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Behavioral Modeling and Simulation with Experimental Analysis of a Four Stroke Engine Using Nanosized Copper Coated Catalytic Converter

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Abstract

A great deal of emphasis is placed on the real societal benefits around nanotechnology for energy efficiency, renewable resources, environmental remediation and pollution prevention. In particular, new and better techniques for pollution control are emerging as nano-particles push the limits and capabilities of technology. Environmental Pollution by vehicles is caused due to tail-pipe exhaust emissions depending on changes in driving cycles, engine condition, fuel composition and air-fuel ratio. Malfunction of engine devices, especially fuel injection system, increases the emissions of the main exhaust components. In the present work, an improved design more suitable for implementation along with improved performance and efficiency in reducing the exhaust emissions from a four stroke spark ignition engine. In the present work some alterations and modifications have been designed so as to increase the retention period of exhaust gases to provide more time for its oxidation and thereby to reduce the harmful emission. In this research, modeling has been done for a four stroke spark ignition engine with nano-sized copper coated catalytic converter. It will throw a light on the reduction in emission achieved by nano-particle coating. This paper opens a gateway to study the changes in the concentration of exhaust emissions due to the nano-material coating. The modeling will help in understanding the mathematical nature of the process. The behavioral modeling, starts from analyzing the practical behavior of four stroke engine with designed catalytic convertor, and then approximating obtained behavior in terms of mathematical equations. These obtained equations actually represent behavior of concern system. Firstly, mathematical model is developed to implement it in the simulink platform. Then, to verify the results obtained from the model, simulation is performed.

Keywords: *Automobiles; catalytic converter; modeling; nano-particle; simulation*

1. Introduction

During the last twenty years, scientists have been looking towards nanotechnology for the answer to problems in medicine, computer science, ecology and even sports. Nanotechnology offers the promise for new solutions and product improvements to a variety of market sectors including materials, electronics, energy, bio-medical, and consumer goods. A great deal of emphasis is placed on the real societal benefits around nanotechnology for energy efficiency, renewable resources, environmental remediation

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and pollution prevention. In particular, new and better techniques for pollution control are emerging as nano-particles push the limits and capabilities of technology. In the automotive industry, nanotechnology applications are manifold. They reach from power train, light-weight construction, energy conversion, pollution sensing and reduction, interior cooling, wear reduction, driving dynamics, surveillance control, up to recycle potential and much more [1]. Environmental Pollution by vehicles is caused due to tail-pipe exhaust emissions depending on changes in driving cycles, engine condition, fuel composition and air-fuel ratio. Malfunction of engine devices, especially fuel injection system, increases the emissions of the main exhaust components [2-3]. Vehicular emissions consist of Carbon dioxide, Carbon monoxide, Nitrogen oxide, hydrocarbons including lead, particulate matter *etc*. The use of nano-particles in the automobiles for pollution prevention has become the epicenter of research in recent days due to increasing need to have clean and green environment. All transport vehicles; both Spark ignition and Compression ignition are equally responsible for emitting different kinds of pollutants [4-5].

Nano-particles prove to be very effective in the reduction of exhaust emissions primarily due to their small size. To control the exhaust emissions from a four stroke engine, the porous holes of the model are coated with the copper nano-particles so that the rate of reaction can be increased. This paper basically deals with modeling and simulation of a complete system which includes a four stroke engine including a prepared model of catalytic converter. The modeling can be very helpful to predict the mathematical nature of the process of exhaust emission reduction through catalytic converter and predict the results by simulation.

The utility of the nano-particles towards automobile pollution control was explained in detail. The nano-particle coating on the catalytic converter of automobiles can be very helpful in the reduction of pollutant concentration and thus reduce the pollution level in atmosphere [6]. Amongst main metals like Au, Ag, Pd, Pt, towards which nanotechnology research is directed, copper and copper based compounds are the most important. The metallic Copper plays a significant role in modern electronics circuits due to it’s excellent electrical conductivity and low cost nano-particles [7]. Copper based nano-particles are gaining wide popularity due to high reactivity and good conductivity [8]. A microprocessor based analyzer was used for measurement of CO and HC emissions [9]. The post pollution control method in two-wheeler automobiles using nano-particle as a catalyst was proposed. A study on nano-particle reveals that the ratio of surface area of nano-particle to the volume of the nano-particle is inversely proportional to the radius of the nano-particle. So, on decreasing the radius, this ratio is increased leading to an increased rate of reaction and the concentration of the pollutants is decreased. It involves the use of copper nano-particle that is cheaper than the platinum, palladium and rhodium nano-particles used in automobiles [10]. Experiments were conducted to improve the engine performance and reduce the emissions of HC and CO from vehicle [11]. To control the exhaust emissions from two stroke single cylinder spark ignition petrol engine having copper nano-particles coated on copper sieve as catalytic converter was used. AVL-422 Gas analyzer was used for the measurement and comparison for CO and unburned hydrocarbon in the exhaust of the engine at various speeds and loads [12]. Various tests conducted on four stroke engine reveal that the copper coated engine showed a better performance than a normal engine [13]. On using copper powder, the catalytic efficiency was found to increase as the size of the powder decreased [14]. Experiments were conducted to improve the engine performance and reduce the emissions of HC and CO from vehicle. Some alterations and modifications have been designed so as to increase the retention period of exhaust gases to provide more time for its oxidation and thereby to reduce harmful emissions [15]. The Experimental Setup is as shown in Figure 1:

