International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 12 | Dec 2018 www.irjet.net p-ISSN: 2395-0072

Experimental Analysis and Modeling for Carbon Dioxide, Oxygen and Exhaust Temperature from Compression Ignition Engine Automobiles using an Innovative Catalytic Converter coated with Nano-particles

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Abstract – *Compression Ignition Engine Automobiles have become a threat for the well being of all living organisms. This research paper is focused on an experiment conducted on a Four Stroke Compression Ignition Engine Test Rig at different loads using a Fabricated Catalytic Converter known as Innovative Catalytic Converter coated with iron oxide nano-particles. A gas analyzer of the model KIGAZ 310 PRO was utilized to find the concentrations of carbon dioxide and oxygen. The thermocouples installed on the test rig were employed to find the Exhaust Gas Temperatures. The results obtained from the experimentation clearly show a significant increase in the concentration of carbon dioxide, oxygen and exhaust gas temperatures after using the Innovative Catalytic Converter coated with iron oxide nano-particles. Behavioral Modeling was also later done to estimate the values of carbon dioxide, oxygen and exhaust gas temperatures at all the values of percent loads on the engine within the given range. The results from the simulation of the developed model reveal that the developed model exactly mimics the practical behavior of the selected test rig. So, it can be used to simulate the values of carbon dioxide, oxygen and exhaust gas temperatures at all the loading conditions within the range.*

Key Words: Carbon dioxide, catalytic converter, modeling, nano-particles, oxygen, 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

Numerous approaches have been presented for reducing air pollution from Compression Ignition engine automobiles.

Wei and Hong have pointed out that air pollution has become an alarming problem than ever before owing to huge number of automobiles moving on roads. This asks for an appropriate treatment method before the exhaust from the automobiles is allowed to enter the atmosphere. Specially, the Compression Ignition engine automobiles have increased tremendously causing heavy traffic and subsequent air pollution [1]. Exhaust emissions from automobiles contain a variety of exhaust emissions among which the main pollutants are CO, HC, NOx and other particulates. All of these pollutants are formed as a result of incomplete process of combustion [2].

Ali et al. reviewed the emissions from diesel engines and the relevant technologies for treatment of exhaust. They described that the emissions from the diesel engine automobiles are one of the main culprits of contaminating the environment [3]. Ladommatos stated that the shortage in supply of oxygen leads to reduction in the formation of CO_2 and water vapor leading to an increase in the formation of CO and soot particles. SO, surplus oxygen is required to reduce the concentration of CO and HC in the exhaust emissions. Oxidation of harmful emissions including CO and HC in to CO_2 is necessary [4].

Baskar, P. and Kumar, A.S. analyzed the effect of oxygen enrichment on the variation of the exhaust emissions from a single cylinder diesel engine. The results clearly revealed substantial decrease in HC, CO and smoke density levels. Increasing the oxygen content facilitates the conversion of CO into less harmful CO_2 along with decrease in the smoke content due to improved combustion process. The content of hydrocarbons, though very small in content also reduced post supply of extra oxygen [5]. Shojaeefard, M.H. et al. used Artificial Neural Networks for the purpose of predicting performance and exhaust emissions from a diesel engine at different conditions of load and speed. Use of a mathematical modeling and simulation software helps in easy prediction of performance and exhaust emissions at all the values of load within the range [6].

This research paper is based on the pollution prevention from Compression Ignition Engine automobiles using the unique properties possessed by nano-particles. Nano-particles have emerged as alternative to bulk particles for providing solutions to various problems. Nano-particles have very active surface area due to their size as compared to macro particles. In the present research work, iron oxide nano-particles were coated on the honeycomb of an Innovative Catalytic Converter and the same was used at the exhaust of a Four Stroke Single Cylinder Compression Ignition Engine Test Rig.

