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Development of a Cost Effective Catalytic Converter for Diesel Automobiles

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Abstract: ***The purpose of the work presented in this paper is to find and suggest a suitable solution to the exhaust pollution coming from the Diesel Automobiles particularly in the metro cities. Due to incomplete combustion of fuel oil pollutants like CO, HC, NO_x are released into atmosphere causing negative impact on air quality, environment and human health. Researchers all over the world concentrated on how to reduce the pollutants. Euro norms specify the allowable percentages of CO, HC and NO_x in the exhaust gases. Euro norms being implemented in the developed countries have given stringent values which has led to the development of catalytic converter which is an added equipment in automobile. Hitherto in the catalytic converters supplied in modern cars, Platinum and Rhodium metals are used for coating monoliths. These metals are rare and hence expensive. In the research carried out by the authors, suitable monolith substrates are tested and used in the catalytic converters with coating materials like CeO_2, ZrO_2 over clay marbles, Copper Monolith and SS Discs which help NO_x¬ abatement and oxygen storage. These were designed, fabricated and tested on automobiles. The results are encouraging showing marked fall of pollutants in exhaust gases.***

*Keywords: **Catalytic Converter, Coating materials, catalysts, Clay marbles, Monolith***

I. INTRODUCTION

In the year 1975 USA has first seen the necessity of cleaning Automobile exhaust gases. Since then the pollution control of automobiles has seen a sea of change in the last four decades. The efforts can be broadly classified into following categories:-

1. Improvement of fuel – unleading & desulphurization
2. Changes in the engine design & engine tuning
3. Additional equipment like EGR and Turbo chargers
4. Development of Catalytic Converters

Due to stringent norms of pollutants in exhaust gases, the first three efforts listed above were insufficient during turn of century. An additional equipment called catalytic converter had to be added to the exhaust pipe and muffler /Silencer for an automobile. That is the exhaust gases have to be treated for removal of CO, HC, PM & NO_X. Table I gives information as to how euro norms were made more and more stringent from Euro I through Euro VI. It can be seen in the latest Euro norms that the PM and NO_X have been made very stringent. However the adoption of Euro norms by India as Bharat Stage I to IV has been slow and implemented watchfully. As Indian scenario sees 15 year old cars plying on roads due to the economical condition of population, which cannot afford expensive new cars. The public transport consisting of buses, cabs and trucks are continuously using more than 15 year old vehicles polluting the atmosphere. Compared to this, in the developed countries cars are junked after 5 years.

The emission norms of Euro and Bharat stage are given in table I (a) and (b)

Table I (a) Euro norms for Diesel Engines

Tier	Date	CO g/km	NOx g/km	HC+NOx g/km	PM g/km
Diesel					
Euro 1	July 1992	2.72	-	0.97	0.14
Euro 2	January 1996	1.0	-	0.7	0.08
Euro 3	January 2000	0.64	0.5	0.56	0.05
Euro 4	January 2005	0.50	0.25	0.30	0.025
Euro 5	September 2009	0.50	0.18	0.23	0.005
Euro 6	September 2014	0.50	0.08	0.17	0.005

Table I (b) Bharat Stage norms

Emission Norms	Year of Implem entation	CO g/km	HC + NO_x g/km	NO_x g/km	PM g/km
Bharat Stage IV	2009	0.74	0.46	0.39	0.06
Bharat Stage V	2014	0.74	0.36	0.28	0.004 5
% Change		NO change	22	28	93

* Generally these norms are for vehicle category N1¬ class 3 of 3.5 ton vehicles in major cities.

It is observed from literature that the development of Catalytic Converter monolith itself is in four generations.

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The monolith carries catalysts – both for oxidation and reduction. It has taken development from two way catalytic converter to three way and four way Catalytic Converters. The four way catalytic Converter has been designed particularly for Diesel automobiles for removal of PM, HC, CO and NO_X from exhaust gases.