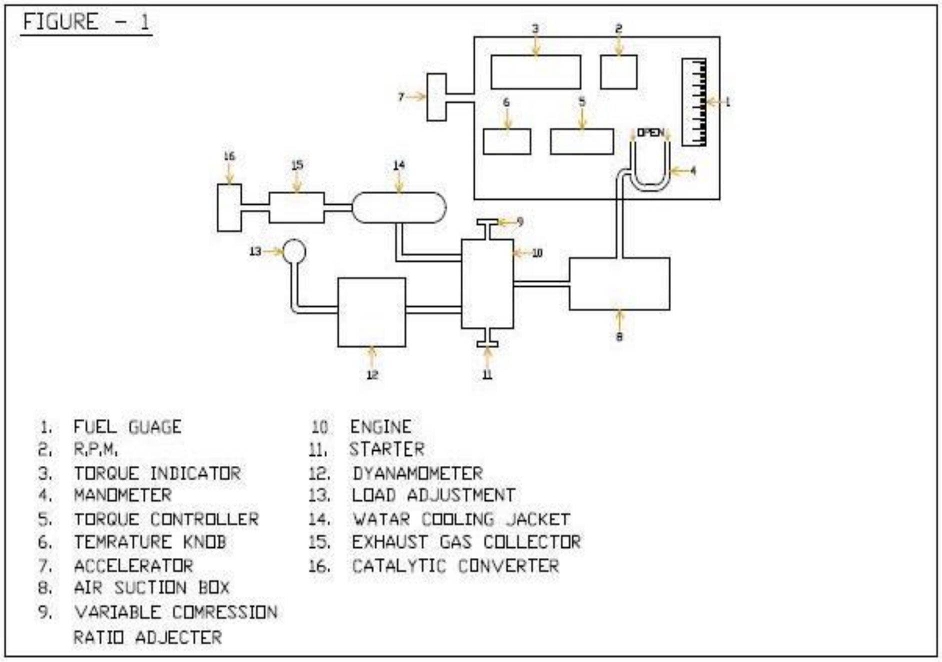

Figure 1. Experimental Setup

This research paper basically deals with the behavioral modeling and simulation of two stroke engine with developed catalytic convertor.

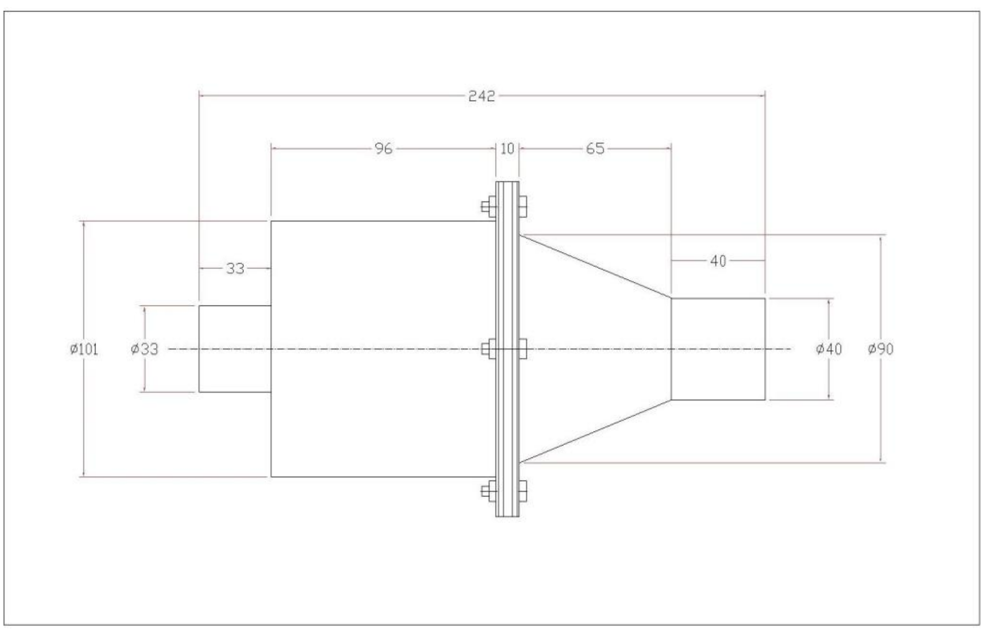

Figure 2. Experimental Setup of Designed Catalytic Converter

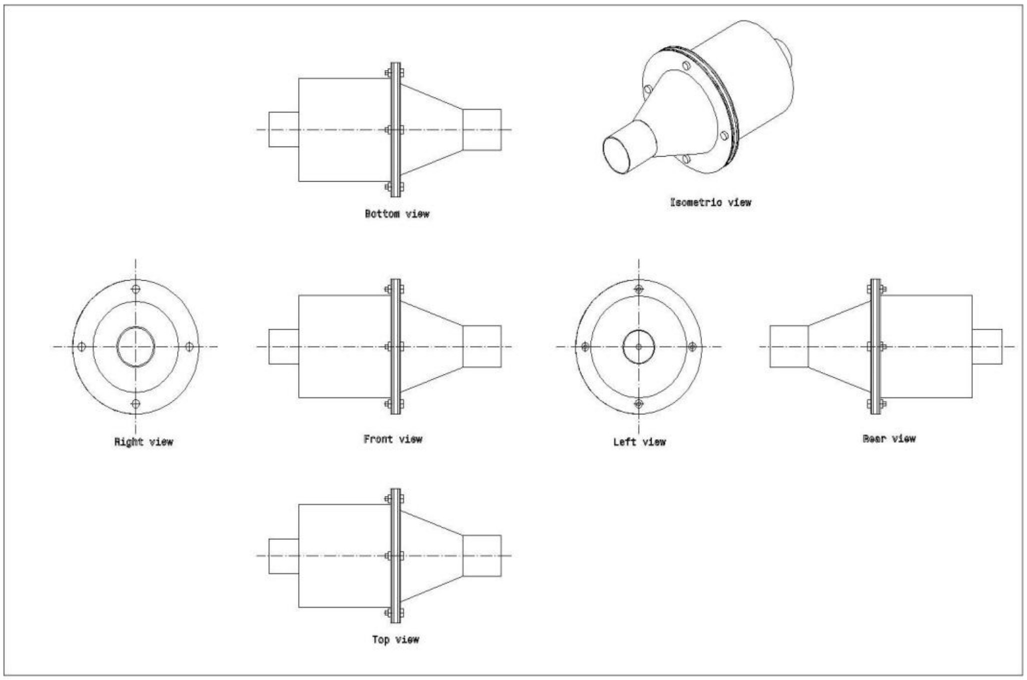

Figure 3. Different Three Dimensional Views of a Catalytic Converter

2. Behavioral Modeling and simulation of Four Stroke Engine and Designed Catalytic Convertor

This section basically deals with the behavioral modeling and simulation of a four stroke engine with developed catalytic convertor. The basic idea of behavioral modeling starts from analyzing the practical behavior of two stroke engine and designed catalytic convertor and then approximating obtained behavior in terms of mathematical equations. These obtained equations actually represent behavior of concern system. Once mathematical equations are obtained, next stage is to implementation of these equations in Simulink platform. The last process is the validation check by the simulation of developed model.

