Experimentation and Behavioral Modeling for Carbon Monoxide and Hydrocarbons from Compression Ignition Engine Automobiles using an Innovative Catalytic Converter coated with Nano-particles

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Abstract:- *Air Pollution from Compression Ignition Engine Automobiles has become a cause of serious concern for all. This research paper is based on the experimental analysis conducted on a Four Stroke Compression Ignition Engine Test Rig at different conditions of loading on the engine using an Innovative Catalytic Converter fabricated during the present research work. An exhaust gas analyzer of the model KIGAZ 310 PRO was used to calculate the concentration of carbon monoxide and hydrocarbons. The results obtained clearly indicate a substantial decrease in the concentration of the carbon monoxide and hydrocarbons after using the fabricated Catalytic Converter coated with iron oxide nano-particles. Behavioral Modeling was also performed to calculate the values of carbon monoxide and hydrocarbons at all the values of percent loads on the engine within the given range. The results obtained by the simulation of the developed model show that the developed model is an exact replica of practical behavior of the actual system. So, it can be used to simulate the values of carbon monoxide and hydrocarbons at all the loading conditions within the range.*

Key Words: Carbon monoxide, catalytic converter, hydrocarbons, modelling, nano-particles, pollution, simulation.

List of Abbreviations

CC	Catalytic Converter
C.I.	Compression Ignition
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DE	Diesel Engine
EGT	Exhaust Gas Temperature
HSU	Hatridge Smoke Unit
NOx	Nitrogen Oxides
O_2	Oxygen
PPM	Parts Per Million
R.P.M.	Revolutions Per Minute
WCC	With Catalytic Converter

1. INTRODUCTION

Various researchers have proposed several methods for control of air pollution from Compression Ignition engine automobiles but there is a need for development of a cost effective, efficient and an improved method for the same. The present research work is pivoted on the concept of nano-technology. Nano-technology offers promising solutions to keep a check on the air pollution from Compression Ignition engine automobiles.

Thakur, M. and Saikhedkar, N.K. explained that the ration of surface area and volume of a nano-particle varies inversely with its size. So, on decreasing the size of a nano-particle, this ration increases significantly. It leads to a significant increase in the atomic activity of a nano-particle which can be utilized in reduction of exhaust emissions concentration from automobiles. The various metals used as a catalyst in catalytic converters include copper, platinum, palladium, gold and rhodium [1].

Kumar, S.T. et al. evaluated the performance of a Four Stroke Single Cylinder Diesel Engine test rig using Rice Bran as an alternate fuel. Various blends of the mixture were used to understand the variation in the exhaust gas characteristics. Various exhaust gases including CO, CO_2, HC, NOx and smoke density were measured using AVL 5 gas analyzer along with a smoke meter. The emissions were calculated at varying loads [2]. Shirneshan, A. presented an emission analysis of a Four Cylinder Diesel engine using diesel engine fueled with methyl ester by using different blends of the mixture. The variation in HC, CO, CO_2 and NOx were studied to obtain the optimal mixture for best results. A suitable multi gas analyzer was used to measure the exhaust emissions concentration [3].

Ajin, C.S. and Sajith V. employed Cerium oxide in a catalytic converter for emissions reduction [4]. Sudrajad experimented on a single cylinder diesel engine to calculate the concentration of exhaust emissions using blends of fuels. The concentrations of CO, CO_2, O_2 and Exhaust Gas Temperature (EGT) were calculated at various percent loads applied on the engine. A Direct Injection diesel engine of the model NF-19SKYANMAR was employed to evaluate the emissions concentrations. The results of the experiment exhibited that the temperature of the exhaust has a significant effect on the formation of exhaust gases, specially, NOx [5].

Panwar et al. investigated the emissions from a diesel engine fueled with methyl ester. The speed of the engine was kept constant at 1500 R.P.M. and the loads were varied [6]. Turushima et al. experimented and described that the oxidation of the harmful exhaust emissions like CO and HC reduces their concentration due to formation of less harmful gas CO_2 and water vapor [7].

2. METHODOLOGY

2.1 Fabrication of Innovative Catalytic Converter

An innovative catalytic converter was fabricated during the present research work using seamless Mild Steel pipes of IS 2062 grade. The innovative catalytic converter facilitates maximum interaction time between the exhaust emissions and the iron oxide nano-particles coated on the honeycomb surface of the catalytic converter.

