc oxides are used as photocatalytic metal oxides. after dip coating of metal oxides these coated wire mesh substrates are brazed inside the converters body at equal intervals. UV bulb is inserted at the center of these substrates making sure that all the substrates get irradiated by the ultra violet light. The catalytic converters body is closed at the ends by closing caps, which is brazed to the cuboid body. These closing caps provide air-tight mountings for the UV bulb at both ends. The closing caps also contains inlet and outlet pipes of the catalytic converter at each ends. The inlet and outlet pipes are brazed and positioned in the closing caps in such a way that the exhaust gases enter from the top right most end of the catalytic converter and exists at the bottom left most end, providing necessary time and space for the gases to get reacted. The electronics and wire for UV bulb are perfectly insulated from the catalytic converters heat. Terminals are provided from the bulb mountings for AC mains of the UV bulb.

IV. TECHNICAL BACKGROUND

In chemistry, photocatalysis is the acceleration of a photoreaction in the presence of a catalyst. In catalysed photolysis, light is absorbed by an adsorbed substrate. In photogenerated catalysis, the photocatalytic activity (pca) depends on the ability of the catalyst to create electron–hole pairs, which generate free radicals (e.g. Hydroxyl radicals: •oh) able to undergo secondary reactions. Its practical application was made possible by the discovery of water electrolysis by means of titanium dioxide. The commercially used process is called the advanced oxidation process (AOP). There are several ways the aop can be carried out; these may (but do not necessarily) involve TiO_2 or even the use of UV light. Generally, the defining factor is the production and use of the hydroxyl radical.

V. DETAILED DESCRIPTION

Automobile Exhaust emissions which have toxic gases such as nitrogen oxides (NO_x), Carbon monoxide (CO) and hydro carbons (HC) are expected to be treated before they reach the atmosphere. Conventional catalytic converters are used to treat the exhaust gases, which makes use of surface catalysis technology of noble metals like platinum palladium and rhodium. These noble metals catalyze the oxidation and reduction of toxic emissions and convert them into non-toxic gases. The limitations with surface catalyst technology is that they prove to be expensive because of the use of noble metals like platinum, palladium and rhodium. Moreover, this process seems to be temperature dependent. The catalytic activity is found to be more effective at higher temperature of exhaust gases which in turn signify that catalytic action at low temperatures (at the initial stages of vehicle running) is not comparatively effective. This invention of photocatalytic converter overcomes the demerits of conventional catalytic converters by making use of photo catalysis technology. Photo catalysis is a catalytic property exhibited by certain metal oxides like TiO_2, ZnO etc. These metal oxides when irradiated by Ultra violet or visible light of suitable wavelength (250-350nm) release free electrons, these electrons separate the water molecules present in the moisture into OH^- and H^+ radicals which oxidize and reduce the toxic emissions into non-toxic gases.

VI.I PHOTOCATALYTIC REACTION OF TiO_2

Ti^{4+} ions receive a photoelectron which is usually generated due to UV irradiation on TiO_2. Photo generated electrons and holes are produced in TiO_2 under UV irradiation. The electrons can be trapped and tend to reduce Ti^{4+} cations to Ti^{3+} state and the holes to oxidize O^{2-} anions for the formation of O^- trapped hole or oxygen gas.

The charge transfer steps as follows:

$$TiO_2 + h\upsilon \longrightarrow e^- + h^+$$
$$e^- + Ti^{4+} \longrightarrow Ti^{3+} + \text{Trapped electron}$$
$$h^+ + O^{2-} \longrightarrow O^- + \text{Trapped hole}$$
$$4h^+ + 2O^{2-} \longrightarrow O_2$$
$$2NO + 2CO \longrightarrow N_2 + 2CO_2$$
$$C_8H_{18} + O_2 \longrightarrow 8CO_2 + 9H_2O$$

VI.II. PHOTOCATALYTIC ACTIVITY OF ZnO

Zinc oxide is a wide bandgap(~3.37eV) *n*-type semiconductor, which has achieved application in many fields such as photo catalysis, solar cells gas sensors and photo detectors. In general, small size ZnO Nano particles have increased specific area and more number of active sites where the photo generated charge

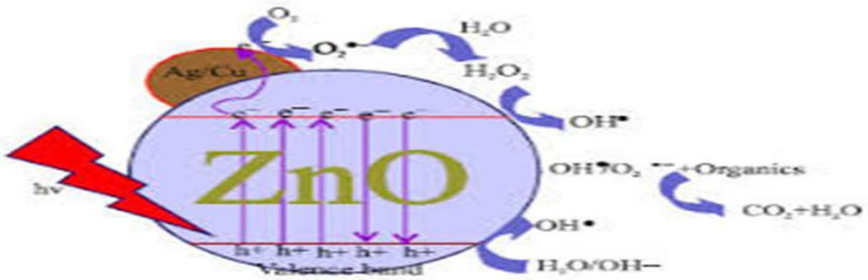

Figure 4. ZnO photocatalytic reactions

carries are able to react with absorbed molecules to form hydroxyl and superoxide radicals. The photo generated holes on ZnO could aid oxidation while the electrons could absorb surface O_2 to form various oxygen species(ROSs), thus assist the catalytic action on toxic emissions.