2.1. Behavioral Modeling of Four Stroke Engine

This subsection presents the complete behavioral modeling of four stroke engine, during modeling of engine following parameters are important and has to address during modeling.

i. Horse power of engine.

ii. Speed of engine in RPM.

iii. Applicable load during running condition.

These three important parameters are basically independent variable for modeling, and it is difficult to address simultaneously. However, among these three, one can be assumed constant, so for modeling of four stroke engine, in this paper horse power of engine is taken as constant, this leads the reduction of one independent variable from the list.

Now following steps provide complete idea of behavioral modeling of four stroke engine.

Step 1. Define the behavior of four stroke engine in terms of input and output variables. For modeling of this paper the input variables are:

i. Speed of engine in RPM.

ii. Applicable load during running condition.

Similarly the output variables for our work are

i. CO in percentage.

ii. HC in PPM.

To analyze the behavior of four stroke engine, practical experiment has been performed and data collected is shown in Table 1.

Table 1

Speed In RPM	Load	CO in %	HC(in PPM)
1500	0.25	1.2	1000
	0.5	1	800
	0.75	1.1	900
	1	1.3	1100
1800	0.25	1	900
	0.5	0.8	750
	0.75	0.9	800
	1	1.1	1000
2000	0.25	0.8	800
	0.5	0.7	700
	0.75	0.9	750
	1	1	850
2200	0.25	1.3	1100
	0.5	1.1	850
	0.75	1.2	950
	1	1.4	1150

Step 2. From Table (1), it is clear that there are two different speed conditions and each speed value consist four different load conditions. So for proper behavioral analysis of two stroke engine, we have to analyze the complete behavior in four parts, *i.e.*, based on different speed conditions. Hence, the complete modeling is also divided in four parts.

Step 3. Modeling of four stroke engine for speed = 1500 RPM. Table 2 shows the behavior of engine for 1500 RPM.

Table 2

Speed In RPM	Load	CO in %	HC(in PPM)
1500	0.25	1.2	1000
	0.5	1	800
	0.75	1.1	900
	1	1.3	1100

Now by dividing the modeling in four parts actually provides reduction of second independent variable, and hence for modeling now we have only one independent variable and two dependent output variables. Figures 4 and 5 shows plot of CO and HC with respect to Load values for fixed speed 1500 rpm.

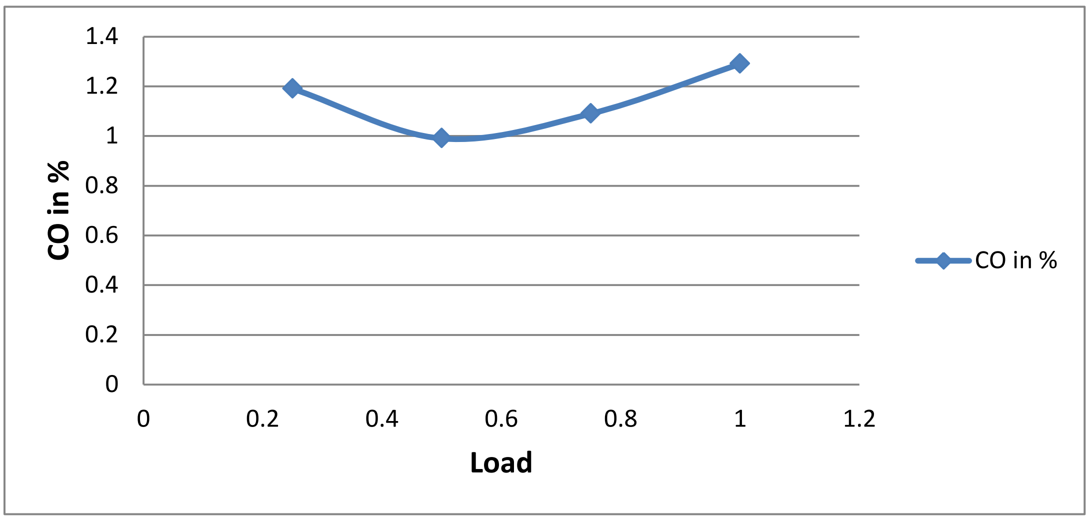

Figure 4. Load versus CO Graph

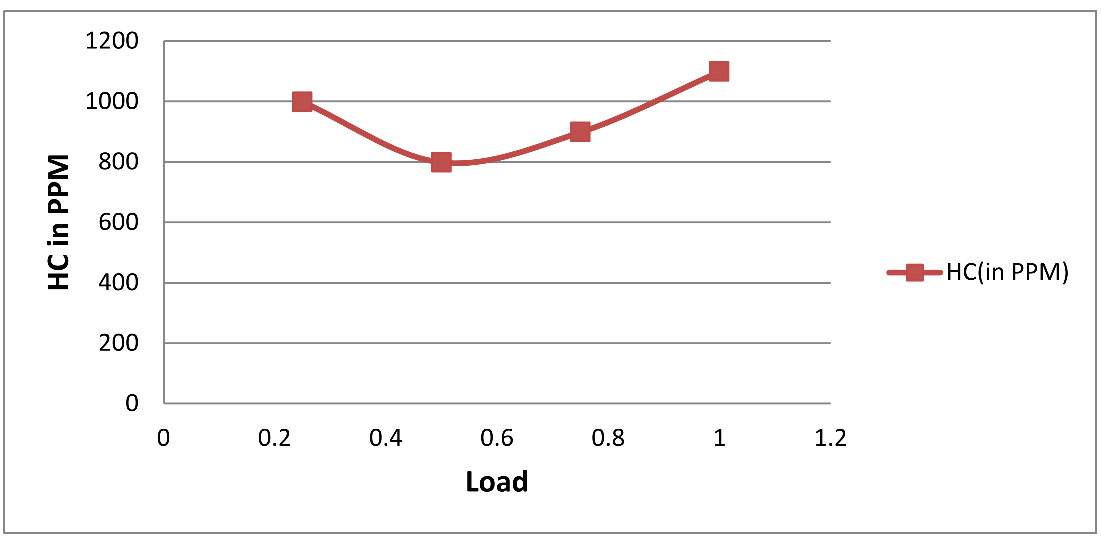

Figure 5. Load versus HC Graph

After using above figures, mathematical equations for CO and HC can be obtained as

$$CO = -2.1333x^3 + 5.6\,x^2 - 4.0667x + 1.89 \quad (1)$$

$$HC = -2.1333x^3 + 5600\,x^2 - 4066x + 1698 \quad (2)$$

Step4. Modeling of equation 1 and 2 in MATLAB Simulink:

After getting the equations the next step is to make Simulink model.