2. METHODOLOGY

2.1 Fabrication of Innovative Catalytic Converter

A catalytic converter named as Innovative Catalytic Converter was fabricated during this research work from Mild Steel seamless pipes of IS 2062 grade. The innovative catalytic converter structure enables maximum time of interaction for the exhaust emissions with the iron oxide nano-particles coated on the honeycomb surface of the Innovative 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

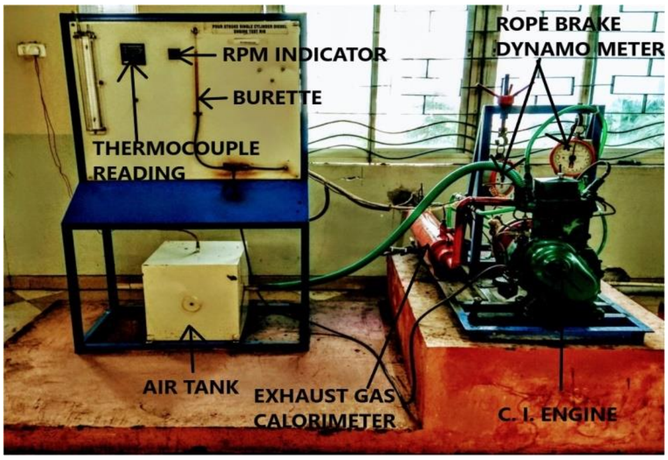

Fig -2: Four Stroke Single Cylinder C.I. engine test rig

For conducting the emissions test on the test rig, a gas analyzer KIGAZ 310 PRO was employed for measurement of the concentration of CO_2 and O_2 in the exhaust of the Four Stroke Single Cylinder Compression Ignition Engine. Thermocouples installed on the test rig were used to find the Exhaust Gas Temperature (EGT) 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_2 with load before and after using Catalytic Converter

S. No.	% Load	CO_2 (Before using Catalytic Converter) (%)	CO_2 (After using Catalytic Converter (%)
1	0	2.5	3.8
2	20	2.9	4.4
3	40	3.3	4.9
4	60	3.8	5.5
5	80	4.3	6.3
6	100	4.9	7.1

Table -2: Variation of O_2 with load before and after using Catalytic Converter

S. No.	% Load	O_2 (Before using Catalytic Converter) (%)	O_2 (After using Catalytic Converter) (%)
1	0	15	17.6
2	20	14.5	17.2
3	40	13.9	16.7
4	60	13.4	16.1
5	80	12.9	15.4
6	100	12.5	14.5

Table -3: Variation of EGT with load before and after using Catalytic Converter

S. No.	% Load	EGT (Before using Catalytic Converter) (°C)	EGT (After using Catalytic Converter) (°C)
1	0	108	121
2	20	115	127
3	40	121	134
4	60	126	140
5	80	133	148
6	100	143	157

2.3 Behavioral Modeling and Simulation

The practical values of emissions during emission test could only be obtained at selected loading conditions. So, behavioral modeling and simulation was performed to estimate the values of exhaust emissions at all the loading values within the range.

Behavioral modeling and simulation for CO_2, O_2 and EGT 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 for validation of the developed behavioral model.

Diesel Engine Behavioral Model for Emissions Test

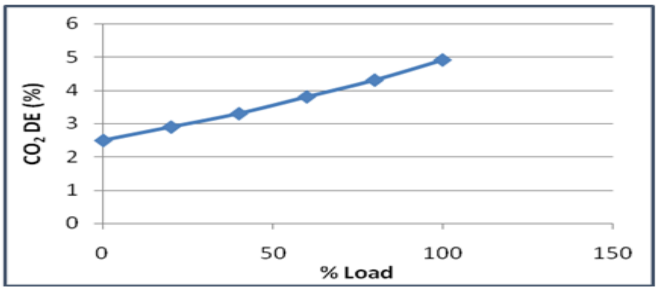

Fig -4: Variation of CO_2 value with % load for Diesel Engine Alone Before Using Catalytic Converter during Emissions Test

The equation representing the variation of CO_2 value with % load for Diesel Engine Alone Before Using Catalytic Converter obtained by curve fitting approach using MATLAB is as follows:

$$CO_2DE = 2\times10^{-7}\times Load^3 + 3\times10^{-5}\times Load^2 + 0.018\times Load + 2.501 \quad (1)$$