However this paper discusses the structural changes of catalytic converter right from Generation I to III giving case studies in support.

Generation I: canisters with clay marbles suitably coated with catalysts for oxidation and reduction of exhaust gas.

Generation II: Steel perforated discs/ meshes used for the coating of catalysts.

Generation III: Usage of metal monoliths for the coating of catalysts.

The authors have fabricated models for the three generations and conducted experiments on automobiles on road. The results are compared and pros and cons discussed.

There are certain advantages and disadvantages of each model. Using experimental results the best model is aimed at. Also financial aspects are discussed in comparison to each other. Ultimate aim is to develop an affordable catalytic converter for retrofitting in the exhaust system of a 15 year old vehicle to reduce the exhaust pollution.

Generation I: Preparation & Fabrication of Clay marble Catalytic Converter

Clay Marble Making:

Pot makers' clay is taken and sufficient water is added to make it into a workable paste. The wet clay is hand rolled into 10mm diameter Marbles. (See Fig. 1) They are then dried in open air at room temperature for one day. The excess moisture evaporates and makes the marbles hard and dry. These dried clay marbles are heated in an oven up to 350^0 C. Initially heating rate of 10^0 C/min till 100^0 C and then 15^0 C/min is used. They are cooled in the furnace to room temperature for a day (See Fig. 2).

Fig. 1. Clay Marbles **Fig. 2. Coated Marbles**

These clay marbles are porous and have good absorbing capacity. So they absorb chemical coating done over it. Due to spherical surface, they have maximum contact area for passing gases. The voids between successive balls help passage of gases freely, thus causing minimum back pressure on engine.

Fabrication of canister for holding clay marbles:

A G.I sheet is taken as material for canister as it is cost effective and light weight. It is formed in to a circular cylinder. Circular plates with perforation are used as top and bottom covers. (Fig. 3)

Fig. 3. Canister preparation

Two such casings are prepared for housing oxidation catalyst coated marbles and reduction catalyst coated marbles separately. Initially all marbles are coated with Al_2O_3 as wash coat. Half of them are then coated with CeO_2 and the other half with ZrO_2. Finally the canisters are fitted in catalytic converter housing as shown in Fig. 4.

Fig. 4.Catalytic Converter Housing

Diesel Particulate Filter (DPF):

A prototype of DPF is prepared using a stainless steel sheet of 5mm thickness. Small holes of 2mm diameter are drilled in this plate. These holes on the DPF hold back the particulate matter & soot at inlet of the catalytic converter. A foam sheet of 5 mm thickness also is added as it is porous and allows flow of gases. (Fig. 5)

Fig. 5. (a) Diesel Particulate Filter and (b) Foam Filter

Generation II: Fabrication of Metal Monolith canisters with perforated circular discs

Different design sections can be formed with different patterns as shown in Fig. 6 (a). However using CFD software, flow channels are optimized as shown in Fig. 6 (b).

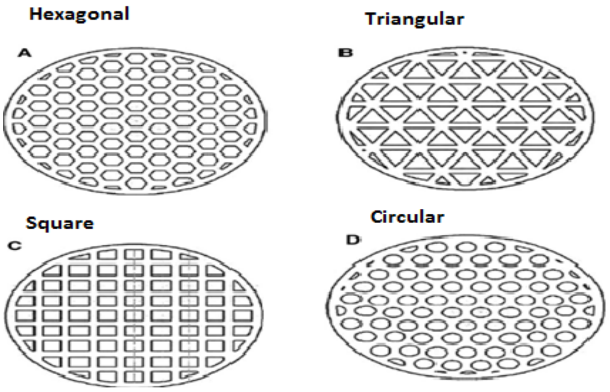

Fig. 6 (a).Different Channels

CFD optimization studies

The CFD flow optimization studies were carried out on simulated geometries for i) Triangular ii) Square iii) Circular and iv) Hexagonal sections. The catalytic converter canister geometry is modeled and the velocity & pressure of gases flowing through different sections are studied.

