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Design and Analysis of Recirculating Catalytic Converter for a Single Cylinder 4-Stroke Petrol Engine

Rishab Singh[1], Tuhin Srivastava[2], Vipul Vibhanshu[3], Sameer Singh[4], Milan Sharma[5]

[1,2,3,4,5]*Department of Mechanical Engineering, KIET-Group of Institution, Ghaziabad - Meerut Highway NH-58, Ghaziabad, Uttar Pradesh 201206*

[1]*rishab.s2607@gmailcom*

Abstract: *The current worldwide trend of increasing energy demand in transportation sector are one of the many segments that is responsible for the growing share of fossil fuel usage and directly contribute to the release of harmful greenhouse gas(GHG) emissions. It is hoped that with the latest findings on exhaust heat recovery to increase the efficiency of ICEs, world energy demand on the depleting fossil fuel reserves would be reduced and hence the impact of global warming due to the GHG emissions would fade away. . Researchers all over the world are concentrating on reduction of these pollutants either by some alternative and renewable fuels or by some hardware modification in the vehicles. One of the modifications is utilization of catalytic converter. An improvement of catalytic converter (CATCON) design requires better fundamental understanding of complex processes taking place involving fluid flow, heat and mass transfer, and chemical reactions. The paper deals with the study of fluid flow inside the CATCON and the study of temperature distribution, chemical reaction and the effect of back pressure using catalytic converter.*

In the present investigation LOMBARDINI 340 engine has been used for the engine trials. CATCON has been developed in the first phase and further modeling and simulation analysis has been performed using CFD (computational Fluid Dynamics). In the next phase of the experiment emission and performance parameters were evaluated and validated by comparing experimental trials with the simulation modeling. During the development of CATCON total time taken to heat rise at optimum level has been considered as the prime focus area and the improvement has been made to reduce the time. In general existing engine time taken during the in heat rise is10-13 minutes but in the present study we reduce the time period to 6-7 minutes hence the improved performance comes out to be much more improved and also reduction in fuel consumption rate in comparison to the existing engine CATCON.

In CFD analysis, various models with different wire mesh grid size combinations were simulated using the appropriate boundary conditions and fluid properties specified to the system with suitable assumptions. Flow field in the catalytic converter is influenced by the flow resistance of the substrate for a given geometric configuration. As the mass flow rate increases, the pressure drop also increases. Compared to the baseline vehicle without CATCON the newly developed CATCON produced 62 % less non-methane hydrocarbon (NMHC), 68% less carbon monoxide (CO), and 60% less oxides of nitrogen (NOx).

Keywords: *Catalytic Converter, Exhaust Emission, Conversion Rate, Temperature, Gasoline,*

1. INTRODUCTION

Since the beginning of the 20^{th} century, Modern Civilization has developed at a fast pace. The invention of the engine, a new device that powered vehicles and manufacturing machinery was the radical factor behind this[1].The startling increasing the number of gasoline driven cars, which is expected to continue atleast for the next three decades and due to their versatility, flexibility and low initial cost, motorized vehicles intensely dominate the markets and freight transport throughout the world which lead to environmental degradation. Accidents, noise, congestion, increased energy consumption and greenhouse gas emissions are the other repugnant impacts of using motor vehicles, as these pollutants affect environment and the human health unpleasantly. The measures that had taken to decrease the levels of the emissions to tolerate limit was clear in the second half of 20^{th} century [2].

The major cause of air pollution in urban areas is Exhaust. Outdated engine designs, defective and deficient road net-works, erratic driving practice and congested and slow moving traffic have increased the problem of vehicular air pollution. Ozone layer in earth's atmosphere contains high concentrations of ozone (O_3). This layer absorbs 97-99% of sun's high frequency ultraviolet light, which damages the life forms on earth. The ozone layer can be depleted by free radical catalysts including Nitric Oxide(NO), Nitrous Oxide(N_2O), Hydroxyl(OH), Atomic Chlorine(CI) and Atomic Bromine(BR).[3-7]

In India the break down maintenance leads to emission of count of pollutants. Vehicular Pollution –A Threat to life form. The exhaust gases affect the values of the environment and destroy the basic quality of clean air. This emission contains smoke, Carbon Dioxide. Increase in unwanted gases and smoke in the atmosphere is affecting the Ozone Layer and due to this Ozone layer will not be in position to check radiation, which lead the exhaust gases emitted by the vehicles disturb the ecological balance in the atmosphere. A Catalytic converter is a device used to reduce the toxicity of emissions from an internal combustion engine. The Catalytic converter can be thought of a post-engine exhaust filter that removes the harmful emissions of an engine and effective in reducing noxious emissions. However, they may have some adverse environmental impacts in use. It reduces almost 80% of the harmful gases resulting from the incomplete combustion of the engine.

