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# Catalytic Converter-An Integrated Approach to Reduce $CO_2$ Emission

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***Abstract* – A major part of the air pollution caused is due to the vehicular emission which is increasing at an alarming rate. The major pollutants from vehicular emissions are a result of incomplete combustion releasing compounds such as carbon monoxide, hydrocarbons and particulate matters. However, the contribution of $CO_2$ is higher than the aforementioned pollutants. The principal greenhouse gas emitted by vehicles is carbon dioxide. About 2347 grams of carbon dioxide is released for every litre of gasoline burned by vehicles. So, it is necessary to minimise the emission of carbon dioxide from vehicles. Materials such as Zeolite, Silicon dioxide have excellent tendency to adsorb $CO_2$. These materials convert $CO_2$ into non-pollutant compounds of carbonates of the respective materials. The scrubbing substance is created by mixing zeolite, silicon dioxide and calcium oxide in a proportion of their increasing order of adsorption tendency, along with adequate quantity of Bentonite sand to bind the mixture.**

**Keywords—$CO_2$ emission, green house gas, exhaust gas, exhaust pollutant, scrubber,**

## I. INTRODUCTION

Undesirable emissions in internal combustion engines are of major concern because of their negative impact on air quality, human health, and global warming. Therefore, there is a concerted effort by most governments to control them. Undesirable emissions include unburned hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM), we present the U.S. and European emissions standards, both for gasoline and diesel operated engines, and strategies to control the undesirable emissions. The role of engine design, vehicle operating variables, fuel quality, and emission control devices in minimizing the above-listed pollutants are also detailed. "Emissions" is a collective term that is used to describe the undesired gases and particles which are released into the air or emitted by various sources, Its amount and the type change with a change in the industrial activity, technology, and a number of other factors, such as air pollution regulations and emissions controls. The U.S. Environmental Protection Agency (EPA) is primarily concerned with emissions that are or can be harmful to the public at large. EPA considers carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO2), ozone (O3), particulate matter (PM), and sulphur dioxide (SO2) as the pollutants of primary concern, called the Criteria Pollutants. These pollutants originate from the following four types of sources.

1. Point sources, which include facilities such as factories and electric power plants.
2. Mobile sources, which include cars and trucks but also lawn mowers, airplanes, and anything else that moves and releases pollutants into the air.
3. Biogenic sources, which include trees and vegetation, gas seeps, and microbial activity.
4. Area sources, which consist of smaller stationary sources such as dry cleaners and degreasing operations.

Gasoline and diesel fuels are mixtures of hydrocarbons, compounds which contain hydrogen and carbon atoms. In a "perfect" engine, oxygen in the air would convert all the hydrogen in the fuel to water and all the carbon in the fuel to carbon dioxide. Nitrogen in the air would remain unaffected. In reality, the combustion process cannot be "perfect," and automotive engines emit several types of pollutants. The outcomes of the several researchers have been discussed hereunder.

Antonio et al. [1] in his paper has discussed the reactivity of Fe-zeolite washcoated with catalyst for the aftertreatment of exhaust gases of an internal combustion engine. Besides, the adsorption capacity of Fe- exchanged zeolite against ammonia and other nitrogen-based gases were found to be increased when compared to other catalysts. Xingzhong et al. [2] has studied the fabrication of Silicon Carbide honeycomb structure with microporous walls by combining extrusion molding with pore forming. By using Ferrous Oxide as pore forming agent, it was found that the pore volume, size and porosity could be controlled without compromising the phase compositions of the SiC honeycomb ceramics. Anupam et al. [3]

explains the functions of a three-way catalytic converter, the effects of the valuable metals that are used as catalysts and significance of catalytic converter to reduce the automobile emissions to prevent pollution. Nitin et al. [4] has suggested the potential substitutes for noble-metal based catalysts. His study has found that lanthanum manganate type perovskite oxide supported by alumina can replace the noble metals as catalytic material for the after treatment of automobile exhaust gases. Perovskite based materials are low in cost and also thermally stable, making them viable for auto-exhaust pollution control applications. Doggali et al. [5] has studied the properties of ceramic materials and their possibilities to be use in environmental catalysis. Cordierite based honeycomb catalyst have been successfully experimented to be used in aftertreatment applications.