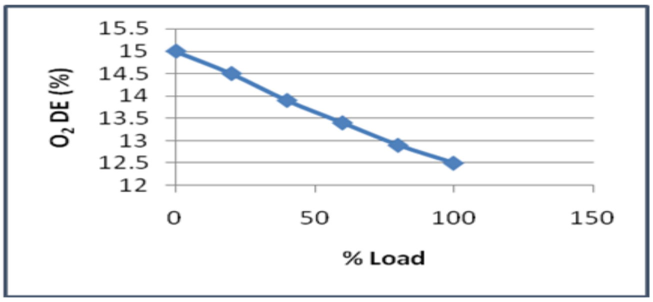

Fig -5: Variation of O_2 value with % load for Diesel Engine Alone Before Using Catalytic Converter during Emissions Test

The equation representing the variation of O_2 value with % load for Diesel Engine Before Using Catalytic Converter obtained by curve fitting approach using MATLAB is as follows:

$$O_2DE = 8 \times 10^{-7} \times Load^3 - 8 \times 10^{-5} \times Load^2 - 0.025 \times Load + 15.00 \quad (2)$$

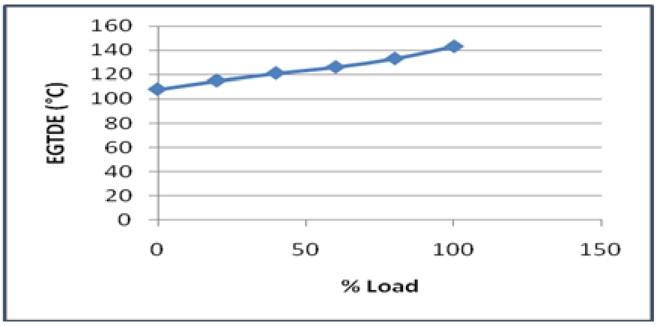

Fig -6: Variation of EGT value with % load for Diesel Engine Alone Before Using Catalytic Converter during Emissions Test

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

$$EGTDE = 3 \times 10^{-5} \times Load^3 - 0.004 \times Load^2 + 0.433 \times Load + 107.9 \quad (3)$$

Table -4: Diesel Engine Simulation Model Test Result for CO_2 value during Emissions Test

S. No.	% Load	CO_2 DE (Practical) (%)	CO_2 DE (Simulation) (%)	Percentage Error
1	0	2.5	2.501	-0.04
2	20	2.9	2.875	0.862069
3	40	3.3	3.282	0.545455
4	60	3.8	3.732	1.789474
5	80	4.3	4.235	1.511628
6	100	4.9	4.801	2.020408
Average Percentage Error				**1.1148**

Table -5: Diesel Engine Simulation Model Test Result for O_2 value during Emissions Test

S. No.	% Load	O_2 DE (Practical) (PPM)	O_2 DE (Simulation) (PPM)	Percentage Error
1	0	15	15	0
2	20	14.5	14.47	0.206897
3	40	13.9	13.92	-0.14388
4	60	13.4	13.38	0.149254
5	80	12.9	12.9	0
6	100	12.5	12.5	0
Average Percentage Error				**0.0353**

Table -6: Diesel Engine Simulation Model Test Result for EGT value during Emissions Test

S. No.	% Load	EGTDE (Practical) (°C)	EGTDE (Simulation) (°C)	Percentage Error
1	0	108	107.9	0.092593
2	20	115	115.2	-0.17391
3	40	121	120.7	0.247934
4	60	126	126	0
5	80	133	132.3	0.526316
6	100	143	141.2	1.258741
Average Percentage Error				**0.325**