Fig -1: Fabricated Innovative Catalytic Converter

2.2 Experimentation on a Four Stroke Single Cylinder C.I. Engine Test Rig

The specifications of the Single Cylinder Compression Engine are as follows:

Engine – Four Stroke Single Cylinder
Type – VRC - 1
Rated Power – 3.7 kW (5 BHP)
Rated R. P. M. – 2200
Fuel – High Speed Diesel Oil
Compression Ratio – 17.5 : 1
Bore – 80 mm
Stroke Length – 110 mm
Lubricating Oil – SAE – 30/40
Method of Ignition – Compression Ignition
Type of Cooling – Water Cooling
Type of Governor – Centrifugal Governor
Governor Class – B1

Loading of Engine: Dynamometer
Dynamometer Type – Rope Brake
Maximum Load Capacity – 20 kg

Test Rig also consists of the following:

1. Measuring burette with 3 way cock
2. Temperature Indicator with thermocouples
3. R.P.M. Indicator
4. Exhaust Gas Calorimeter
5. Air Tank with orifice

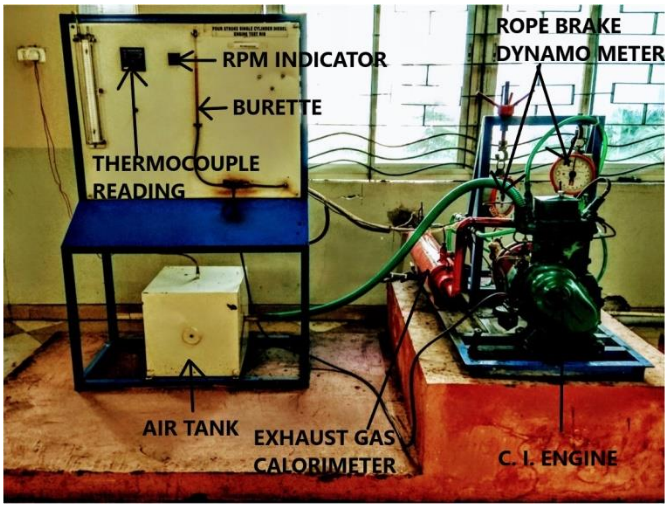

Fig -2: Four Stroke Single Cylinder C.I. engine test rig

For performing emissions test, a multi gas analyzer of the model KIGAZ 310 PRO was used to measure the values of CO and HC emitted from the Four Stroke Single Cylinder Compression Ignition Engine. Emissions test is the advanced test used to estimate the concentration of exhaust emissions emitted from Diesel Engine automobiles.

The specifications of KIGAZ 310 PRO are as follows:

Parameters	Sensor	Measuring range	Resolution	Accuracy*	T_{90} response time
Long-life O_2	Electrochemical	From 0 % to 21 %	0.1 % vol.	±0.2 % vol.	30 s
CO (with H_2 compensation)	Electrochemical	From 0 to 8000 ppm	1 ppm	From 0 to 200 ppm: ±10 ppm From 201 to 2000 ppm: ±5 % of the measured value From 2001 to 8000 ppm: ±10 % of the measured value	30 s
NO	Electrochemical	From 0 to 5000 ppm	1 ppm	From 0 to 100 ppm: ±5 ppm. From 101 to 5000 ppm: ±5 % of the measured value	30 s
Low range NO	Electrochemical	From 0 to 500 ppm	0.1 ppm	From 0 to 100 ppm: ±2 ppm From 101 to 500 ppm: ±2 % of the measured value	**30 s**
NOx	Calculated**	From 0 to 5155 ppm	1 ppm	-	-
NO_2	Electrochemical	From 0 to 1000 ppm	1 ppm	From 0 to 100 ppm: ±5 ppm. From 101 to 1000 ppm: ±5 % of the measured value	80 s
SO_2	Electrochemical	From 0 to 5000 ppm	1 ppm	From 0 to 100 ppm: ±5 ppm. From 101 to 5000 ppm: ±5 % of the measured value	80 s
CO_2	Calculated**	From 0 to 99 % vol	0.1% vol	-	-
CH_4	Semiconductor	From 0 to 10000 ppm From 0 to 1 % vol From 0 to 20 %LEL	1 ppm 0.0001 % vol 0.002 %LEL	±20 % of full scale	40 s
Flue gas temperature	K thermocouple	From -100 to +1250 °C	0.1 °C	±0.4 % of the measured value or ±1.1 °C	45 s
Ambient temperature	Internal NTC	From -20 to +120 °C	0.1 °C	±0.5 °C	
Ambient temperature	Pt100 (1/3 DIN external probe)	From -50 to +250 °C	0.1 °C	±0.3 % of the measured value ±0.25 °C	30 s
Dew point temperature	Calculated**	From 0 to +99 °Ctd	0.1 °C	-	-
DHW temperature	TcK (external probe)	From -200 to +1300 °C	0.1 °C	±0.4 % of the measured value or ±1.1 °C	-
Draft	Piezoelectric	From -10 to +10 Pa From -1000 to +1000 Pa	0.1 Pa 1 Pa	From -100 to -10 Pa: ±2 Pa From -10 to +10 Pa: ±0.5 Pa From +10 to +100 Pa: ±2 Pa Above: ±2 % of the measured value	-
Differential pressure	Piezoelectric	From -20 000 to +20 000 Pa	1 Pa	From -20 000 to -751 Pa: ±0.5 % of the measured value ±4.5 Pa From 750 to -61 Pa: ±0.9 % of the measured value ±1.5 Pa From -60 to 60 Pa: ±2 Pa From 61 to 750 Pa: ±0.9 % of the measured value ±1.5 Pa From 751 to 20 000 Pa: ±0.5 % of the measured value ±4.5 Pa	-
Losses	Calculated**	From to 100%	0.1%	-	-
Flue gas velocity	Calculated**	From to 99.9 m/s	0.1 m/s	-	-
Excess air (λ)	Calculated**	From 1 to 9.99	0.01	-	-
Lower efficiency (ηs)	Calculated**	From 0 to 100%	0.1 %	-	-
Higher efficiency (ηt) (condensation)	Calculated**	From 0 to 120%	0.1%	-	-
Opacity index	External instrument	From 0 to 9	-	-	-

Fig -3: Emissions test before and after using Innovative Catalytic Converter using KIGAZ 310 PRO

Table -1: Variation of CO with load before and after using Catalytic Converter

S. No.	% Load	CO (Before using Catalytic Converter) (PPM)	CO (After using Catalytic Converter) (PPM)
1	0	751	534
2	20	758	546
3	40	763	569
4	60	775	578
5	80	963	749
6	100	1257	986

Table -2: Variation of HC with load before and after using Catalytic Converter

S. No.	% Load	HC (Before using Catalytic Converter) (PPM)	HC (After using Catalytic Converter) (PPM)
1	0	11	6
2	20	12	8
3	40	13	9
4	60	15	10
5	80	18	13
6	100	21	17

2.3 Behavioral Modeling and Simulation

Since, the practical values of emissions obtained by smoke test and emission test could be obtained at only selected loading conditions, behavioral modeling and simulation was performed to obtain the value of exhaust emissions at all the loading values within the range.

Behavioral modeling and simulation for CO and HC values obtained during Emissions test was performed at three stages:

1. For Diesel Engine alone
2. For Catalytic Converter alone
3. For Complete Model

Then, the obtained simulation results were compared with experimental results to check the validity of the developed model.

Diesel Engine Behavioral Model for Emissions Test

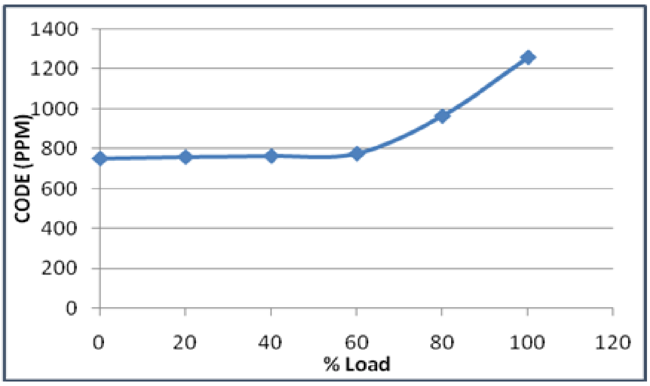

Fig -4: Variation of CO value with % load for Diesel Engine Alone Before Using Catalytic Converter during Emissions Test

The equation representing the variation of CO value with % load for Diesel Engine Alone Before Using Catalytic Converter obtained by curve fitting approach using MATLAB is as follows:

$$CODE = -5.7229 \times 10^{-7} \times Load^5 + 0.00013652 \times Load^4 - 0.0099379 \times Load^3 + 0.27204 \times Load^2 - 2.1186 \times Load + 754.05 \quad (1)$$