Fig. 6(b) indicate the geometries used in the ICEM software and Table II shows pressure drop comparison for different channels

Table II: Pressure drop in different channels at different velocities.

Velocity m/s	Pressure Drop in different channels, Pa			
	Triangular	Square	Circular	Hexagonal
5	3133.651	1791.750	672.776	333.651
10	6296.048	3612.103	1373.542	696.435
15	9486.329	5460.006	2101.880	1109.747
20	12704.386	7335.478	2859.319	1592.042

It is seen that hexagonal section gives minimum pressure drop across all channels. For a best efficiency of engine the pressure drop (back Pressure) should be minimum. Circular section is second best. However due to ease of fabrication Circular Section is used. Fig. 6 (c) shows the CFD pattern for Circular section.

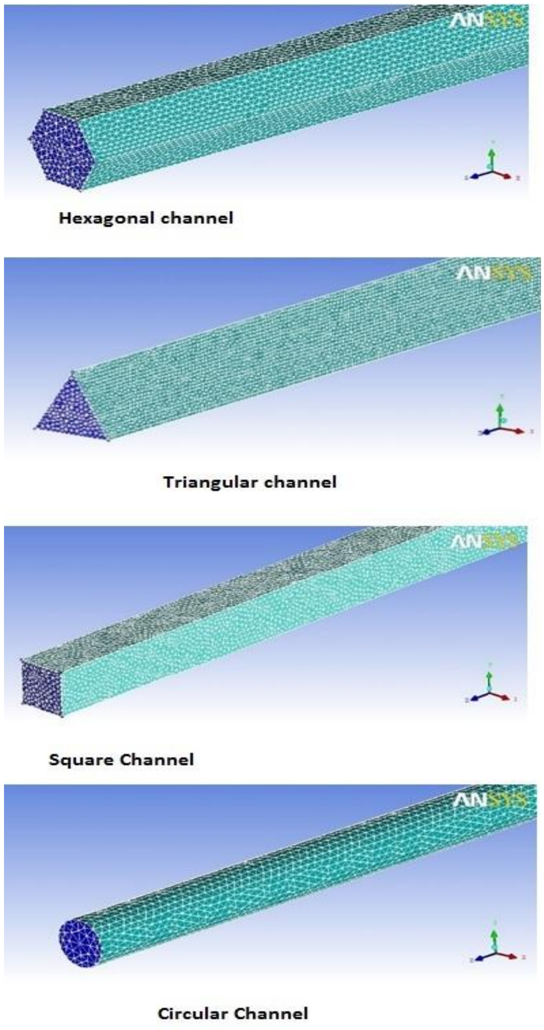

Fig. 6(b). Flow channels by CFD

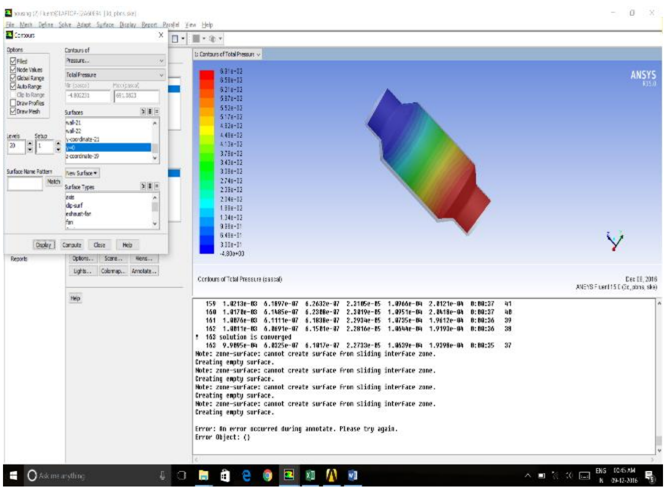

Fig. 6 (c) Total pressure drop across circular channel CFD pattern

Stainless steel is highly corrosion resistant, and has high hot strength, ductile and can resist heat damage. SS304 sheets available in the market are used. Circular shaped discs are cut out form the sheet. The size of the circular disc is that of the inner diameter of the canister. The sheets are stacked into two sets one for oxidation catalyst and second for reduction catalyst. (Fig 7)

Fig. 7. Stacked SS Discs

They are introduced into canisters. Fabrications of the canisters are already discussed under generation I.