Shin'ichi et al. [6] reviews the advancements made in automobile exhaust catalysts. He discusses the catalysts that were developed by Toyota, for use in low emission vehicles and for lean burn engines, their properties and effectiveness in conversion. Mukula et al. [7] reviewed the impact of un treated exhaust gases on environment and the necessity of catalytic converter to mitigate the effects of emission gases released into the atmosphere. Paul et al. [8] has presented the significance of channel shape of the substrate on catalyst efficiency and converter performance. The proper distribution of the exhaust gases is necessary for the desired efficiency of conversion. Qiancheng et al. [9] has studied the construction and applications of honeycomb structure in various fields. He elucidates the different variants of polygonal geometry that could be featured with the honeycomb structure and their corresponding effects in heat transfer. Prashant et al. [10] reviews the characteristics and functions of catalytic converters and compared the performances of various types of catalytic converters. The effectiveness of using catalytic converters, on account of the reduction in emissions of toxic gases before and after the implementation of catalytic converters are discussed, that were found to be much lower than non- implemented vehicles.

Julie et al. [11] has reviewed the imminent necessity of catalytic converters and their developments to prevent or in the worst case mitigate the adversity of air pollution in the near future. The temperature of the exhaust stream of gases should be within 1000 degree centigrade to avoid the deactivation of catalyst material by sintering. Marika et al. [12] elucidates the results of using silver based catalysts to reduce nitrogen oxides emissions in lean burn engines. The hydrocarbons released act as reducing agent along with the use of silver and alumina as catalysts. The hydrocarbons reduce nitrogen oxides to molecular nitrogen ultimately. Mohiuddin et al. [13] explains the outcome of his experimentation on performance characteristics of catalytic converter. The analysis and simulation of two catalytic converters, Fiat and Proton shows that Fiat converter has better efficiency than the latter. Balakrishna et al. [14] has proposed a design to optimize the catalytic converter for particulate matter reduction while achieving low back pressure. Maintaining a low back pressure increases fuel efficiency. The use of catalytic beads of proper shapes, the pressure drop can be minimised without compromising the volumetric efficiency. Valery et al. [15] discusses the design calculations of the ceramic substrate that would ensure proper flow of gases through the catalytic converter. The catalyst carriers in the form of rectangular parallelepiped provides the suitable flow characteristics to the exhaust gases.

Naveenkumar et al. [16] has analysed the performance characteristics of catalytic converters, focussing on the flow properties of exhaust gases into the converter. The performance can be improved by decreasing the divergence angle of the converter's inlet which increases the flow uniformity. Best results were obtained for inlet angle of 15 degrees. Karuppusamy et al. [17] has studied the flow properties of gases in the catalytic converter and their effect on back pressure and engine performance. The nonuniformity in the flow of gases can be minimise by decreasing the inlet cone angle. Zukerman et al. [18] has designed a smart catalytic converter that features NOx storage, ammonia production and selective catalytic reduction. Liu et al. [19] studied a possible system for thermoelectric generation by the exploitation of automotive exhaust gases. The incorporation of a heat recovery system reduces the back pressure of the catalytic converter. Andreassi et al. [20] investigated the role of channel cross-section shape on mass and heat transfer processes. The development of catalytic converter systems for automotive applications is, to a great extent, related to monolith catalyst support materials and design. In this paper improvements of converter channels fluid dynamics aiming to enhance pollutant conversion in all the engine operating conditions are studied.

## II. DESCRIPTION

### A. Complete Combustion

In complete combustion, the reactant burns in oxygen, and produces a limited number of products. When a hydrocarbon burns in oxygen, the reaction will primarily yield carbon dioxide and water. When elements are

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burned, the products are primarily the most common oxides. Carbon will yield carbon dioxide, sulfur will yield sulfur dioxide, and iron will yield iron(III) oxide. Nitrogen is not considered to be a combustible substance when oxygen is the oxidant, but small amounts of various nitrogen oxides (commonly designated Nox species) form when the air is the oxidant. Combustion is not necessarily favorable to the maximum degree of oxidation, and it can be temperature-dependent. For example, sulfur trioxideis not produced quantitatively by the combustion of sulfur. NOx species appear in significant amounts above about 2,800 °F (1,540 °C), and more is produced at higher temperatures. The amount of NOx is also a function of oxygen excess.

In most industrial applications and infires, air is the source of oxygen (O2). In the air, each mole of oxygen is mixed with approximately 3.71molof nitrogen. Nitrogen does not take part in combustion, but at high temperatures some nitrogen will be converted to NOx (mostly NO, with much smaller amounts of NO2). On the other hand, when there is insufficient oxygen to completely combust the fuel, some fuel carbon is converted to carbon monoxide and some of the hydrogen remains unreacted. A more complete set of equations for the combustion of a hydrocarbon in the air, therefore, requires an additional calculation for the distribution of oxygen between the carbon and hydrogen in the fuel. The amount of air required for complete combustion to take place is known as theoretical air. However, in practice, the air used is 2-3x that of theoretical air.