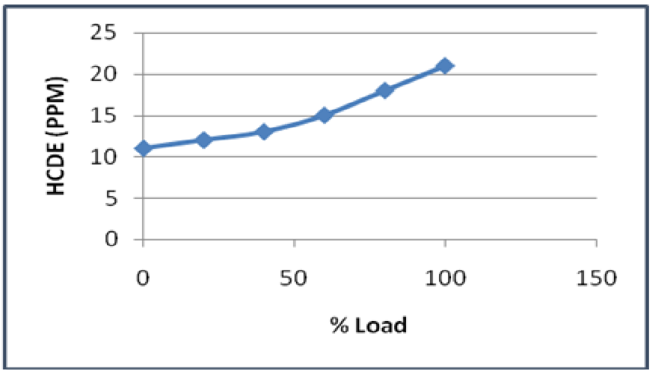

Fig -5: Variation of HC value with % load for Diesel Engine Alone Before Using Catalytic Converter during Emissions Test

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The equation representing the variation of HC value with % load for Diesel Engine Before Using Catalytic Converter obtained by curve fitting approach using MATLAB is as follows:

$$HCDE = -2.2416 \times 10^{-10} \times Load^5 - 1.7597 \times 10^{-7} \times Load^4 + 4.1652 \times 10^{-5} \times Load^3 - 0.0019178 \times Load^2 + 0.073615 \times Load + 10.961 \quad (2)$$

Table -3: Diesel Engine Simulation Model Test Result for CO value during Emissions Test

S. No.	% Load	CODE (Practical) (PPM)	CODE (Simulation) (PPM)	Percentage Error
1	0	751	752.2	-0.15979
2	20	758	761	-0.39578
3	40	763	759	0.524246
4	60	775	784	-1.16129
5	80	963	954	0.934579
6	100	1257	1254	0.238663
Average Percentage Error				**-0.0032**

Table -4: Diesel Engine Simulation Model Test Result for HC value during Emissions Test

S. No.	% Load	HCDE (Practical) (PPM)	HCDE (Simulation) (PPM)	Percentage Error
1	0	11	10.96	0.363636
2	20	12	11.97	0.25
3	40	13	13.03	-0.23077
4	60	15	15.02	-0.13333
5	80	18	17.96	0.222222
6	100	21	20.96	0.190476
Average Percentage Error				**0.1103**

Catalytic Convertor Behavioral Model for Emissions Test

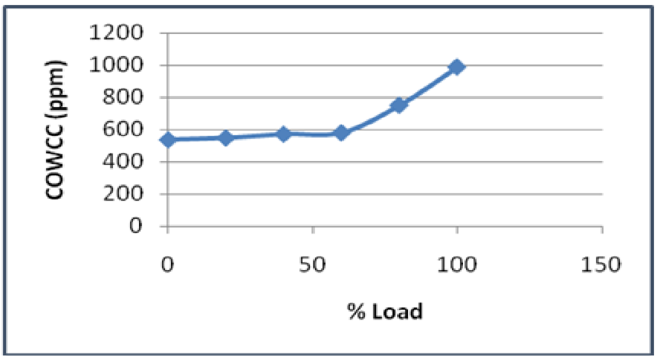

Fig -6: Variation of CO value with % load for Catalytic Converter Alone during Emissions Test

The equation representing the variation of CO value with % load for Catalytic Converter Alone obtained from curve fitting approach using MATLAB is as follows:

$$COWCC = 9.4636 \times 10^{-12} \times Load^8 - 3.229 \times 10^{-9} \times Load^7 + 4.191 \times 10^{-7} \times Load^6 - 2.55 \times 10^{-5} \times Load^5 + 0.00071731 \times Load^4 - 0.0070601 \times Load^3 - 0.013917 \times Load^2 + 0.8762 \times Load + 533.59 \quad (3)$$