By using computational fluid Thundil et.al [2012] analyzed the fluid flow in catalytic converter. This study includes the effect of fluid flow due to geometry changes through the use of commercial CFD tool. This fluid assumed to be air. A section of catalytic converter had solved for analysis owing to its rotational symmetry and the governing equations will be solved for analysis through this. Predicted numerical results were legalized with those available in literature. These numerical results used the optimum geometry required to have a uniform velocity profile at the inlet to the substrate [8].

For automotive emission, Patel et.al[2012] examined the effect of catalytic converter. In this paper Air pollution generated from mobile sources is a problem of general interest. Owing to incomplete combustion in the engine, there were a number of incomplete combustion products CO, HC, NOx, particulate matters, etc. Air quality, environment and human health have negative impact through these pollutants that leads in stringent norms of pollutant emission. The alternative technologies such as improvement in engine design, fuel pre-treatment, use of alternative fuels, exhaust treatment or better tuning of the combustion process etc. reduce the emission levels of the engine[9].

Mareket.al[2002] analyzed and imitated catalytic conversion of toxic components in exhaust gas as dependence of mixture preparation. This paper rendered mathematical model of gas flow in a exhaust system stated resistant of gas flow through catalytic converter, as this is useful in calculations of physical parameter of gas done with overall engine output parameters which enables optimization of whole exhaust system at conservation of high temperature in the monolith [10].

Makwana et al[2013] developed nickel based catalytic converter and found that reduction of toxic substances emission from combustion engines could be achieved in automotive exhaust after treatment process is applied based on oxidation and reduction processes which are takes place in catalytic converter. Catalytic converter uses platinum group of metal such as Pt, Pd and Rh [11].

Mohiuddinet.al[2007] purposed the result of an experimental study of the performance and conversion efficiencies of ceramic monolith three-way catalytic converters(TWCC) employed in automotive exhaust lines for the reduction of gasoline emissions. On the basis of emission test results, the converters were cut extract the substrate or honeycomb inside the housing and analyzed for microstructure and materials composition by using Scanning Electron Microscopy(SEM) and Energy Dispersive Analysis(EDX)[12].

The effect of monolithic catalytic converter was analyzed by Ghasemiet.al[2009]. In this research, a new design for inlet diffuser of catalytic converter was proposed and fabricated. It was composed of tube to tube cones which distribute the flow uniformly at the entrance face of monolith that results the new design for inlet diffuser tends to a less uniform temperature field at the monolith entrance but the flow distribution becomes more uniform[13].

2. PROCEDURE

2.1 VIRTUAL SIMULATION

The recirculating cc consists of a wall which is used to recirculate the exhaust over the cc which make the rate of heat transfer to increase to almost two folds. The increased rate of heat transfer increases the rate of increase of the temperature and reduces the cold start time. Simulation CFD software, part of the Digital Prototyping solution, provides fluid flow and thermal simulation tools to help predict and optimize product behavior and validate designs before manufacturing. In catalytic converter there are various part with different materials.

3. EXPERIMENTAL SETUP

A LOMBARDINI make, single cylinder, air cooled, 15W40 CF4 multi grade oil petrol engine was selected for the present research work, which is primarily used for auto rickshaws and household electricity generations. A square box section has been used to mount the engine to hold it and a padding is laid under the square section box to prevent vibrations.

