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Modeling and Simulation of Four Stroke Spark Ignition Engine with Nano-Particle Coated Catalytic Converter for Analysis of Exhaust Emissions

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Abstract: Nanotechnology is being explored for its potential to provide new solutions to coping with and cleaning up pollutants in our air, water, and land, and enhancing the performance of traditional technologies used in cleanup attempt. The intent behind this article is to present the outcome of an experimental examine of the performance and transformation efficiency of copper Nano-particle coated catalytic converter employed in motor vehicle tailpipe for the minimization of exhaust emission. Pollution is in general produced through the exhaust of motorized cars in addition to the combustion of fossil fuels. In the present work, the catalytic converter in which there were two wire mesh with nanoparticle coatings were studied to investigate the effect of varying key parameters on conversion efficiencies. In accordance with the emission test the amount of pollutants corresponding to various RPMs and loads were obtained. After that to verify experimental results the process of modeling and simulation was used. The primary idea of behavioral modeling starts from studying the sensible behavior of four stroke engine and designed catalytic converter, after which approximating received behavior in phrases of mathematical equations. These obtained equations honestly represent conduct of issue machine. When mathematical equations are acquired, subsequent phase is to implementation of these equations in Simulink platform. The last procedure is the validation check by using the simulation of advanced model.
Keywords : Modified Catalytic converter, Simulink platform, Spark-ignition engine, Nano-particle, Modeling

I. INTRODUCTION

A significant question that is often been talked about among the environmentalists over the many years and present, that is air pollution[1]. One among the primary contributors are considered to be the emission of hazardous gases generated by automotive tailpipe; both SI (Spark ignition) and CI (Compression ignition) are equally answerable for emitting completely different reasonably pollutants[1]. A number of the best known kinds having direct hazardous influences take for instance, carbon mono oxide (CO), hydrocarbons, nitrogen oxides (NO_x), and so on. Other the secondary pollutants which go through a series of reactions within the ecosystem and come to be unsafe to health[2]. These types of pollutants are incredibly unhealthy for the natural environment. The CO emissions combined with hemoglobin in the bloodstream causes the lowering of oxygen-active sites that provide asphyxia. Nitrogen oxides (NO_x) lead to acid rain and photochemical smog, and are irritating to the eyes and skin. A pollutant is a phenomenon which modifications the stability of the environment and nature under normal condition. Carbon di oxide is not perceived as a pollutant in nature recycles in cases where CO_2 goes above 5000 ppm then it turns out to be a wellness and fitness issues[3]. Hence, we require consciousness our studies and development efforts more and more to monitor, identify and, if possible, eliminate the impurities from the air, water and soil. In such a context, nanotechnology offers an enormous variety of abilities and technologies to enhance the best of current surroundings. Additionally it is useful in improving the overall performance of conventional technologies used for the clean-up manner[4]. Nanotechnologies are user interface technologies that incorporate a variety of concept and application areas. Including traditional aspects of knowledge such as chemistry, physics and mechanical engineering in addition to modern aspects such as nano-bio technology and also sub areas of microelectronics[5]. In that context, nanotechnologies have turn out to be progressively more important throughout the last couple of years. A nanometre is billionths of a meter. The critical size below which the properties of material changes, depends on the material itself. By changing the size of such components, the control of the chemical composition and the targeted manipulation of the atomic structure it is possible to produce macroscopic materials with radically unique characteristics and functionalities[6]. Today, nanoparticles with unique capabilities are already being developed on a huge scale and built-in into items. Generally, the nanotechnological items now available on the market are quite unspectacular and have develop into a practically unperceived portion of everyday's life. Nanotechnology is the also considered as the generation next technology or the technology for the future. Because of their smaller size, nanoparticles have very high surface area compared with their bulk equivalent thus nanoparticles are being explored as a way to remove or break toxic substances from the environment[7]. Nanoparticles are extra reactive and react to a more volume because of their smaller size. Nanoparticles have greater surface to be had for chemical interactions. Nanoparticles will also be able to exhibit more significant chemical reactivity on account of unusual crystal structures and lattice order[8]. During the conversion of poisonous to non-toxic gases nanotechnologies perform a vital role. Today the reduction of exhaust emissions in automobiles is not imaginable without catalysts any more. They are made from high grade stainless steel containing catalytically active materials, used for the transformation of pollutant to nitrogen and carbon dioxide. The nanoparticle coating on the catalytic converter of vehicles can be more beneficial in the lowering of pollutant level and hence minimize the toxins rate in environment[9]. The consequence of catalysts usually depends on the size of the surface. If the material chosen for the catalytic operation is scaled to the nanometre range, the particular surface increases substantially. The shape and composition are selected in such way that exhaust emission interact optimally with the catalytically active layer, and their chemical transformation into harmless substances is accelerated. Copper nano particle were taken into consideration to do this research work, since it is less expensive as compared to rhodium platinum, and palladium which are usually used[9, 10]. Also Copper possesses an effective electrical conductivity. Because of quite affordable price, this metal plays an important role in modern electronic circuit. Due to its excellent catalytic behaviour, superior compatibility and surface improved Raman scattering activity, Cu nanoparticles have drawn the eye of scientists for use as vital aspect within the future nano-devices. For the modification, catalytic chamber is opened using arc welding and cutting then the two sets of stainless steel wire mess coated with Cu nanoparticle are installed at the junctions and fitted with the help of nuts and bolts. For the measurement and comparison of carbon mono oxide and unburned hydrocarbon in the exhaust of the engine at various speeds and loads, a gas analyser (EPM-1601) was used. Several tests carried out on 4 stroke engine show that the copper coated engine exhibited a much better performance as compared to a standard engine. On using Cu nanoparticle, the efficiency of conversion was found to increase as the size of the particle decreased.