VI. EXPLODED VIEW

This image illustrates our prototype catalytic converter in exploded view. Starting from the left, is side cap for the converter with an inlet for exhaust air. Following the cap is a wire mesh, coated with TiO_2 and another mesh

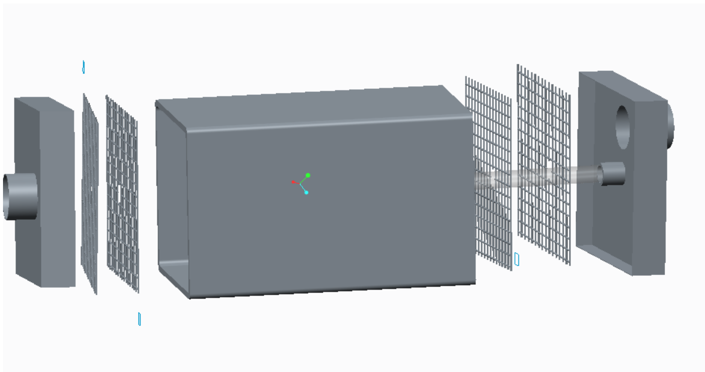

Figure 5. Exploded view of the photocatalytic converter design

coated with ZnO. This mesh coating is repeated again inside the housing of the photocatalytic converter which is made of sheetmetal. The meshes have a hole of equal diameter for UV lamp to pass through it. It is finally covered by other end of the side cap with support for bulb and a hole for outlet air.

VII. LABORATORY TESTING

We hold the privilege of developing a prototype for our project, and we tried testing the engine emissions after attaching our catalytic converter to a 4 stroke, single cylinder kirloskar diesel engine operating at No load conditions with exhaust temperature of 189^0 C at the National Institue of Technology(NIT), Trichy. The analysis was made using a flue gas analyser approved by NIT, Trichy.

The following results were recorded for the diesel engine before the use of catalytic converter.

Table1. Emission gas analysis of the diesel engine

	TRIAL 1
CO	0.06% vol
HC	20ppm
CO_2	2.90% vol
O_2	16.15% vol
NO	97 ppm
x	6.554

The following results were recorded after the use of our prototype,

Figure 6. Photocatalytic Converter attached to an engine at NIT-T

Photocatalytic converter operating at the same conditions with each trial being performed evry 5 minutes.

Table 2. Emission Analysis after attaching Photocatalytic converter

	TRIAL 1	*TRIAL 2*	*TRIAL 3*	*TRIAL 4*	*TRIAL 5*	*TRIAL 6*
CO	0.07% vol	0.06% vol	0.07% vol	0.07% vol	0.07% vol	0.06% vol
HC	20ppm	23ppm	21ppm	21ppm	25ppm	19ppm
CO_2	2.60% vol	2.10% vol	2.30% vol	2.40% vol	2.40% vol	2.10% vol
O_2	16.87% vol	17.55% vol	17.28% vol	17.40% vol	17.21% vol	17.77% vol
NO	88 ppm	69 ppm	72 ppm	72 ppm	73 ppm	62 ppm
x	6.554	6.554	6.554	8.282	7.905	9.162

We tested the emissions again immideatly after removing the catalytic converter to derive the following test reports.

Table 3. Emission Analysis after the removal of photocatalytic converter

	TRIAL 1	*TRIAL 2*
CO	0.07% vol	0.07% vol
HC	18 ppm	18 ppm
CO_2	2.90% vol	2.70% vol
O_2	16.74% vol	16.90% vol
NO	86 ppm	81 ppm
x	6.600	6.600

VIII. CONCLUSION

A photocatalytic converter has been developed which makes use of photocatalytic property of semiconductor metal oxides like TiO_2 and ZnO under ultraviolet irradiation to reduce and oxidize the toxic pollutants of exhaust emissions. Thereby avoiding the use of noble precious metals like platinum, palladium and rhodium, reducing cost and paving a new way in the field of catalytic converters.

Thereby, from the emission results we can derive at a conclusion that with proper development of this concept, we can achieve better emission control using the concepts of photocatalysis in catalytic converters.

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