Fig. 8. Wash coat and catalyst coated SS Discs & Clay Marbles

Generation III: Metal Monoliths:

Fabrication of a metallic monolith substrate:

Copper is chosen Copper alloy substrate

Copper is Malleable, Metallic and Ductile element having a characteristic reddish brown color.

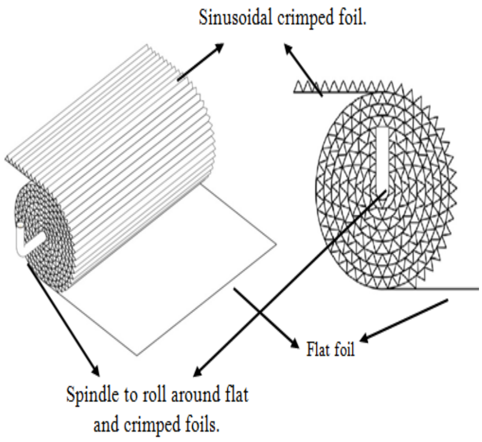

Fig. 9. Fabrication of metal monoliths by rolling

Copper substrate

Copper foil of 0.3 mm thickness is used.

Design of metal monoliths from copper:

Metal foils can be formed into different design structure, the most common of which is based on rolling alternate corrugated and flat strips of metal foil as shown in Fig.10. This is achieved by crimping a metal strip on a pair of rollers having teeth of pre-specified profile.

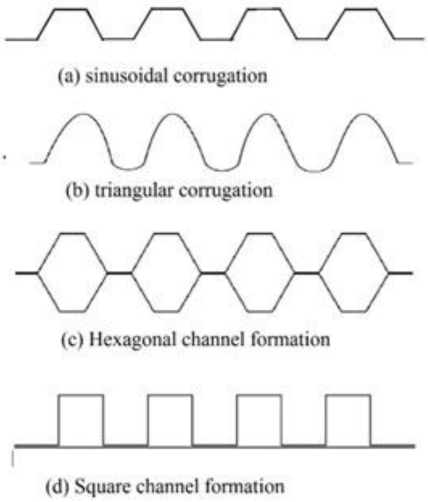

Fig. 10 Channel formation in monolith

Multiple parallel channels are achieved between the corrugated strips as sheets are rolled around a spindle until designed diameter of monolith is achieved. To achieve variation in number of cells per unit area, the pitch and width of profile on the crimping rolls are carefully altered. (Fig. 11 & 12)

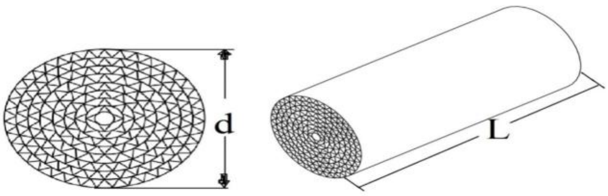

Fig. 11. Corrugated (Rolled) metal monolith

Fig. 12. Triangular channel monolith

Material selection for substrate

Copper sheets were used for the substrate preparation as it has good physical properties to absorb the gases. This copper sheet of 0.3 mm thick is made into triangular channel monolith to a diameter of 76 mm and is used for the catalyst coating.