**B. Incomplete Combustion**

Incomplete combustion will occur when there is not enough oxygen to allow the fuel to react completely to produce carbon dioxide and water. It also happens when the combustion is quenched by a heat sink, such as a solid surface or flame trap. Same as complete combustion, water is produced by incomplete combustion. However, carbon, carbon monoxide, and/or hydroxide are the products instead of carbon dioxide.

For most fuels, such as diesel oil, coal or wood, pyrolysis occurs before combustion. In incomplete combustion, products of pyrolysis remain unburnt and contaminate the smoke with noxious particulate matter and gases. Partially oxidized compounds are also a concern; partial oxidation of ethanol can produce harmful acetaldehyde, and carbon can produce toxic carbon monoxide. The quality of combustion can be improved by the designs of combustion devices, such as burners and internal combustion engines. Further improvements are achievable by catalytic after-burning devices (such as catalytic converters) or by the simple partial return of the exhaust gases into the combustion process. Such devices are required by environmental legislation for cars in most countries and may be necessary to enable large combustion devices, such as thermal power stations, to reach legal emission standards. The degree of combustion can be measured and analyzed with test equipment. HVAC contractors ,firemen and engineers use combustion analyzers to test the efficiency of a burner during the combustion process. In addition, the efficiency of an internal combustion engine can be measured in this way, and some U.S. states and local municipalities use combustion analysis to define and rate the efficiency of vehicles on the road today. Carbon monoxide is one of the products from incomplete combustion. Carbon is released in the normal incomplete combustion reaction, forming soot and dust. Since carbon monoxide is considered as a poisonous gas, complete combustion is more preferable, as carbon monoxide may also lead to respiratory troubles when breathed since it takes the place of oxygen and combines with hemoglobin.

**C. Problems associated with incomplete combustion**

**Environmental Problems:**

These oxides combine with water and oxygenin the atmosphere, creating nitric acid and sulfuric acids, which return to Earth's surface as acid deposition, or "acid rain." Acid deposition harms aquatic organisms and kills trees. Due to its formation of certain nutrients which are less available to plants such as calcium and phosphorus, it reduces the productivity of ecosystem and farms. An additional problem associated with nitrogen oxides is that they, along with hydrocarbon pollutants, contribute to the formation of tropospheric ozone, a major component of smog.

**Human health problems:**

Breathing carbon monoxide causes headache, dizziness, vomiting, and nausea. If carbon monoxide levels are high enough, humans become unconscious or die. Exposure to moderate and high levels of carbon monoxide over long periods of time are positively correlation with risk of heart disease. People who survive severe CO poisoning may suffer long-term health problems. Carbon monoxide from air is absorbed in the lungs which then binds with haemoglobin in human's red blood cells. This would reduce the capacity of red blood cells to carry oxygen throughout the body.

## NOMENCLATURE OF CATALYTIC CONVERTER

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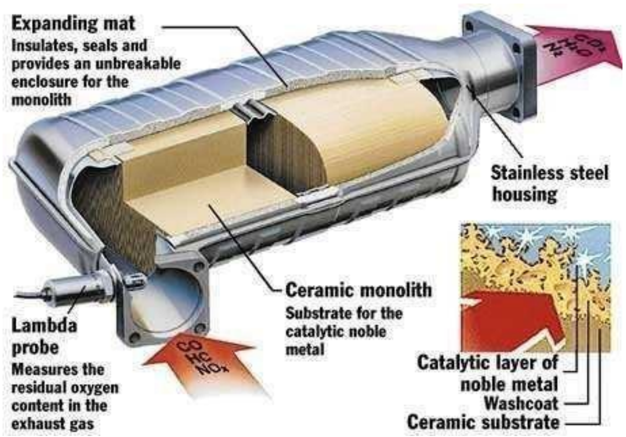


**Fig. 1 Nomenclature of catalytic converter**

Fig.1 shows the nomenclature of catalytic converter and it is described as follows:

The core or substrate: The core is often a ceramic honeycomb in modern catalytic converters, but stainless steel foil honeycombs are used, too. The honeycomb surface increases the amount of surface area available to support the catalyst, and therefore is often called a "catalyst support".

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.

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.

