PERFORMANCE ANALYSIS OF CATALYTIC CONVERTERS IN SPARK IGNITION ENGINE EMISSION REDUCTION

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ABSTRACT

Petrol engines give more hours power, which enables them to attain higher top speed and better acceleration. The refined driving experience offered by the petrol engines still remains unparalleled. Apart from this, less noise, less vibration, easy to start in cold weather are some of the unique advantages of petrol engine. But thermal efficiency and harmful emissions are the two aspects that need to be improved. Generally three way catalytic converter is used to reduce the emissions without any change in the design of the engine. However, its presence leads to increase in exhaust back pressure resulting in high fuel consumption and decrease in volumetric efficiency. Our present work is focused to reduce the back pressure and emission level by modifying the design of the catalytic converter geometry, substrate diameter and length and new wash coat materials employing low cost zeolite synthesised from coal fly ash. Experiments were carried out in twin cylinder petrol (MPFI) engine with attaching the newly fabricated Converter with varied cone angles-30, 35, 40 and 45 degrees separately near to the exhaust manifold. Load tests were conducted and AVL-444 di-gas analyser was used to measure CO, HC, CO_2, O_2, and NOx. The CO and HC reduce by 85% and 80% respectively for 35 and 40 degree cone angle catalytic converters. Around 60% of NOx emission is reduced with 35 degree cone angle catalytic converter.

KEYWORDS: *Back pressure, MPFI engine, AVL-444 di-gas analyser.*

I. INTRODUCTION

Due to rapid increase in vehicles movement year by year, the automobile pollution control regulatory bodies tightened the emission level every year. Ultra low emission or zero emission vehicles are aimed and more preferred for future. So the researchers adopt multi dimensional approach for reducing emission level. Modification of fuels, Modification of engine design and operating parameters and Treatment of exhaust products of combustion are some of the major approaches. Many researchers are focusing on modification of fuels, and engine design, but very few researchers are concentrating on engine out emission reduction. Among various pollution control devices, Catalytic converter is being widely used. The significance of the catalytic converter is that it reduces harmful gases without any change in the design of the engine. Catalytic converter is a stainless steel container with a porous ceramic structure, mostly a single honey comb structure with many flow passages, through which the exhaust gas flows[Jan Kaspar et al [1], Vesna Tomasic et al[2]]. The flow passages are in many shapes viz., square, triangular, hexagonal and sinusoidal. In early times, loose granular ceramic were used with the gas passing between the packed spheres. However, later on ceramic monoliths were opted owing to its less volume, low mass and easy packaging facility. The monolith walls were coated with active catalyst layer, called washcoat, composed of porous, high surface area inorganic oxides such as gamma alumina, Ceria, Zirconia. Noble metal catalyst such as Platinum, Palladium and Rhodium are deposited on the surface and within the pores of the washcoat. When the exhaust gas flows in a catalytic converter it diffuses through the washcoat pore structure to the catalytic sites where heterogeneous chemical reactions occur, which varies depending on the type of catalyst installed [Ulrich G et al [3]]. Mostly vehicles running on gasoline are fitted with a three way converter, which converts the three main pollutants in automobile exhaust viz., carbon monoxide and unburned hydrocarbon undergo catalytic combustion and oxides of nitrogen are reduced back to nitrogen. The need for improvement of design and performance of catalytic converter has arisen due to prevailing stringent emission regulations. Efforts are being made for design improvement by reduction of emission during normal driving operations and cold start conditions. Some researchers have tried to reduce cold start emission by using chemically or electrically heated catalysts and thereby minimizing the catalyst warm up period during the cold engine start. Few others have made efforts to improve the performance of catalyst during post warm up period. In addition to the various innovative efforts taken to reduce emissions, various attempts for design optimization of existing three way catalytic converter are also made. This involves optimization of the converter geometry, selection of substrate and wash coat materials and the converter location in the exhaust line [Jonathan D et al. [4] C. Lahousse et al [5]. The catalytic converter geometry considered for study was shown in Fig1. The attempts of earlier researchers are summarised in section. II. The details of wash coat, fabrication of catalytic converters and experimentation were explained in sections III and IV. The experimental results and detailed discussion were presented in Section V and concluded in section.VI.