Discharge= $C_d (\sqrt{(2gh)} * A_1 * A_2)/\sqrt{(A_1 2 - A22)}$ (1)

Where,

g: acceleration due to gravity(m/s2)

h: manometric head of equivalent air head (m)

A_1 :(Π/4)*D2

A_2 :(Π/4)*d2

D: External dia. of orifice plate (internal dia. Of the pipe) =28.3 mm

d: Internal dia. of orifice plate=12 mm

C_d: Coefficient of Discharge

According to the ACME standard the value ofCd can be calculated by the following formula

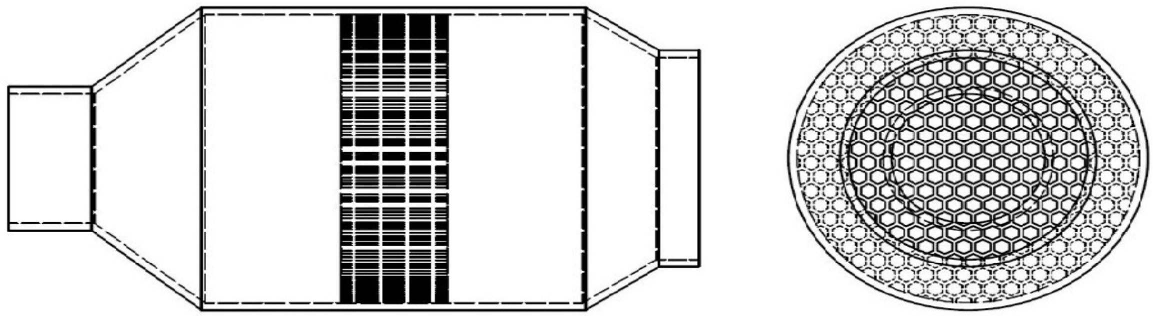


Fig. 1. Side and Top view of catalytic converter

TABLE 1: Design of Recirculating Catcon Outer Casing Specification:

Material	Mild Steel
Thickness	2mm

TABLE 2: Honey comb specification:

Material	Ceramics Monolith with catalyst wash coat
Structure	regular hexagon
Thickness	2mm (side): 1mm (b/w)
Density	6 hexagon in 1 cm2
Input OD	40mm
Honeycomb Dia	84mm

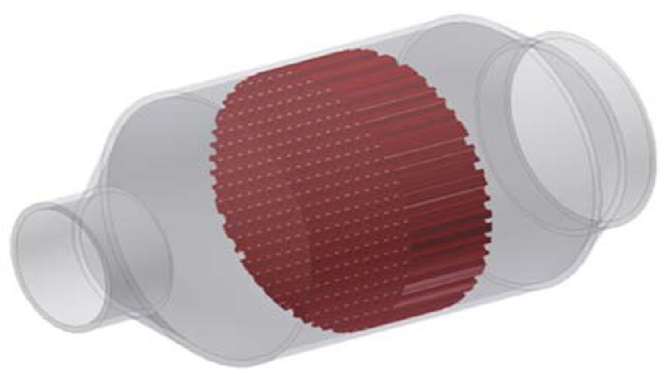


Fig. 2. Recirculating Catcon

TABLE 3: Physical Parameter

Density	$\rho = m/v$
Manometric Head	$h = hm(\rho m/\rho p-1)$
Acceleration due to gravity	9.81m/s2
Reynold Number	$Re=\rho VD/\mu$
Discharge	A=Qv
Coefficient of discharge	$Cd = [0.598 + 0.468\{(\frac{d}{D})^4 + 10\left(\frac{d}{D}\right)^{12}\right]\sqrt{1-(\frac{d}{D})^4} + (0.87 + 8.1(\frac{d}{D})^4)\sqrt{\frac{1-(\frac{d}{D})^4}{ReD}}$

TABLE 4: Engine Specification

Bore x Stroke	84 mm x 64 mm, Single cylinder, Air Cooled
Swept Volume	338 cc
Compression ratio	8:1
Rated Power	8 kW @ 4400 rpm
Max Torque	19 Nm @ 3000 rpm
Valve Timing System	Belt Driven Single Overhead Camshaft
Lubrication	Forced Lubrication Vane Pump
Luboil	15W40 CF4 multi grade oil
Luboil Capacity	1.7 ltrs
Starting System	Electric Start with Auto-Decomp on Camshaft
Electric System	12V, 18 amps flywheel mounted alternator,
Recommended Battery	12 V, 44 Ah
Weight of Engine	30.5 kg