### D. Substrate material

The catalytic converter is made up of several materials. The catalyst core or substrate varies according to the vehicle. For example, when these devices are used in automotives the core is usually a ceramic monolith with a honeycomb structure. When manufactured in large quantities, ceramic cores can be inexpensive. Metallic foil monoliths are made of iron-chromium-aluminum combination, and used in some applications. Metallic cores are less expensive when manufactured for use in small production runs, such as in sports cars in which low back pressure and reliability under constant high load is essential. Both these materials are designed to provide a high surface area to support the catalyst washcoat.

The catalyst washcoat is a carrier for the catalytic materials, which is used to disperse the materials over a high surface area. Titanium dioxide, aluminium oxide, silicon dioxide, or a combination of silica and alumina can be used. The catalytic materials are suspended in the washcoat before application to the core. Washcoat materials have rough, irregular surface to increase surface area, which helps to maximize the catalytically active surface available to react with the engine exhaust.

**Fig. 2 Substrate materials**

### E. SCRUBBER MATERIALS

Scrubber is a cement like paste hardened and placed on the way of exhaust gases. It facilitates the reduction of $CO_2$(Which is a greenhouse gas) levels being emitted, thereby reducing the effect of pollution further. The chemicals used for scrubber are chosen on the basis of carbondioxide adsorbing tendency.

**Scrubber materials:**

Zeolite: Zeolites are highly porous rocks and while they occur in nature, they can be manufactured as well. Their toughness, high surface area and ability to be reused hundreds of times makes them ideal candidates for carbon dioxide scrubbing. Zeolite, which has octagonal “windows” between its interior pore spaces, is special because it is highly capable of filtering out carbon dioxide ($CO_2$) from a gas mixture.

**Silica:** Silica is incorporated for the binding of zeolite with the added advantage of silica being a carbon dioxide adsorber.

**Calcium oxide:** Calcium oxide is a promising sorbent for the capture of carbon dioxide. What’s more, once the lime has lost its reactivity, the spent material can be used to make cement. The biggest advantage of the new method is that it takes place at higher temperatures which go up to 650 °C because the reaction between lime and carbon

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dioxide, which forms calcium carbonate and releases heat. Bentonite sand: Bentonite sand is used as a binding agent.

**Magnesium Oxide:**
Also known as magnesia , is a white hygroscopic solid mineral that occurs naturally as periclase it consists of latice ions $Mg_2$+ and $O_2$- ions. It is thermodynamically stable at high pressures and temperatures .

$$MgO + CO_2 \longrightarrow MgCO_3$$

**Activated Carbon:**
Also known as activated charcoal, it has low-volume pores that increase adsorbtion and chemical reactions due to its high degree of porosity it has a surface area of 3000$m_2$ . It is commonly derived from coal and coke.

**F. SHAPE OF CATALYTIC CONVERTER**
Fig.3 shows the honeycomb structure of the converter. The shape of catalytic converter should be selected as round honeycomb structure because it is easy for manufacturing. By choosing this shape, surface area of substrate increases. Also, with these shape, minimum time required for assembly and it is easy for maintenance. With the use of round honeycomb structure, mass of substrate get reduced and flow area increases. With use of round shape backpressure reduces about 10 to 15%. Also thermal conductivity goes on increases by choosing this shape. There are other shapes like oval, rectangular used. But in this shape, pressure drop is more as compared to round shape. Also wall thickness is more in case of the rectangular shape. Therefore surface area is reduced. For this reason shape of catalytic converter should be selected as round honey comb structure .

| Chemicals | Proportions |
|---|---|
| Zeolite | 150 g |
| Silica | 50 g |
| Calcium Oxide | 50 g |
| Bentonite sand | 20 g |

**Table 1. Chemical components and proportions**

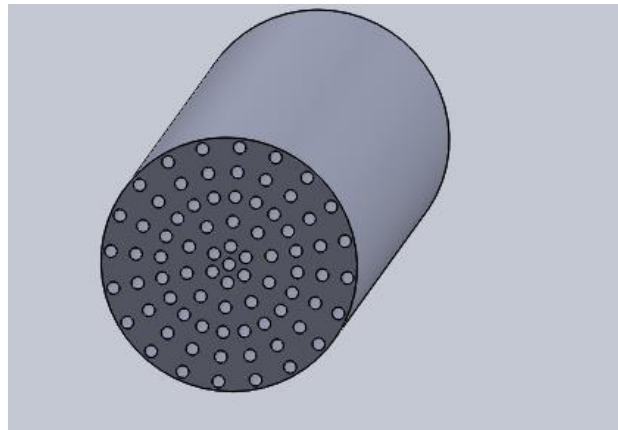

**Fig.3 Round Honeycomb Structure**

**G. SPACE VELOCITY**
Space velocity is the ratio of exhaust gas flow rate to the volume of converter . Space velocity means residential time of exhaust gases in converter or reactor. In general space velocity means amount of entering volumetric flow rate of reactants divided by the reactor volume. If space velocity goes on increasing then converter volume decreases. i.e. performance of catalytic converter goes on decreasing. So, space velocity is assumed in proportion with converter volume. Space velocity varies from about 20000 to 25000 per hour depending upon the duty cycle of engine. Table 1 shows the chemical components and its properties.