Fig 1 Catalytic converter

II. PRESSURE DROP IN A CATALYTIC CONVERTER

The total pressure drop in a catalytic converter can be categorized into two. One is pressure drop formed in the monolith, another is pressure drop caused by inlet and outlet cones of the converter. The pressure drop of an individual substrate is influenced by numerous factors such as the substrate frontal area, length, cell density and wall thickness. Mlyaire et al. [6], and Jinkegong et al. [7] have reported the importance of cell shape and cell size in the overall performance of a catalytic converter. Tanaka et al. [8] conducted emission analysis and concluded that a square cell reduces emission slightly better than the hexagonal cell. Andreassi et al. [9] Conducted studies using fixed cell densities and hydraulic diameters, and concluded that at a constant cell density of 300 cpsi, a square cell is better in terms of pressure loss. The superiority trend is square> hexagonal> sinusoidal> triangular. At a constant hydraulic diameter of 1.26 mm, the trend is triangular>sinusoidal>square>hexagonal. Bassem H. Ramadan et al. [10], E. Abu-Khiran et al. [11] and F. Ekstrom et al. [12] evaluated the back pressure, but the focus was on a single cell density using single channel three-dimensional (3D) analyses.
Apart from the pressure drop formed in the monolith, the design of the inlet and outlet cones of the converter affects the total pressure drop. Entrance effects are due to the boundary layer growth, flow mal distribution, and sudden contraction when flow enters the monolith. Therefore a fully developed laminar flow profile would arise after a certain distance in the channel [Douglas Ball et al. [13]. Thundil Karuppa Raj et al. [14], performed the pressure drop analysis by varying the inlet pipe angle (30º, 45º and 60º) using C.F.D but the author used air as working fluid. Many researchers said that the change in diameter and length was more important for short converters and it became gradually less important for long converters. So the present work was focused to analyse the performance of the catalytic converter, by changing the inlet and outlet cone angle, and monolith length and diameter, keeping the monolith overall volume and cell shape constant.

III. FLY ASH AS CATALYST SUPPORT

3.1 Monoliths

Cordierite honeycomb monoliths with following dimensions (as shown in table-1) were purchased from Bocent Advanced Ceramics Co. Ltd, China. Low cost Na-X zeolite like material was synthesised from coal fly ash (Mettur thermal power plant Tamilnadu, India.). Then the Na+ in the zeolite was ion exchanged to $CuCl_2$ (Fisher scientific) to get Fe-X zeolite. The synthesis of zeolite and Na+-ion exchange method was detailed in our previous work. [D.Karthikeyan and C.G.Saravanan [15].

Table 1 Parameters of monoliths

Diameter in mm	Length in mm	Wall thickness in mm	Cell Density cpsi	Cell Shape	Overall Volume in m^3
75	90	0.17	400	Square	397.40
80	80	0.17	400	Square	401.92
85	70	0.17	400	Square	397.01
100	50	0.17	400	Square	392.50

3.2 Monolith washcoating

Washcoating is one of the process of depositing a zeolitic layer on the internal channels of monoliths, through a dip-coating method. Details of washcoating procedure were described by many authors [Meille V [16], Juan M. Zumaro et al. [17]. A Slurry was prepared using a mixture of 20 weight % Fe-X zeolite, 2 weight % alumina and the remaining weight % of water. The monolith piece was dipped in the slurry for one minute and excess slurry was removed by flowing compressed air through the monolith channels for a fixed time of 5 seconds from both the ends. The wash coated monolith was then dried at 120°C for two hours. This stepwise dipping and drying process was repeated until the desired quantity (15% weight of monolith) of wash coat was deposited on the monolith support. Finally the monolith was calcined at 500°C for 5 hours. The deliberate calcinations reduced the likelihood of crack formation in the wash coat layer. The adherence of the washcoat was determined by the so-called adherence test, which consists in determining the weight loss of the coated monolith in an ultrasonic bath.

IV. EXPERIMENTAL STUDY

4.1 Fabrication of catalytic converter

Four catalytic converters were fabricated with incorporating the above said monoliths, and varying the inlet and outlet cone angles as shown in Table 2. Fig 2 shows the photographic view of catalytic converters.