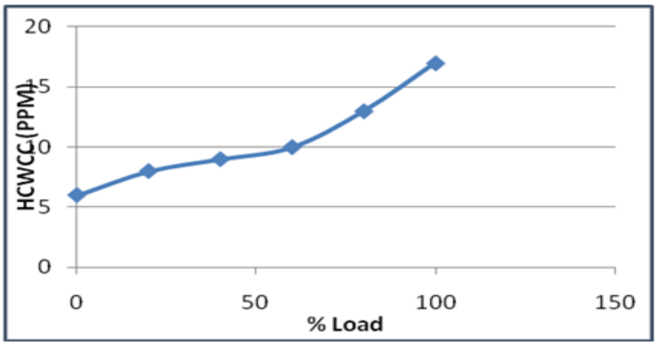

Fig -7: Variation of HC value with % load for Catalytic Converter Alone during Emissions Test

The equation representing the variation of HC value with % load for Catalytic Converter obtained by curve fitting approach using MATLAB is as follows:

$$HCWCC = -5.6046 \times 10^{-9} \times Load^5 + 1.1852 \times 10^{-6} \times Load^4 - -6.0547 \times 10^{-5} \times Load^3 - 0.00032018 \times Load^2 + 0.12215 \times Load + 6.0017 \quad (4)$$

Table -5: Catalytic Converter Simulation Model Test Result for CO during Emissions Test

S. No.	% Load	COWCC (Practical) (PPM)	COWCC (Simulation) (PPM)	Percentage Error
1	0	534	533.6	0.074906
2	20	546	545.2	0.14652
3	40	569	569.3	-0.05272
4	60	578	582.5	-0.77855
5	80	749	747.3	0.226969
6	100	986	988.9	-0.29412
Average Percentage Error				**-0.1128**

Table -6: Catalytic Converter Simulation Model Test Result for HC during Emissions Test

S. No.	% Load	HCWCC (Practical) (PPM)	HCWCC (Simulation) (PPM)	Percentage Error
1	0	6	6.002	-0.03333
2	20	8	8.004	-0.05

3	40	9	8.961	0.433333
4	60	10	10.1	-1
5	80	13	12.91	0.692308
6	100	17	16.94	0.352941
Average Percentage Error				**0.0658**

Complete Behavioral Model for Diesel Engine with Catalytic Converter for Emissions Test

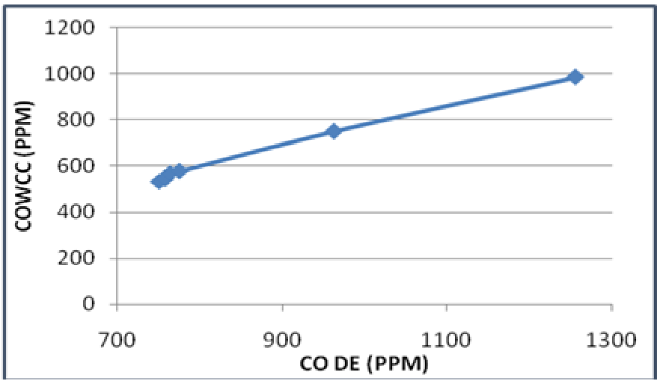

Fig -8: Variation of CO value for Complete Behavioral Model Before and After Using Catalytic Converter during Emissions Test

The equation representing the variation of CO value with % load for Complete Behavioral Model obtained by curve fitting approach using MATLAB is as follows:

$$COWCC = 8.1771 \times 10^{-7} \times CODE^3 - 0.002962 \times CODE^2 + 4.3237 \times CODE - 1388 \quad (5)$$

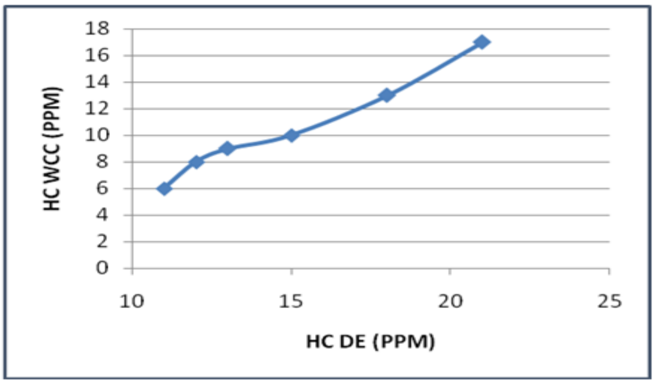

Fig -9: Variation of HC value for Complete Behavioral Model Before and After Using Catalytic Converter during Emissions Test

The equation representing the variation of HC value and % load for Complete Model obtained by curve fitting approach using MATLAB is as follows:

$$HCWCC = -0.0029543 \times HCDE^4 + 0.20217 \times HCDE^3 - 5.0602 \times HCDE^2 + 55.835 \times HCDE - 221.57 \quad (6)$$