TABLE 5: Calculation of Volume Flow Rate at Different RPM

S.No	Crank Speed(rpm)	Left Hand Scale(cm)	Left Hand Scale(cm)	Diff. head(cm)
1	2050	47.2	45.6	1.6
2	2300	47.5	45.3	2.2
3	2400	47.6	45.2	2.4
4	2600	47.8	45.1	2.7
5	2850	48	45	3.0
6	3000	48.1	45	3.1
7	3300	48.3	44.6	3.7

Fig. 3.Test rig for emission and temperature measurement

$$Cd = [0.598 + 0.468\{(\tfrac{d}{D})^4 + 10(\tfrac{d}{D})^{12}\}]\sqrt{1-(\tfrac{d}{D})^4} + (0.87 + 8.1(\tfrac{d}{D})^4)\sqrt{\frac{1-(\frac{d}{D})^4}{ReD}} \ldots\ldots\ldots\ldots \quad (2)$$

Where,
d/ D = .424
Re = (ρVD)/μ ………………………………. (3)
ρ: density of exhaust gases (taken at 600 degrees) = .405 kg/ m3

V: velocity of exhaust through the pipe (√ (2gh) = 26.12 m/s
μ: dynamic viscosity of exhaust = 37.9*10-6 Pa-s [22]

On calculating,
R_e = 7899.06
Now substituting value of Re in eq. (2)
C_d =0.6167

Therefore, to calculate discharge we find the mercury head
h = x((ρ hg/ ρ exhaust)-1)
Where x is head of manometric fluid (mercury)
h = x*((13600/.405)-1)

Since, x depends on rpm, for 3000 rpm x = .031 m and hence h = 1040.956654m
Theoretical Calculation

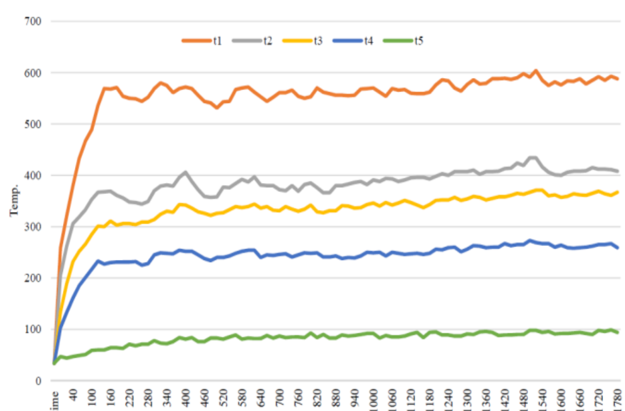
Volume flow rate = (Π/4)*d2*l*(N/2)/60
(4 stroke, check reference paper)
N =rpm of the engine
L =stroke length=.064m
d =bore dia. =.084m

Comparative analysiswas done after development of Recirculating Catalytic Converter with the standard available Catalytic Converter. The main study were to focus on the temperature variation of exhaust gases along the tailpipe and through resonator as well. The readings were taken at different rpm with direct exhaust, normal Catcon and recirculating Catcon.

Apart from this the emission reading mainly CO and UBHC (Unburnt Hydrocarbons) were taken using AVL Di-Gas Analyzer. The simple catalytic converter as well as the recirculating catalytic converter was fitted in the custom made resonating chamber and a complete test rig was developed with rpm and temperature measurement facility.

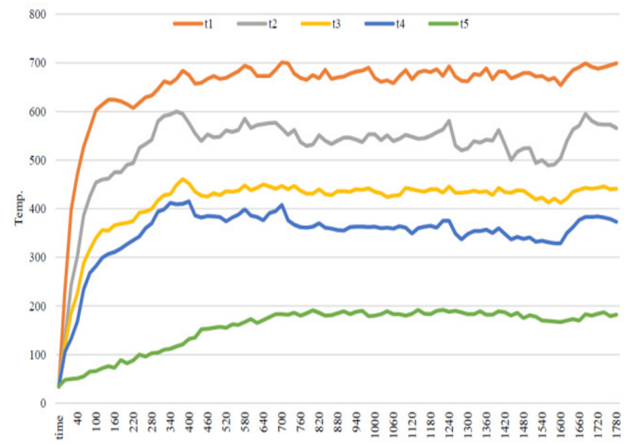
4. RESULTS

The present study was carried on an unmodified catalytic convertor to convert it into a modified recirculating catalytic converter to be used on a single cylinder four stroke LGA-340 engine which is LOMBARDINI Gasoline engine of 340 cc. The re-circulating catalytic convertor reduces the heat up time from 496 seconds to 343 seconds, this turn reduces a remarkable amount of the harmful emission during this time. Computational fluid dynamics (CFD) is a powerful tool for calculating the flow field inside the catalytic converter.Apart from the CFD data, due to the experimental investigation carried out the Temperature-Time Graph at Different Position using thermocouples has been plotted.