Catalytic Convertor Behavioral Model for Emissions Test

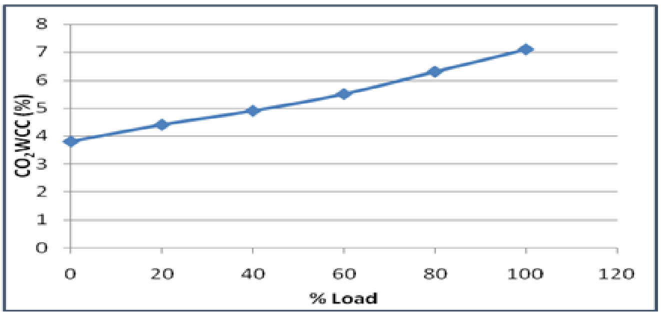

Fig -7: Variation of CO_2 value with % load for Catalytic Converter Alone Before Using Catalytic Converter during Emissions Test

The equation representing the variation of CO_2 value with % load for Catalytic Converter obtained from curve fitting approach using MATLAB is as follows:

$$CO_2WCC = 9.7522 \times 10^{-7} \times Load^3 - 3.5331 \times 10^{-5} \times Load^2 + 0.026886 \times Load + 3.8348 \quad (4)$$

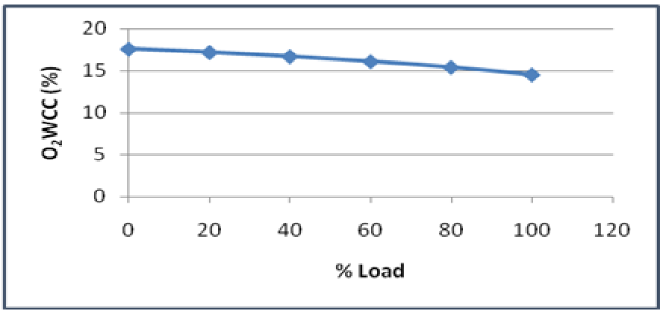

Fig -8: Variation of O_2 value with % load for Catalytic Converter Alone Before Using Catalytic Converter during Emissions Test

The equation representing the variation of O_2 value with % load for Catalytic Converter Alone obtained by curve fitting approach using MATLAB is as follows:

$$O_2\,WCC = -5.5759 \times 10^{-7} \times Load^3 - 6.0353 \times 10^{-5} \times Load^2 - 0.01936 \times Load + 17.609 \quad (5)$$

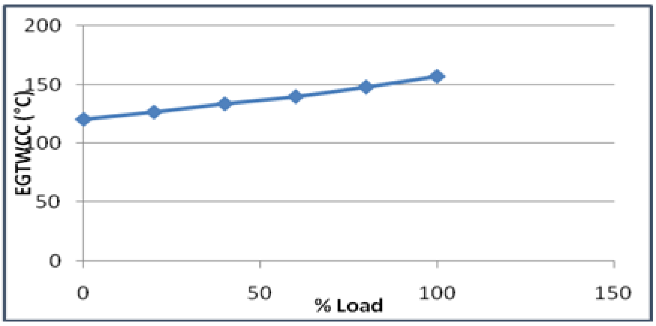

Fig -9: Variation of EGT value with % load for Catalytic Converter Alone Before Using Catalytic Converter during Emissions Test

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

$$EGTWCC = 1.2139 \times 10^{-5} \times Load^3 - 0.0010049 \times Load^2 + 0.3427 \times Load + 120.72 \quad (6)$$

Table -7: Catalytic Converter Simulation Model Test Result for CO_2 value during Emissions Test

S. No.	% Load	CO_2WCC (Practical) (%)	CO_2WCC (Simulation) (%)	Percentage Error
1	0	3.8	3.835	-0.92105
2	20	4.4	4.366	0.772727
3	40	4.9	4.916	-0.32653
4	60	5.5	5.531	-0.56364
5	80	6.3	6.259	0.650794
6	100	7.1	7.145	-0.6338
Average Percentage Error				**-0.1702**

Table -8: Catalytic Converter Simulation Model Test Result for O_2 value during Emissions Test