**H. VOLUME OF CATALYTIC CONVERTER**
This parameter is also important in designing of catalytic converter. The volume of catalytic converter is 0.5 to 1 times that of the engine swept volume . Also, volume of catalytic converter depends upon engine swept volume and is inversely proportional to the space velocity. If, volume of catalytic converter is lower than half of the engine swept volume then, space velocity increases tremendously. Because of this, reaction between catalyst and exhaust gases does not take place and emission goes on increasing. Hence, it is kept in the range of engine swept volume.

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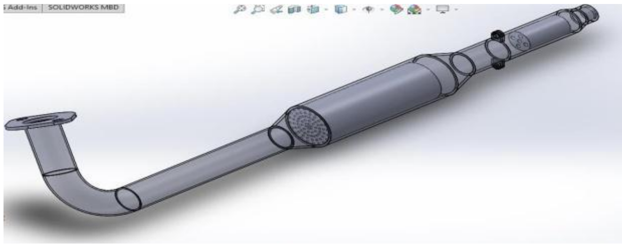

**Fig.4 Catalytic converter with scrubber**

### IV RESULTS AND DISCUSSION

A single phase single-species incompressible flow simulation with Air as the working fluid will be carried out.

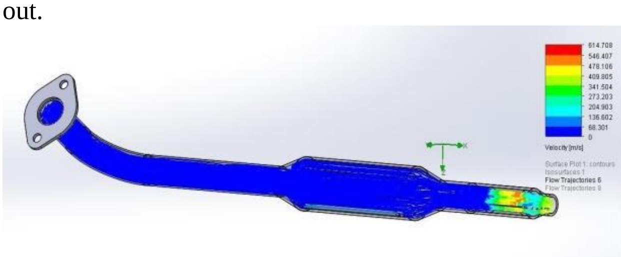

**Fig. 5 Velocity distribution through the catalytic converter**

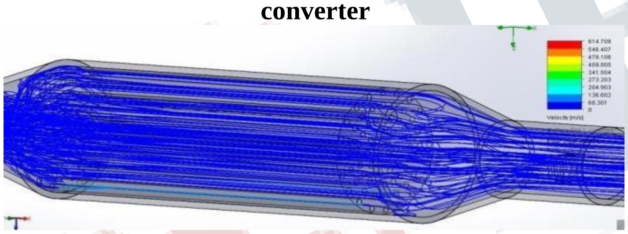

**Fig. 6 Velocity distribution through substrate**

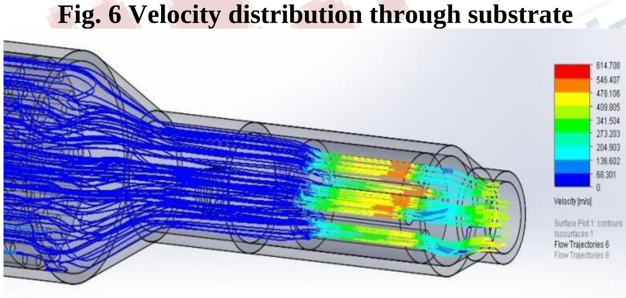

**Fig. 7 Velocity distribution through scrubber**

**Fig.8 Pressure distribution through catalytic converter**

The velocity of gases rapidly in the middle section, where the fluid velocity changes as it passes through the porous substrate. The pressure drop can be high due to the inertial and viscous resistance of the porous media. Fig. 4 – 8, shows the velocity and pressure distribution through the scrubber.

### V CONCLUSION

The catalytic converter model along with scrubbing substance as an approach to reduce carbon dioxide adopted by us has been tested for preferred compliance in a government approved testing centre. The use of zeolite, silicon dioxide and calcium oxide combination as scrubbing substance in the catalytic converter was significantly able to increase the reduction of Carbon dioxide exhaust emissions. The results obtained substantiates that the proposed method works. This opens room for more opportunities in after treatment of exhaust gases. So, the incorporation of methods to dynamically detect and measure the amount of harmful gases emitted during the operation of the engine. Such a method would pave way for near zero emissions from automobiles.

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