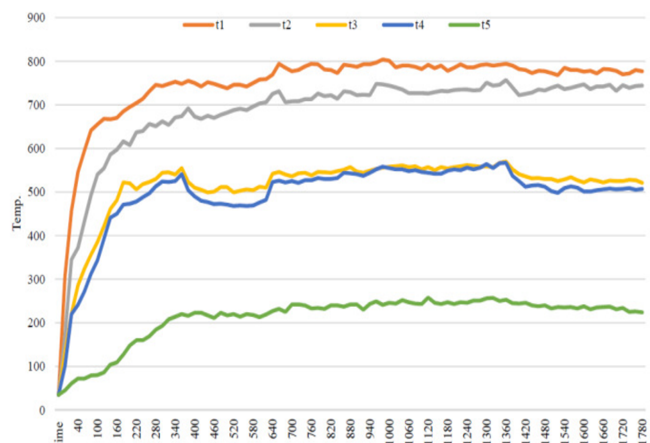


@1300rpm

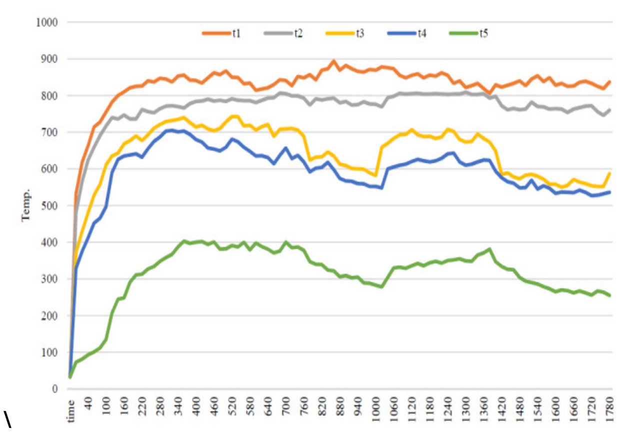
Temperature and emission readings has been taken at every interval of 30sec upto 1800seconds. Validating it through the experimental investigation it has been found that the temperature is more uniform in case of Recirculating Catalytic Converter as compare to Normal Catalytic Converter. Also the CO & HC emission are around 3% less and reduces the heat up time from 496 seconds to 343 seconds compared to Normal Catalytic Converter.



@1800rpm



@2400rpm



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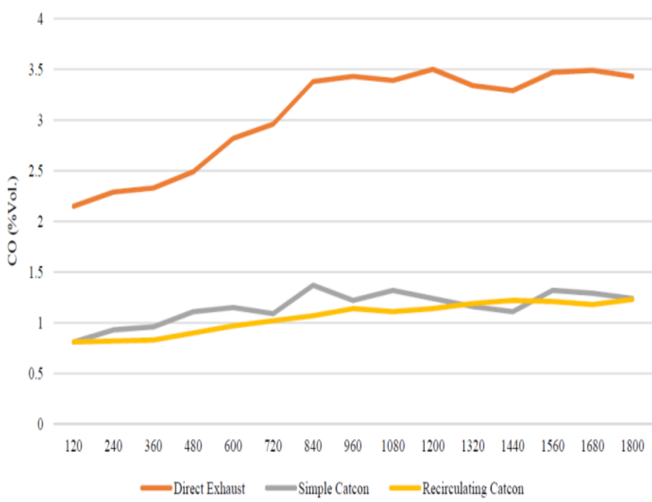
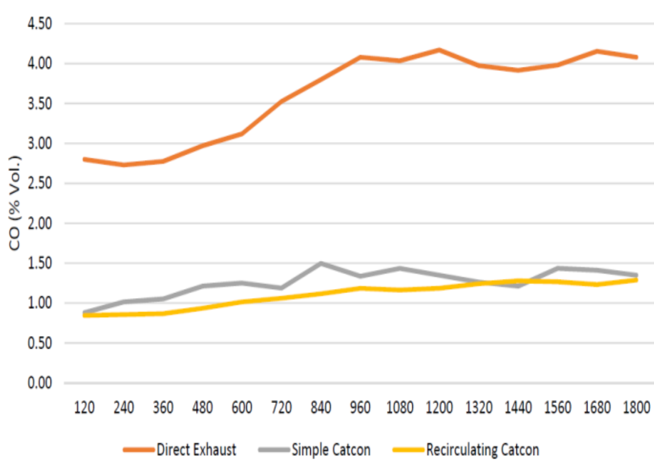
@3000rpm