The experimental study was conducted with exhaust of a stationary, four stroke, twin cylinder, water cooled petrol (nano)engine with a displacement volume of 624 c.c. Figure 3 illustrates the test facility for this study and the engine specification is shown in Table 3.

Table 2 Parameters of Catalytic Converter**.**

Cone angle in degree	**Diameter of monolith in mm**	**Length of monolith in mm**
30	75	90
35	80	80
40	85	70
45	100	50

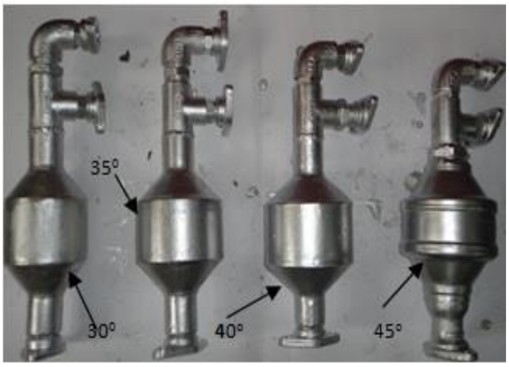

Fig.2 Photographic view of catalytic converters (30º, 35º, 40º and 45º)

The engine was directly coupled to an eddy current dynamometer. An AVL-di-gas (NDIR Type) analyser was used to measure CO (Carbon monoxide), HC (Hydro carbon), CO_2 (Carbon dioxide), O_2 (Oxygen) and NO_x. The exhaust gas sample to be evaluated was passed through a cold trap (moisture separator) and a filter element to prevent water vapour and particulates entering into the analyser. CO and CO_2 emission were measured in terms of percentage volume, NO_x and HC were measured in ppm (parts per million) hexane equivalents.

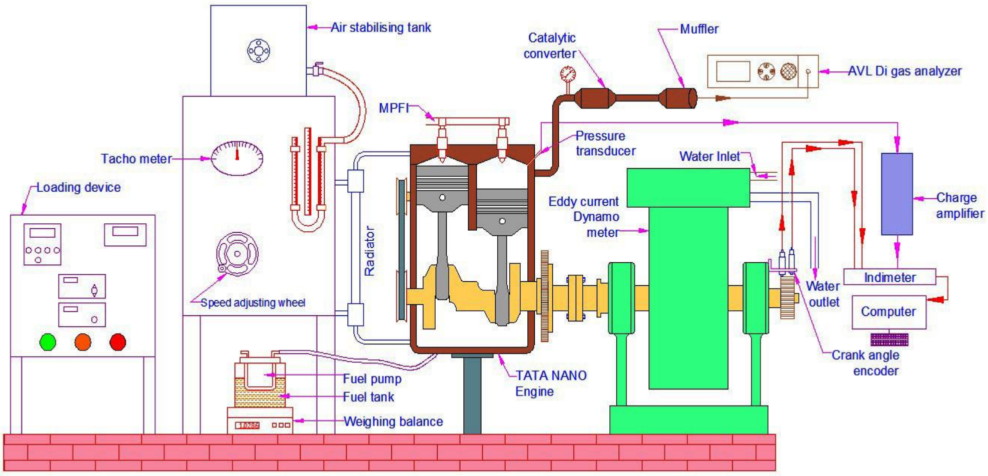

Fig.3 Experimental setup

The temperature of the Exhaust gas was measured by Chromel-Alumel Thermocouple. The fuel tank was placed over a weighing machine, to measure the fuel consumption. Without catalytic converter, the engine was run at different loads (4, 7, 10, 13 and 16 kW) at a rated speed of 2500 rpm. In each case, the concentration of HC, CO, CO_2, O_2 and NO_x were measured. Similarly in each load condition after the study state is reached the fuel consumption was measured with a fixed time interval of one minute using stop watch. Then the catalytic converter with cone angle 30º was fitted to the Engine exhaust manifold such that the exhaust gas enters the convertor axially. Then the engine was run at the same load conditions as it was when run without catalytic converter and the concentration of CO, HC, CO_2, O_2 and NO_x were measured in each case. Then, the above process was repeated using converters with cone angle 35º, 40º and 45º. Fig 4 shows the photographic view of 40º cone angle catalytic converter along with a pressure gauge fitted in the engine exhaust manifold.

Fig.4 Photographic view of Catalytic converter (40° Cone angle) fitted in the exhaust manifold.