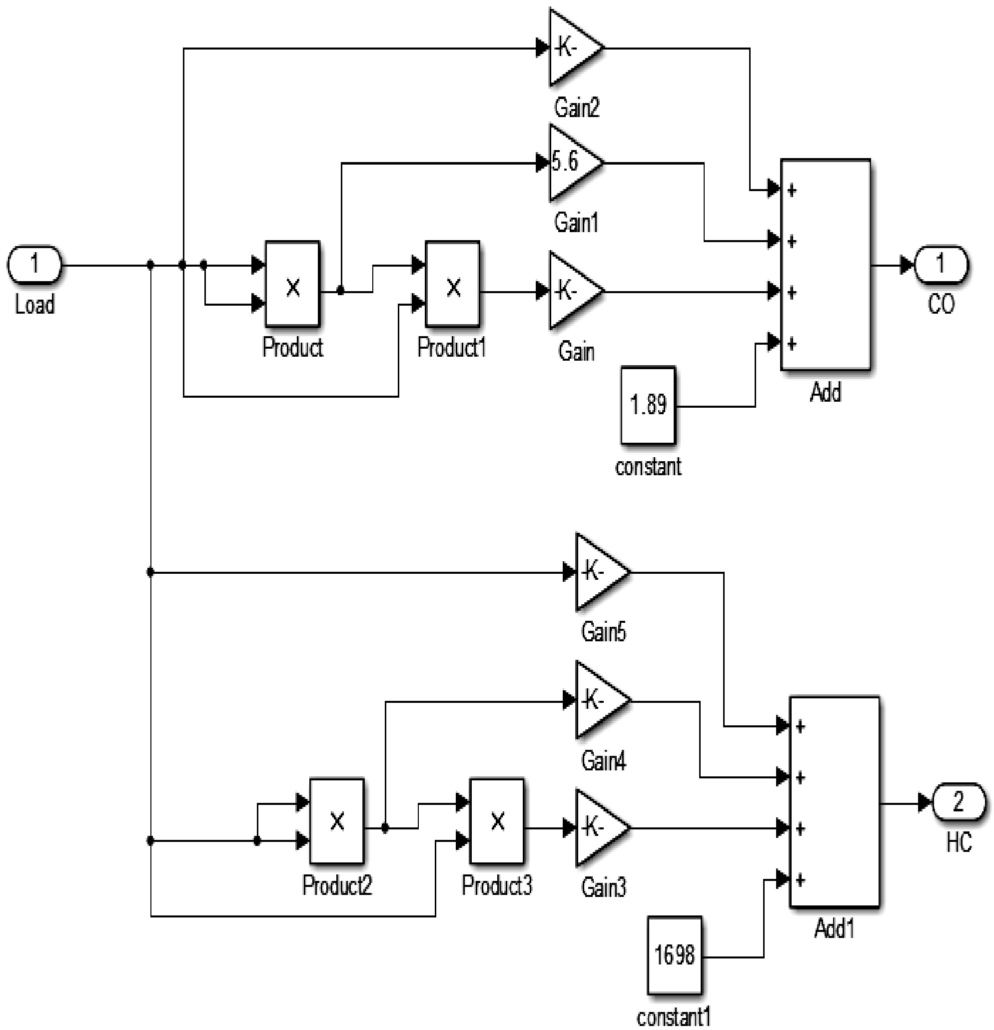

Figure 6. Actual Simulation Model of Two Stroke Engine for 1500 rpm

Step5. Similarly we can obtain equations for CO and HC for speed of 1800, 2000 and 2200 rpm.

The equations obtained are as follows:

i. For Speed = 1800 rpm.

$$CO = -2.1333x^3 + 5.6\,x^2 - 4.0667x + 1.69 \quad (3)$$

$$HC = -2.1333x^3 + 2400\,x^2 - 2166x + 1298 \quad (4)$$

ii. For Speed = 2000 rpm.

$$CO = -4.2667x^3 + 8.8\,x^2 - 5.1333x + 1.59 \quad (5)$$

$$HC = -1.066x^3 + 2800\,x^2 - 2033.3x + 1148 \quad (6)$$

iii. For Speed = 2200 rpm.