S. No.	% Load	O_2WCC (Practical) (%)	O_2WCC (Simulation) (%)	Percentage Error
1	0	17.6	17.61	-0.05682
2	20	17.2	17.19	0.05814
3	40	16.7	16.7	0
4	60	16.1	16.11	-0.06211
5	80	15.4	15.39	0.064935
6	100	14.5	14.51	-0.06897
Average Percentage Error				**-0.0108**

Table -9: Catalytic Converter Simulation Model Test Result for EGT value during Emissions Test

S. No.	% Load	EGTWCC (Practical) (°C)	EGTWCC (Simulation) (°C)	Percentage Error
1	0	121	120.7	0.247934
2	20	127	127.3	-0.23622
3	40	134	133.6	0.298507
4	60	140	140.3	-0.21429
5	80	148	147.9	0.067568
6	100	157	157.1	-0.06369
Average Percentage Error				**0.0166**

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

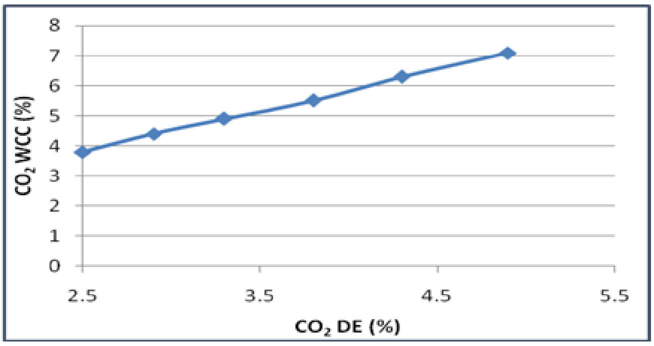

Fig -10: Variation of CO_2 value for Complete Behavioral Model Before and After Using Catalytic Converter during Emissions Test

The equation representing the variation of CO_2 value with % load for Complete Behavioral Model obtained by curve fitting approach using MATLAB is as follows:

$$CO_2WCC = 0.024 \times CO_2DE^3 - 0.247 \times CO_2DE^2 + 2.162 \times CO_2\,DE - 0.426 \quad (7)$$

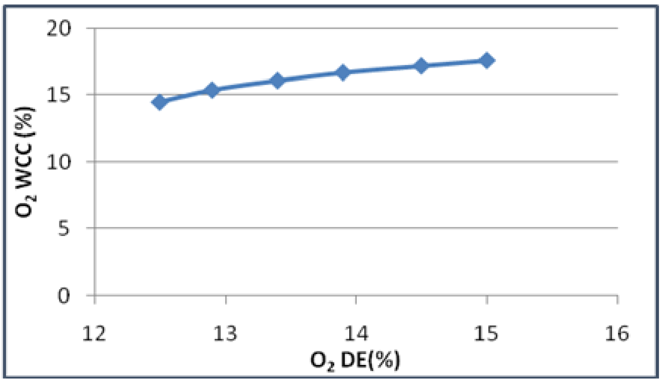

Fig -11: Variation of O_2 value for Complete Behavioral Model Before and After Using Catalytic Converter during Emissions Test

The equation representing the variation of O_2 value and % load for Complete Model obtained by curve fitting approach using MATLAB is as follows:

$$O_2WCC = 0.134 \times O_2DE^3 - 5.843 \times O_2DE^2 + 85.61 \times O_2DE - 404.7 \quad (8)$$

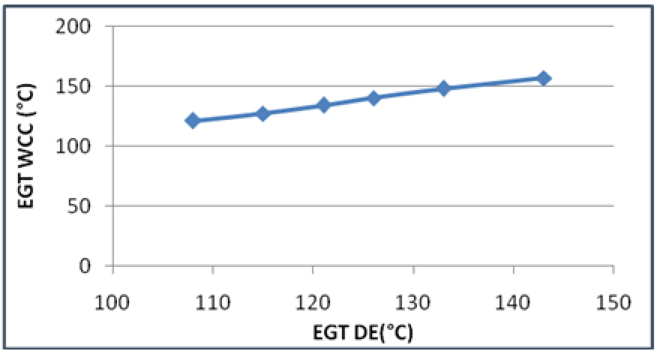

Fig -12: Variation of EGT value for Complete Behavioral Model Before and After Using Catalytic Converter during Emissions Test