Table 3 Specification of test engine

Engine	Nano Engine
Type	2-cylinder, 624 cc, MPFI
Bore diameter	73.5 mm
Stroke	73.5
Maximum power	37 bhp @ 5000 rpm
Maximum torque	51 Nm @ 3000 rpm
Dynamometer constant	9549.5
Compression ratio	9.5:1

V. RESULT AND DISCUSSION

Fig 5 and Fig 6 shows the variation of brake specific fuel consumption and brake thermal efficiency with brake power of the engine. It is seen from the graph that the B.S.F.C is decreased marginally when the cone angle of the catalytic converter is increased. On the other hand brake thermal efficiency is marginally increased when the cone angle of the converter is increased. It is observed that brake thermal efficiency was very low in cause of catalytic converter with 30° cone angle and is consistent with Karuppasamy and Senthil [18]. It is because of the sudden expansion of the exhaust gas in the divergent portion of the cones create turbulence, and there is a flow resistance across the frontal area of the monolith. So the back pressure is high in this cause. In agreement with many researchers it is true that when the back pressure created inside the catalytic converter is increased it affects the brake thermal efficiency.

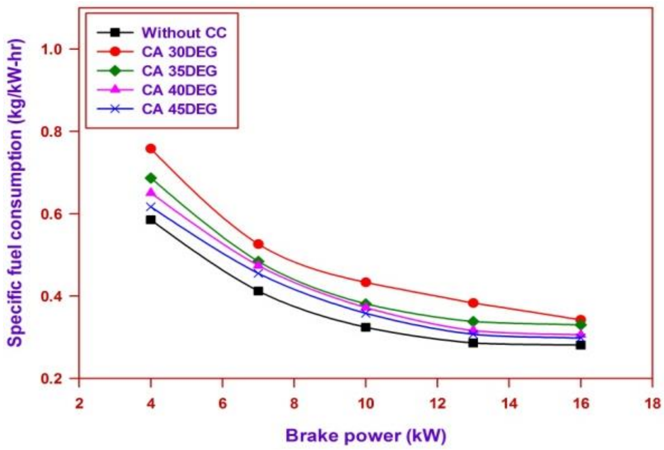

Fig 5 SFC against brake power

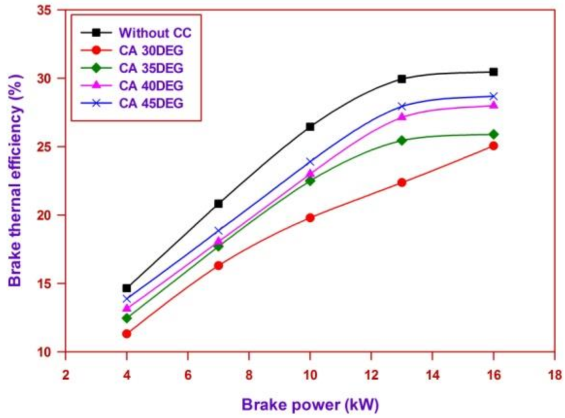

Fig 6 BTE against brake power

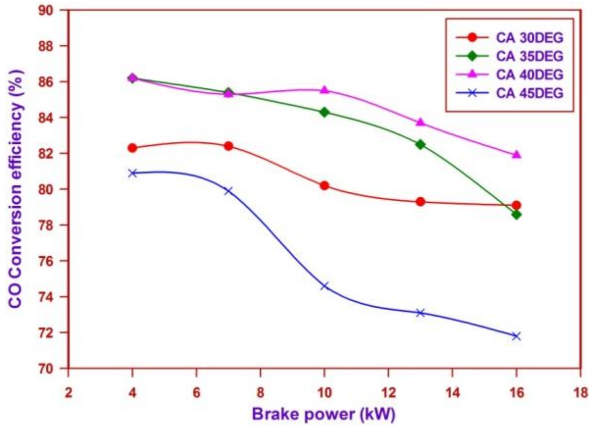

Fig 7 CO emission against brake power

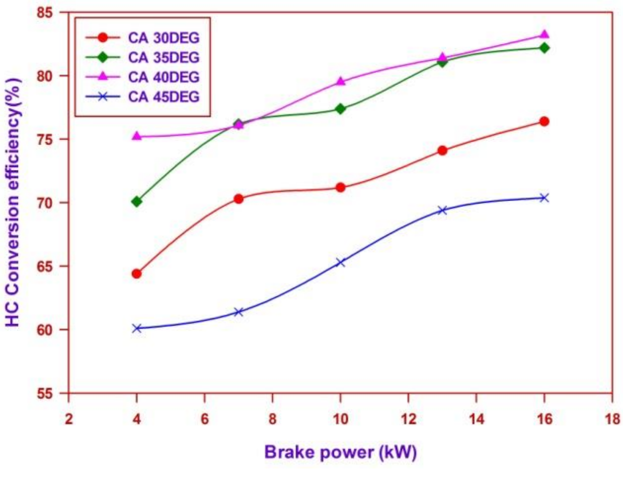

Fig 8 HC emission against brake power

Figs. 7 and 8 show the variation of CO and HC conversion efficiency with brake power of the engine. As far as the cone angle is concerned, same trend was observed with CO and HC conversion as seen in NOx conversion efficiency. But around 85% of CO conversion was achieved at lower load (4kw and 7kw) conditions, and around 80% of HC conversion was achieved at higher load (13kw and 16kw) conditions. It is seen from the graph that, the conversion efficiencies were almost same in case of 35º and 40º cone angle catalytic converters. It is evident from the graphs that increasing the cross-sectional area and decreasing the length of the monolith beyond certain value , results in diminishing effect on emission reduction performance as reported by Silva et al.[19].