Fig. 4. Temperature variation of Recirculation Catcon at different RPM

CO% **CO%**

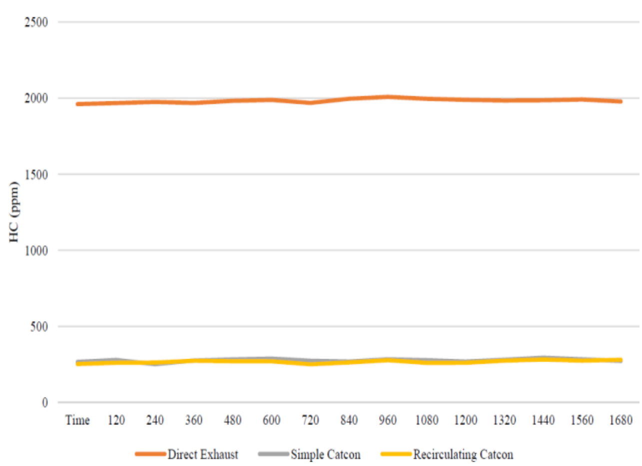


@2400rpm

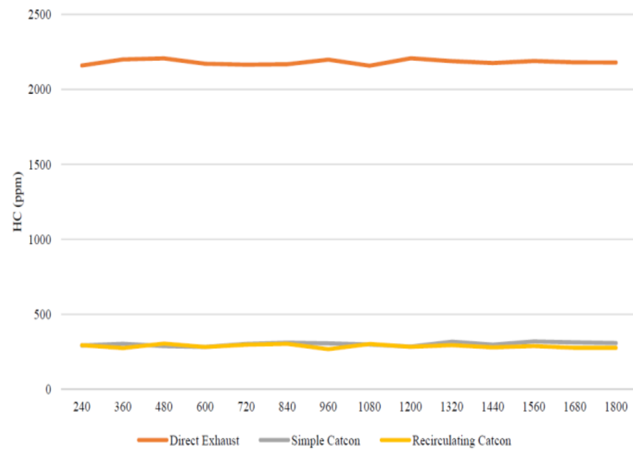


@3000rpm

Unburnt HC **Unburnt HC**



@2400rpm



@3000rpm

Fig. 5. Exhaust Emission variation of Recirculation Catcon at different RPM

5. CONCLUSIONS

Thus the conclusion can be drawn that the effectiveness of the re-circulating catalytic convertor is higher than that of the traditional design of the catalytic convertor. The honeycomb utility is increased as the temperature distribution is more uniform. This recirculation reduced heat up time remarkably reduces the exhaust. This increases the effectiveness of the catalytic convertor by just adding a new wall to recirculate the exhaust around the catalytic convertor. This reduced pollution if enumerated over large number of vehicles can be very remarkable to control pollution. Apart from the CFD data, due to the experimental investigation carried out the Temperature-Time Graph at Different Position using thermocouples has been plotted. Temperature and emission readings has been taken at every interval of 30sec upto 1800seconds. Validating it through the experimental investigation it has been found that the temperature is more uniform in case of Recirculating Catalytic Converter as compare to Normal Catalytic Converter. Also the CO & HC emission are around 3% less and reduces the heat up time from 496 seconds to 343 seconds compared to Normal Catalytic Converter.

Further it has been suggested to carry enhance the heat transfer rate of the recirculating CATCON with the change in materials and thickness variation and compare the results.

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