$$CO = -2.1333x^3 + 5.6\,x^2 - 4.0667x + 1.99 \quad (7)$$

$$HC = -2666.7x^3 + 6800\,x^2 - 4933.3x + 1948 \quad (8)$$

Step 6. Development of complete model including two models

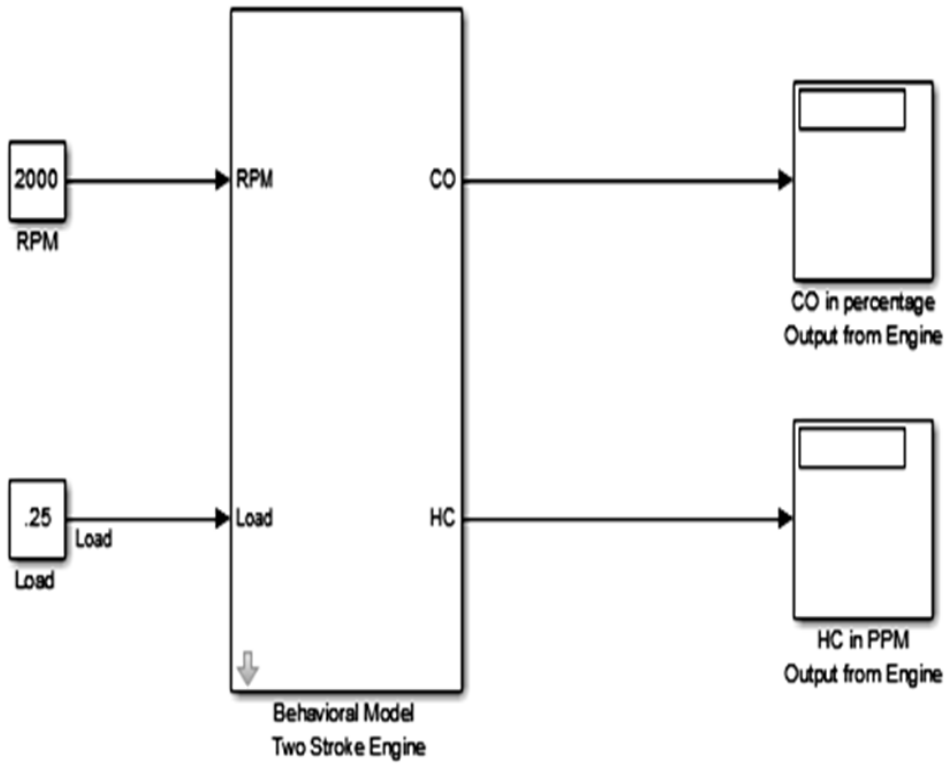

Figure 7. Complete Model of Four Stroke Engine

2.2. Behavioral Modeling of Catalytic Convertor for Four Stroke Engine

In this subsection we provide behavioral modeling of physically designed catalytic convertor for getting reduction in amount of CO and HC obtained from four stroke engine with the help of nano material. Fundamental steps are same as we have discussed in earlier subsection.

Step 1. Behavior analysis: Table 3 and Table 4, shows the practical behavior of physically designed catalytic convertor. Figures 8 and 9 shows corresponding plots.

Table 3

COWOCC IN %	COWCC IN %
0.7	0.45
0.8	0.55
0.9	0.5
1	0.65
1.1	0.7
1.2	0.75
1.3	0.8
1.4	0.85

Table 4

COWOCC IN %	COWCC IN %
0.7	0.45
0.8	0.55
0.9	0.5
1	0.65
1.1	0.7
1.2	0.75
1.3	0.8
1.4	0.85

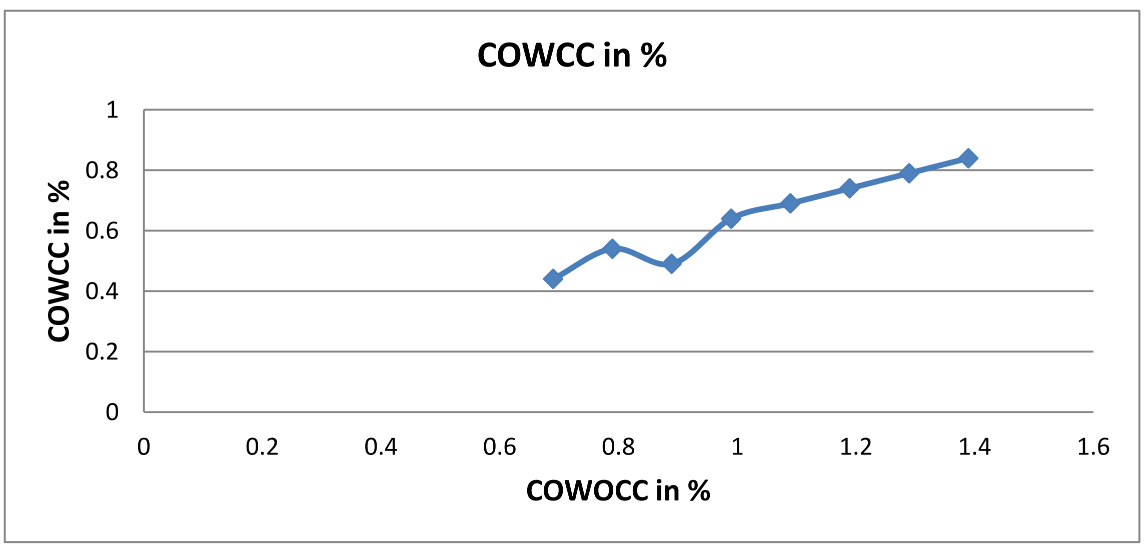

Figure 8. COWOCC versus COWCC Graph

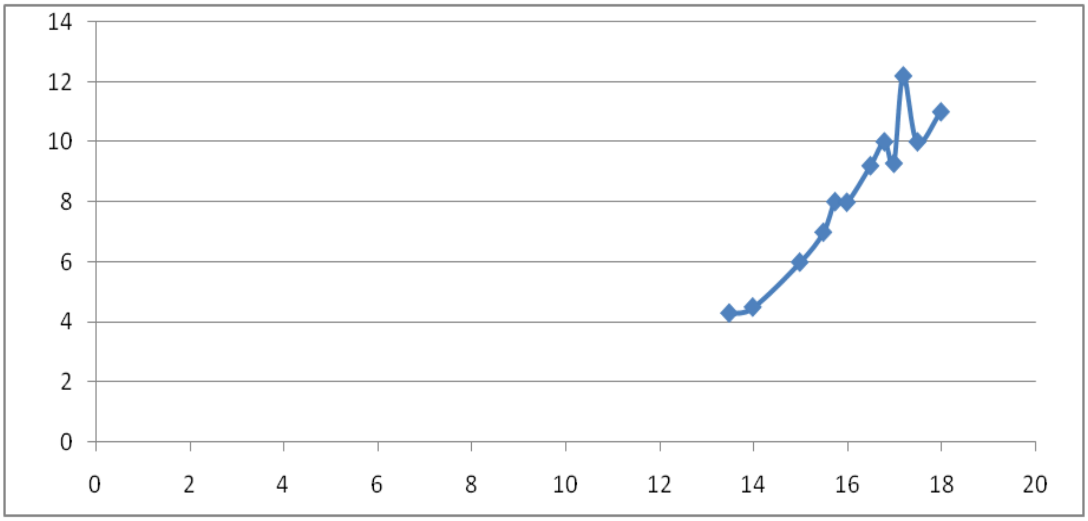

Figure 9. HCWOCC versus HCWCC in PPM Graph

Step2. Generation of mathematical equations with the help of Figures 8 and 9

The obtained equations for reduced CO and HC are:

$$COWCC = 22.75CO^5 - 114.4CO^4 + 226.3CO^3 - 220.3\,CO^2 + 106.5CO - 20.24 \quad (9)$$

$$HCWCC = 0.0.054HC^3 - 1.394\,HC^2 + 12.44\,HC - 31.46 \quad (10)$$

Step3. Modeling of equation 9 and 10 in MATLAB Simulink:

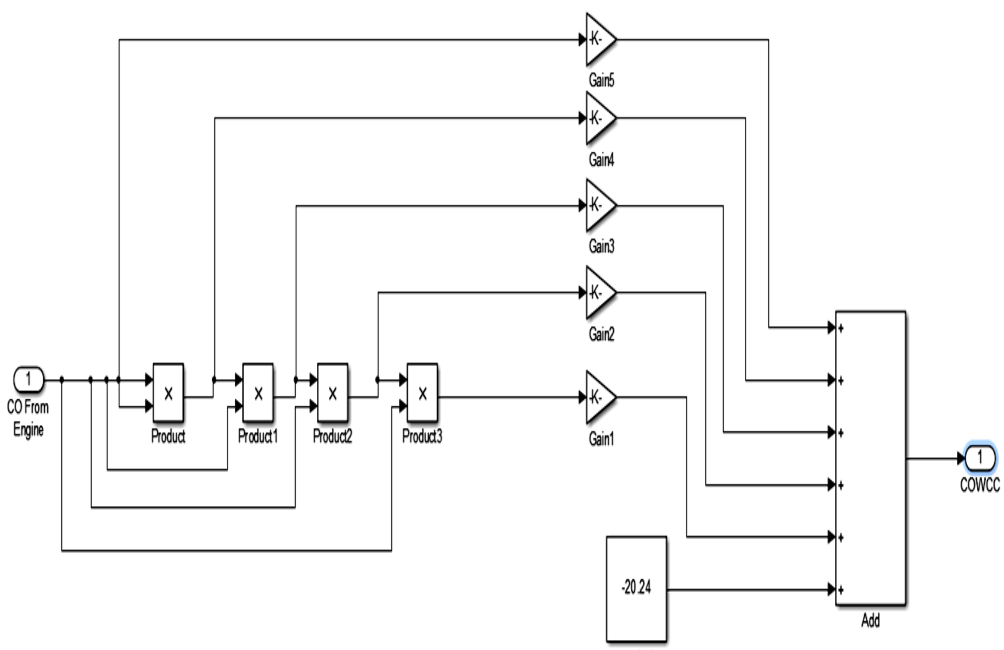

Figure 10. Simulation Model for COWCC

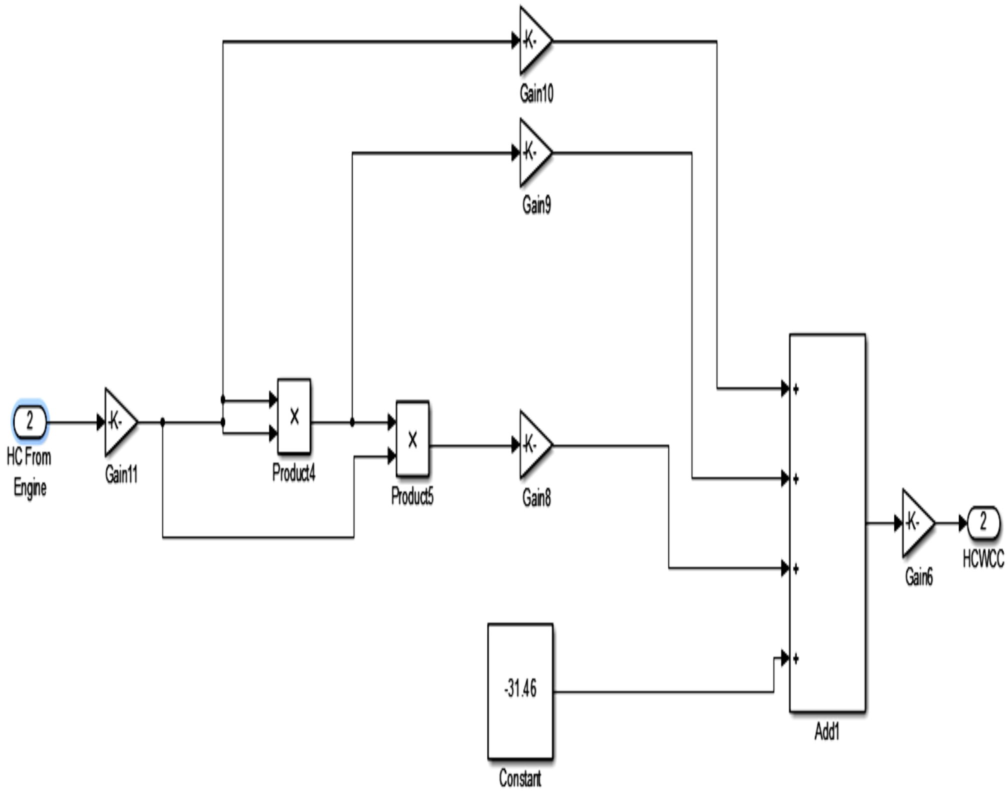

Figure 11. Simulation Model for HCWCC

Step4. Development of complete Catalytic Convertor model including the two in same model:

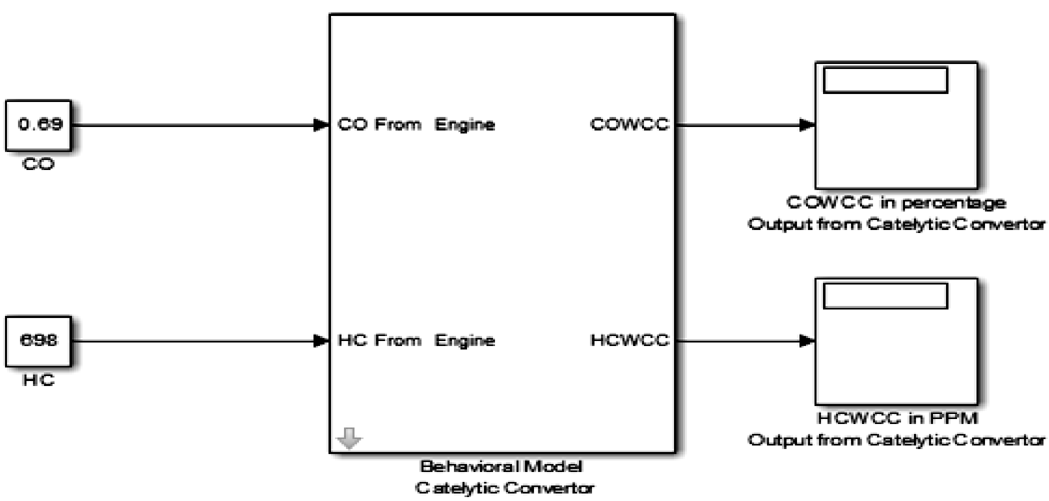

Figure 12. Simulation Model of Catalytic Convertor

2.3. Simulation of Complete System and Simulation Results

The complete simulation model for this paper has been successfully implemented and shown in Figure 13.

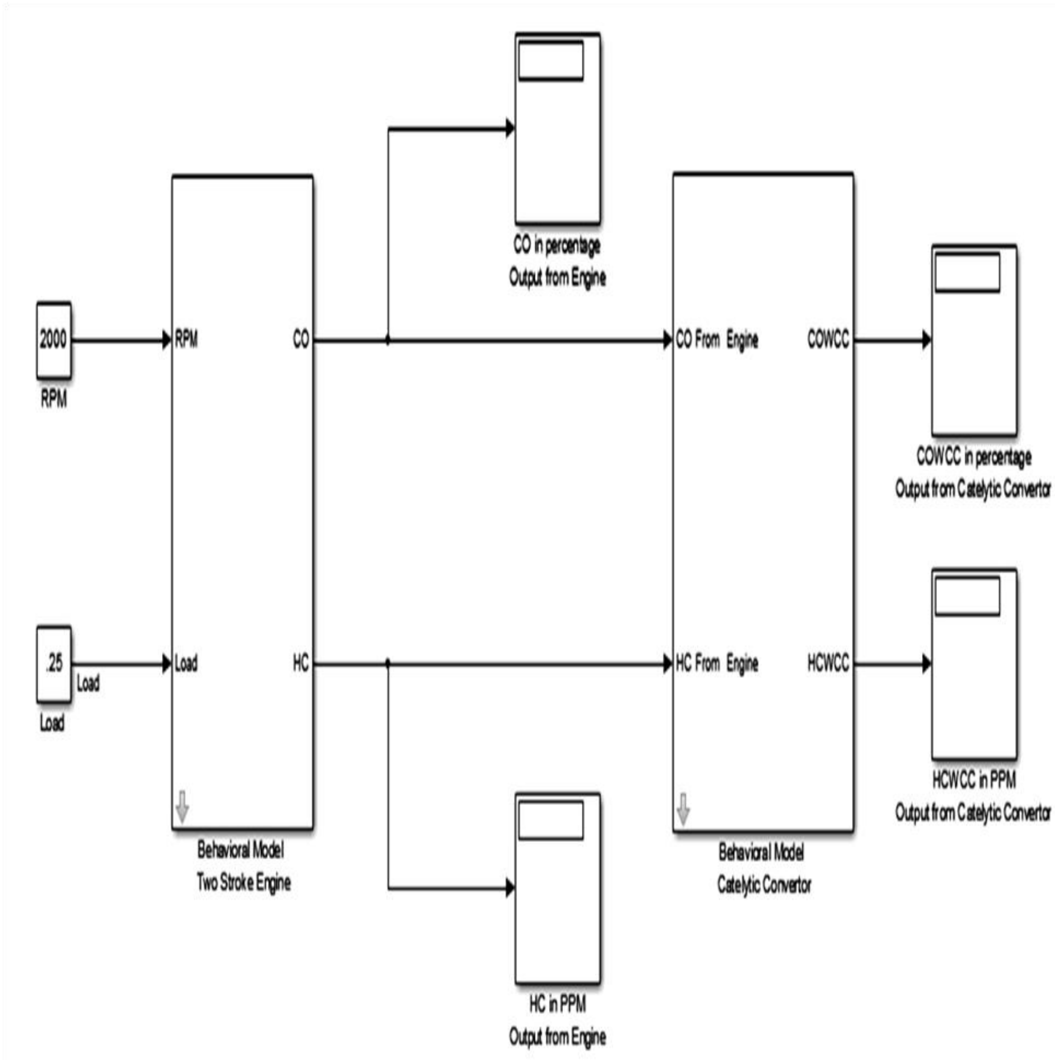

Figure 13. Simulation Model of Four Stroke Engine with Catalytic Converter

2.4. Analysis of Developed Simulation Model

After development of simulation model for a physical device, it must undergo for testing. This subsection provides a complete statistical analysis for practical engine with catalytic convertor and simulation model developed. To present a deep analysis, the complete analysis is divided in two parts. In first part we have shown analysis of engine model alone, while in second part an analysis of complete engine with catalytic convertor as shown is briefly discussed.

2.4.1. Analysis of Engine Alone

For the proper analysis of developed engine model, comparative evaluated values for the two stroke engine are shown in Table 5.

Table 5

Speed In RPM	Load	CO in %			HC in PPM		
		Practical	Simulation	Percentage Error	Practical	Simulation	Percentage Error
1500	0.25	1.2	1.19	0.83	1000	998	0.20
	0.5	1	0.99	1.00	800	798	0.25
	0.75	1.1	1.09	0.91	900	898	0.22
	1	1.3	1.29	0.77	1100	1098	0.18
1800	0.25	1	0.99	1.00	900	898	0.22
	0.5	0.8	0.79	1.25	750	748	0.27
	0.75	0.9	0.89	1.11	800	798	0.25
	1	1.1	1.09	0.91	1000	998	0.20
2000	0.25	0.8	0.79	1.25	800	798	0.25
	0.5	0.7	0.69	1.43	700	698	0.29
	0.75	0.9	0.89	1.11	750	748	0.27
	1	1	0.99	1.00	850	848	0.24
2200	0.25	1.3	1.29	0.77	1100	1098	0.18
	0.5	1.1	1.09	0.91	850	848	0.24
	0.75	1.2	1.19	0.83	950	948	0.21
	1	1.4	1.39	0.71	1150	1148	0.17

From Table 5 it is clearly observable, that the maximum percentage error obtained for CO is 1.43% and for HC is 0.29%, which are very small and hence the developed behavioral simulation model of four stroke engine is the exact replica of practical four stroke engine considered for this work.