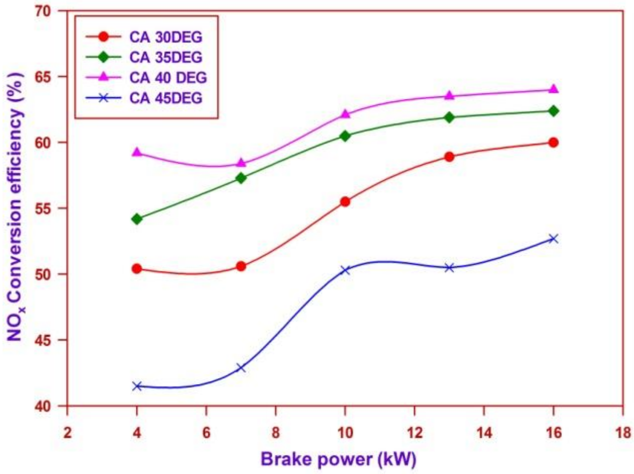

Fig 9 NO_x emission against brake power

Fig 9 shows the variation of NOx conversion efficiency with brake power. It is seen from the graph that as diameter of the monolith was increased, the NOx conversion efficiency also increased though the volume of monolith was maintained constant as reported by Subramanyeswararao [20]. It is seen from the figure that around 62% of NOx conversion was achieved at 16 kW load condition by 40° cone angle catalytic converter. There is no much performance difference between 35º and 40º cone angle converters, but for 45ºcone angle there is a decrease in NOx conversion efficiency. This may be due to low residence time of exhaust gas inside the monolith (Dia 100 x 50).

VI. CONCLUSION

Four catalytic converters were successfully fabricated and tested in twin cylinder petrol engine. The following conclusions could be drawn from the experimental results.

- It is observed from the experimental result that by increasing the catalyst frontal area and decreasing its length, pressure drop can be significantly improved.
- The gas flow mal distribution was minimized by changing the inlet and outlet cone angles. Based on the experimental study the brake thermal efficiency is found to be increasing upto 35° cone angle and on reaching 30° cone angle it starts reducing.
- As the cross sectional area of monolith (i.e., the diameter of the monolith) is increased, the brake thermal efficiency also increases.
- The exhaust emissions (CO, HC, NO_x) get increased with the increase of diameter of monolith upto certain value. In our study, it is observed that diameter 85 × 70 mm monolith catalytic converter reduces emissions significantly compared to other catalytic converters.
- Emission reduction starts decreasing with diameter 100 × 50 mm monolith catalytic converter. This is due to decrease in the residence time of the exhaust gas inside the monolith.
- It is observed from our experimental study that out of the same volume of monoliths taken, the one with larger cross sectional area and smaller length warms up quicker.

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