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

$$EGTWCC = -0.00068073 \times EGTDE^3 + 0.25659 \times EGTDE^2 - 30.971 \times EGTDE + 1330.6 \quad (9)$$

Table -10: CO_2 values for Complete Behavioral Model Before and After Using Catalytic Converter during Emissions Test

S. No.	% Load	CO_2 WCC (Practical) (%)	CO_2 WCC (Simulation) (%)	Percentage Error
1	0	3.8	3.812	-0.31579
2	20	4.4	4.318	1.863636
3	40	4.9	4.857	0.877551
4	60	5.5	5.45	0.909091
5	80	6.3	6.124	2.793651
6	100	7.1	6.916	2.591549
Average Percentage Error				**1.4532**

Table -11: O_2 values for Complete Behavioral Model Before and After Using Catalytic Converter during Emissions Test

S. No.	% Load	O_2 WCC (Practical) (PPM)	O_2 WCC (Simulation) (PPM)	Percentage Error
1	0	17.6	17.03	3.238636
2	20	17.2	16.65	3.197674
3	40	16.7	16.25	2.694611
4	60	16.1	15.7	2.484472
5	80	15.4	14.99	2.662338
6	100	14.5	14.18	2.206897
Average Percentage Error				**2.74**

Table -12: EGT values for Complete Behavioral Model Before and After Using Catalytic Converter during Emissions Test

S. No.	% Load	EGTWCC (Practical) (°C)	EGTWCC (Simulation) (°C)	Percentage Error
1	0	121	121	0
2	20	127	127.2	-0.15748
3	40	134	133.6	0.298507
4	60	140	140.1	-0.07143
5	80	148	147.9	0.067568
6	100	157	156.9	0.063694
Average Percentage Error				**0.0334**

3. RESULTS AND CONCLUSION

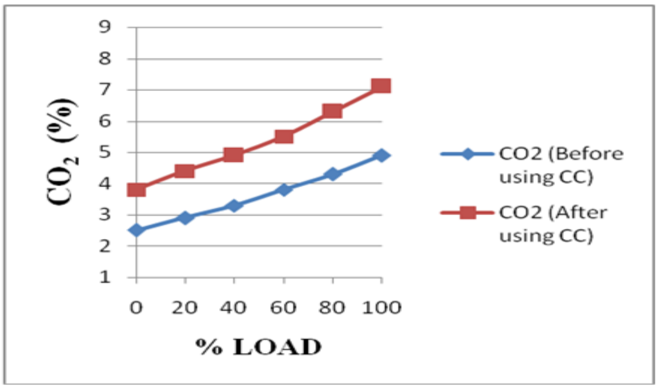

Fig -13: Variation of CO_2 value with load before and after using Innovative Catalytic Converter

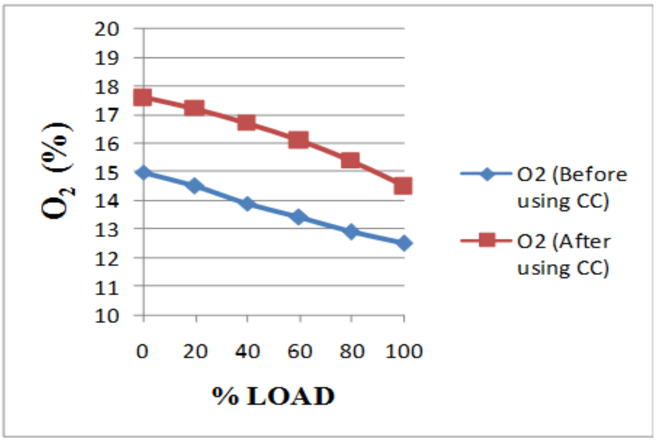

Fig -14: Variation of O_2 value with load before and after using Innovative Catalytic Converter