2.4.2. Analysis of Complete Engine with Catalytic Convertor

For the proper analysis of developed Catalytic Convertor model, comparative evaluated values for the Catalytic Convertor are shown in Table 6.

Table 6

Speed In RPM	Load	COWCC in %			HCWCC in PPM		
		Practical	Simulation	Percentage Error (in %)	Practical	Simulation	Percentage Error (in %)
1500	0.25	0.75	0.7584	0.84	800	752.489	5.94
	0.5	0.65	0.6005	7.62	700	648.188	7.4
	0.75	0.7	0.6904	1.37	750	694.263	7.43
	1	0.8	0.8097	1.21	850	855.268	0.62
1800	0.25	0.65	0.6005	7.62	700	694.263	0.82
	0.5	0.55	0.4219	5.45	650	619.583	4.68
	0.75	0.63	0.5065	7.94	680	648.188	4.68
	1	0.7	0.6904	1.37	730	752.489	3.08
2000	0.25	0.55	0.4219	5.45	650	648.188	0.28
	0.5	0.45	0.3287	8.89	600	581.866	3.02
	0.75	0.5	0.5065	1.3	630	619.583	1.65
	1	0.6	0.6005	0.08	700	671.731	4.04
2200	0.25	0.8	0.8097	1.21	900	855.268	4.97
	0.5	0.75	0.6904	7.95	750	671.731	9.5
	0.75	0.8	0.7584	5.2	850	719.832	8.14
	1	0.85	0.8997	5.85	950	933.489	1.74

From Table 6 it is clearly observable, that the maximum percentage error obtained for CO is 8.89 % and for HC is 9.5 %, which are very small and hence the developed behavioral simulation model of complete engine with catalytic convertor is the exact replica of practical complete four stroke engine with catalytic convertor considered for this work.

3. Results and Discussion

The idea behind the work is to create a structure that exposes the maximum surface area of catalyst to exhaust stream, also minimizing the amount of catalyst required. Air pollution can be remediated using nanotechnology in several ways. One is through the use of nano-catalysts with increased surface area for gaseous reactions. Catalysts work by speeding up chemical reactions that transform harmful vapors from cars and industrial plants into harmless gases. To achieve this objective, an innovative design of catalytic converter for automobiles is proposed using nano-particle as a catalyst. The converter uses two different types of catalyst, reduction and oxidation catalyst. The catalyst increases the rate of reaction by adsorption of reactants in such a form that the activation energy for reaction is reduced far below its value in non-catalytic reaction. Copper metal is selected for the present work as it is cheaper than platinum, palladium and rhodium also it adsorbs the reactants molecule strongly enough to hold and active the reactants ,but not so strongly that the product can't breakaway also the diffusion of reactants and products into and out of the pore structure of copper took place efficiently. Due to this, the pollution level for the exhaust emission of S.I. engine has found to be reduced that is better with nano-sized catalytic converter. The exhaust gases pass through a bed of catalyst and the catalytic action takes place at surface of copper that is porous and the higher catalytic activity towards the oxidation of carbon mono-oxide and hydro-carbons could be due to the higher catalytic surface area of small nano-particles. Air pollution can be remediated using nanotechnology in several ways. One is through the use of nano-catalysts with increased surface area for gaseous reactions. Catalysts work by speeding up chemical reactions that transform harmful vapors from cars and industrial plants into harmless gases. The idea behind the work is to create a structure that exposes the maximum surface area of catalyst to exhaust stream, also minimizing the amount of catalyst required. In the present work, the experimentation has been done for a four stroke engine with and without catalytic converter and the results clearly reveals that the emission level can be reduced by the use of catalytic converter.

There are two methods of control of pollution namely; pre-pollution control and post pollution control. Many environmentalists are interested in using precious metal nano-particles as exhaust filters, both for vehicles and for power plants. The proposed method is very effective in the prevention of environmental pollution contributed from two-wheeler automobiles. It involves the use of copper nano-particle that is cheaper than the platinum, palladium and rhodium nano-particles used in automobiles. Copper metal is selected for the present work as it adsorbs the reactants molecule strongly enough to hold and active the reactants, but not so strongly that the product can't breakaway also the diffusion of reactants and products into and out of the pore structure of copper took place efficiently. Due to this, the pollution level for the exhaust emission of S.I. engine has found to be reduced that is better with nano-sized catalytic converter.

4. Conclusion

In the current scenario, the pollution control is a crucial area for research and development. many of work has been done by the researchers in this connection, but the area is still lacking for an efficient technique which can provide highly robust emission control for all the operating conditions of vehicles. The idea behind the work is to create a structure that exposes the maximum surface area of catalyst to exhaust stream, also minimizing the amount of catalyst required. The exhaust gases pass through a bed of catalyst and the catalytic action takes place at surface of copper which are porous and the higher catalytic activity towards the oxidation of CO and HC could be due to the higher catalytic surface area of small nanoparticles.

The proposed method is very effective in the prevention of environmental pollution contributed from two-wheeler automobiles. It involves the use of copper nano-particle that is cheaper than the platinum, palladium and rhodium nano-particles used in automobiles. This paper opens a gateway to study the changes in the concentration of exhaust emissions due to the nano-material copper coating. The modeling will help in understanding the mathematical nature of the process and simulation will help in predicting the results with ease.

Nomenclature:

CO – Carbon Monoxide

CC – Catalytic Converter

HC – Hydrocarbon

COWCC – CO emission in % with catalytic converter

COWOCC – CO emission in % without catalytic converter

HCWCC – HC emission in PPM with catalytic converter

HCWOCC – HC emission in PPM without catalytic converter

x – Load

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