Table -7: CO values for Complete Behavioral Model Before and After Using Catalytic Converter during Emissions Test

S. No.	% Load	COWCC (Practical) (pm)	COWCC (Simulation) (PPM)	Percentage Error
1	0	534	538.7	-0.88015
2	20	546	547.4	-0.25641
3	40	569	545.4	4.147627
4	60	578	575.2	0.484429
5	80	749	751	-0.26702
6	100	986	988.4	-0.24341
Average Percentage Error				**0.4975**

Table -8: HC values for Complete Behavioral Model Before and After Using Catalytic Converter during Emissions Test

S. No.	% Load	HCWCC (Practical) (PPM)	HCWCC (Simulation) (PPM)	Percentage Error
1	0	6	6.08	-1.33333
2	20	8	7.832	2.1
3	40	9	8.925	0.833333
4	60	10	10.18	-1.8
5	80	13	12.83	1.307692
6	100	17	17.1	-0.58824
Average Percentage Error				**0.0865**

3. RESULTS AND CONCLUSION

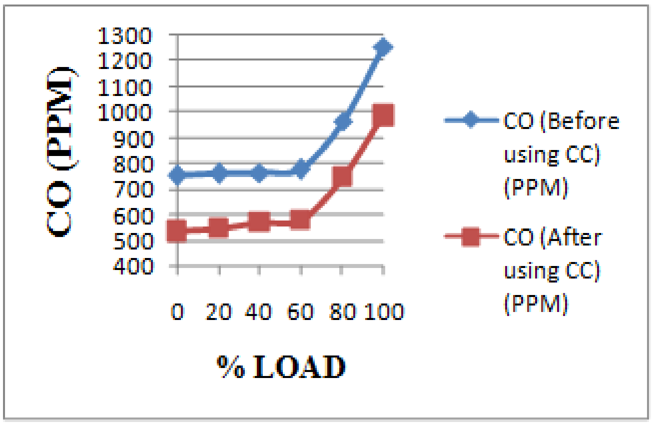

Fig -10: Variation of CO value with % load before and after using Innovative Catalytic Converter

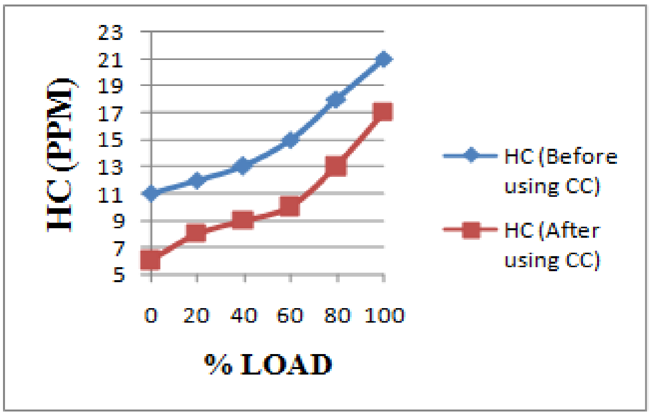

Fig -11: Variation of HC value with % load before and after using Innovative Catalytic Converter

It is clear from the graph between % load and CO value that the CO value reduces considerably after using the Innovative Catalytic Converter. This decrease can be accounted to the oxidation of the exhaust gas by iron oxide nano-particles. Due to oxidation, a portion of harmful CO gets converted to less harmful CO_2.

The graph between % load and HC shows that HC values decrease after using the Innovative Catalytic Converter. Due to oxidation, a portion of harmful HC gets converted to less harmful CO_2. The extra oxygen facilitates in the reduction of the HC concentration. It can be observed from the graph that the HC values increase considerably at 80 % load and 100 % load. It can be accounted to the reason that the concentration of HC increases as the engine approaches full load condition. However, the concentration of the HC is far less after using the Innovative Catalytic Converter as compared to before using it.

The innovative design of the fabricated Catalytic Converter increases the volume and decreases the velocity of flow of exhaust gases leading to an effective decrease in harmful exhaust. The honeycomb of the catalytic converter neglects the chances of back pressure. So, the proposed method of reducing the concentration of carbon monoxide and hydrocarbons using an innovative catalytic converter is very effective and can be implemented in practice with suitable adjustments.

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BIOGRAPHIES

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