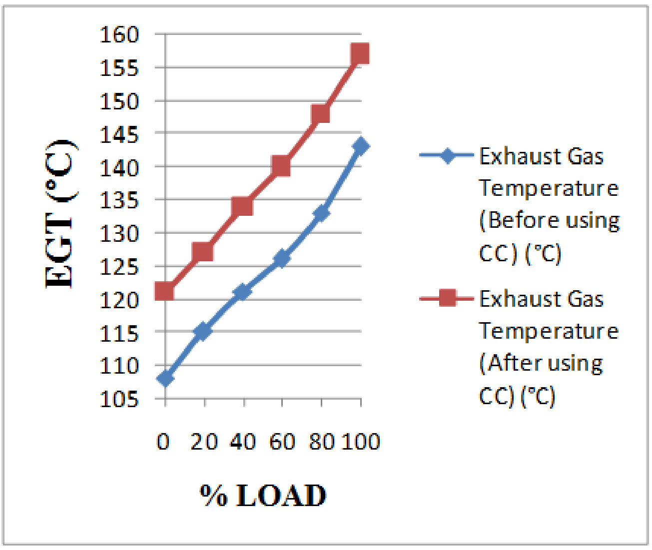

Fig -15: Variation of EGT value with load before and after using Innovative Catalytic Converter

The graph between % load and CO_2 value reveals that the CO_2 value increases considerably after using the Innovative Catalytic Converter. This increase can be accounted to the oxidation of the exhaust gas by iron oxide nano-particles. Due to oxidation, a portion of harmful CO and HC gets converted to less harmful CO_2.

It is clear from the graph between % load and O_2 value that the O_2 value increases considerably after using the Innovative Catalytic Converter. This increase can be accounted to the oxidizing nature of iron oxide nano-particles. Iron oxide nano-particles contain surplus oxygen which facilitates in the oxidation of the harmful exhaust gas emissions in to less harmful exhaust gas emissions. 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 graph between % load and EGT value indicates that the EGT value increases considerably after using the Innovative Catalytic Converter. This increase can be accounted to the oxidizing nature of iron oxide nano-particles. Iron oxide nano-particles contain surplus oxygen which facilitates in better combustion thereby increasing the exhaust gas temperature. The oxidation of the harmful exhaust gas emissions in to less harmful CO_2 contributes to further increase of exhaust gas temperature.

REFERENCES

1) Wei Y.P. and Hong Y.S., "Co-relation Analysis between Motor Vehicle Types and Air Pollution in Shijiazhuang City," Earth and Environmental Science, vol. 153, 2018, pp. 1-7.

2) Zhai H., Wei P., Zhang X., Kumar T.S., Shiv kumar D.B., Mala D., Chandrashekhar M. and Elango T., "The Status of Air Pollution and Characteristic Analysis," Hebei Journal of Industrial Science and Technology, vol. 30, no. 4, 2013, pp. 301-305.

3) Ali A., Shaukat A. and Adnan I., "Emissions from Diesel Engine and Exhaust After Treatment Technologies," 4th International Conference on Energy, Environment and Sustainable Development, 2016.

4) Ladommatos N., Balian R., Horrocks R. and Cooper L., "The Effect of Exhaust Gas Recirculation on Soot Formation in a High Speed Direct Injection Diesel Engine," SAE Technical Paper, vol. 1, no. 48, 1996, pp. 71-91.

5) Baskar P. and Senthil Kumar A., "Effects of Oxygen Enriched Combustion on Pollution and Performance Characteristics of a Diesel Engine," Engineering Science and Technology – An International Journal, vol. 19, 2015, pp. 438-443.

6) Shojaeefard M.H., Etghani M.M., Akbari M. and Ghobadian B., "Artificial Neural Networks based Prediction of Performance and Exhaust Emissions in Direct Injection Engine using Castor Oil Biodiesel – diesel blends," Journal of Renewable and Sustainable Energy, vol. 4, 2012, pp. 1-19.

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