Fig.13 (a) prepared copper monolith, (b) mixture of metal catalyst and wash coat slurry

Fig. 14. ZrO_2 coated Copper monolith substrate

Fig. 15. Cerium oxide coated copper monolith substrate

Coating Procedure

Dip coating technique is used for both the models. Initially aluminum oxide slurry is made, 25gms of AL2O3 is added to 5gm of Polyvinyl alcohol, 2ml acetic acid and 50ml distilled water is mixed to prepare the slurry and is stirred at 600 rpm for one hour. This is used as wash coat on the three monoliths viz clay marbles, SS discs and Copper monolith. The models are Calcinated in a muffle furnace at 2500 C for 30 minutes. Similarly oxidation catalyst is prepared with 10gms of Cerium Oxide added to 2.5gm PVA, 2ml acetic acid and 20ml distilled water are added to it and stirred at 600 rpm for one hour. After the slurry preparation is completed, the wash coated models are coated with same procedure and Calcinated at 2500 C in muffle furnace for 30 minutes.

Similarly Reduction Catalyst Zirconium Dioxide is used for slurry preparation in the same way as in case of Oxidation catalyst. This coating is done on the second monolith, of all the three models. The coated Oxidation & Reduction monoliths are placed in the respective canisters. Finally both the Oxidation and Reduction canisters/monoliths are mounted in the Catalytic Converter Housing (Fig. 4).

II. EXPERIMENTAL PROCEDURE

The fabricated monolith substrates (Clay marbles, SS Discs & Rolled Copper sheet) are taken to laboratory. These are assembled in the catalytic converter casing one after the other (Fig. 4).

The assembly is then taken to Swaraj Mazda Mini bus (Specifications given in Table III) and fitted in the exhaust pipe (Fig. 16).

Fig. 16. On road vehicle Testing fitted with catalytic converter.

Before fitting the catalytic converter the pollution check is carried out using gas analyzer on the bus by running the engine in idling condition. Then the readings are taken with the catalytic converter fitted. The Tables IV a, b, c & d give the comparative results.

Table III: Specifications of the on-road diesel engine vehicle – Swaraj Mazda

PARTICULARS	SPECIFICATIONS
Engine	In-line OHV Diesel engine
Fuel	Diesel
No. of cylinders	Four
Maximum torque	222 Nm ra1750 rpm
Bore diameter	100 mm
Stroke length	110 mm
Starting	Self starting
Working cycle	Four stroke
Method of cooling	Water cooling
Method of ignition	Compression
Cubic Capacity	3455

III. RESULTS

(a) Clay marbles: 10mm Diameter

Table IV (a)

	CO% Vol	HC % Vol
Without Catalytic Converter	1.99	57.50
With Catalytic Converter	0.26	10.50

(b) Perforated SS Discs: Dia 76 mm, No. of discs per stack 67 nos, Hole dia 2 mm, Pitch 5mm, plate thickness 1.2 mm, Grade SS 304

Table IV (b)

	CO% Vol	HC % Vol
Without Catalytic Converter	1.99	57.50
With Catalytic Converter	0.18	7.45

(c) Copper Monolith: 76 mm diameter rolls with a 0.3 mm thick copper sheet

Table IV (c)

	CO % vol	HC % vol
Without catalytic converter	1.99	57.50
With catalytic converter	0.261	32.4

(d) Comparison between Three models:

Table IV (d)

Monolith material	Without Catalytic Converter	With catalytic Converter	Difference	Percentage of improvement
Clay Marbles	HC: 57.50 CO: 1.99	10.50 0.26	47 1.73	82 87
SS Discs	HC: 57.50 CO: 1.99	7.45 0.18	50.05 1.81	87 91
Copper Monolith	HC: 57.50 CO: 1.99	32.4 0.261	25.1 1.72	43.6 86.5

IV. CONCLUSIONS

From the results it is clear that SS metal discs are giving better performance than the clay and Copper substrates. Further, instead of dip coating, spray coating using nano powders of Al_2O_3, CeO_2 & ZrO_2 will definitely give better performance and they will last for longer time. At the same time clay marbles are also equally effective.

If the economics aspect is studied, it is obvious that clay marbles are cheaper compared to SS discs and Copper monolith. But longevity of clay marbles is to be established.

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