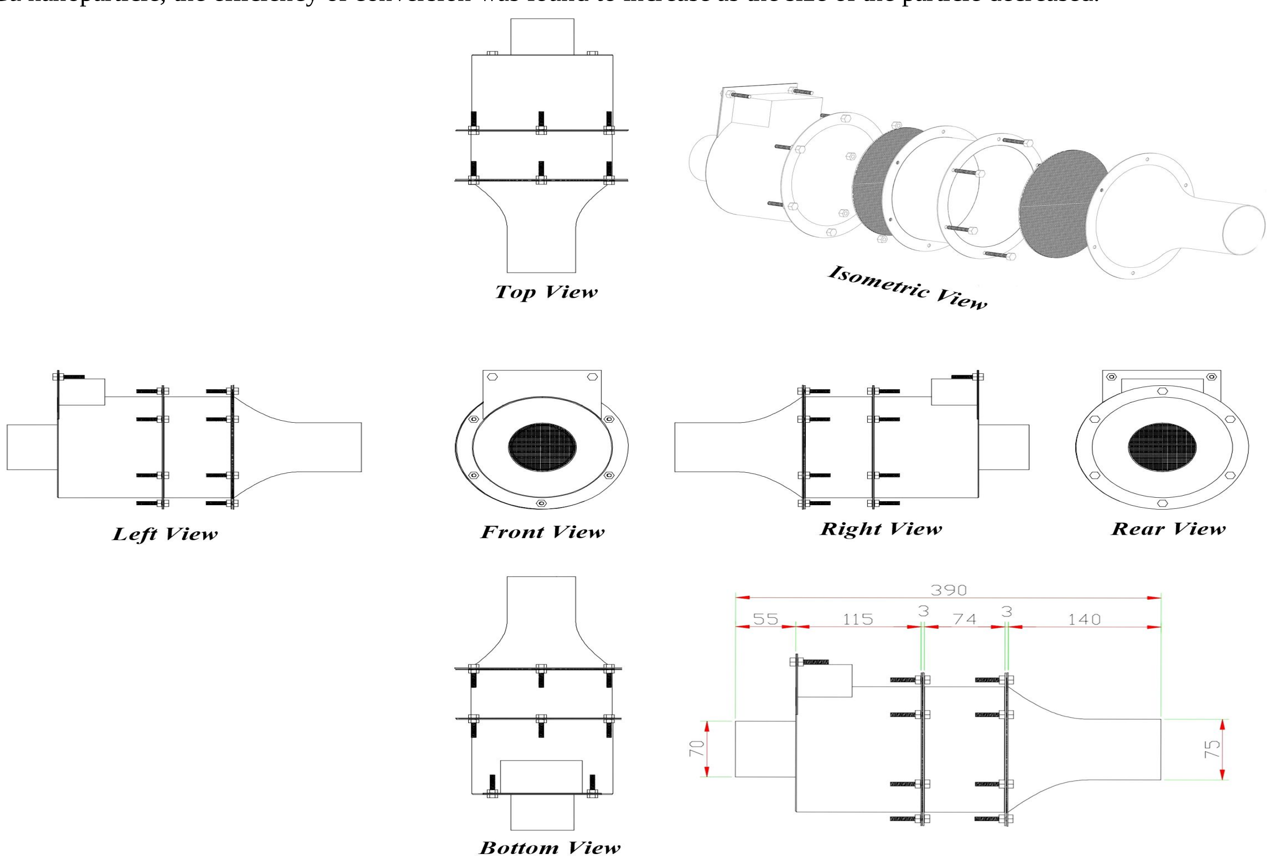

Fig.1 Different view of modified catalytic converter

II. BEHAVIORAL MODELING AND SIMULATION

In behavioral system hypothesis along with dynamic systems modeling, a behavioral model reproduces the desired behavior of the original (examined) system like there is a one to one correlation between the behavior of the original system and the simulated system[11]. The behavioral perspective is motivated by the goal of acquiring a framework for system assessment that respects the fundamental physics and sets up the suitable mathematical concepts from that point. The behavior may be achieved in simulation with a mixture of ideal or otherwise physically unrealistic components if it successfully recapitulates the behavior of the system under analysis.

This phase generally relates to the behavioral modeling and simulation of 4-stroke engine with modified catalytic converter. The general concept of behavioral modeling begins from analysing the practical behavior of 4-stroke engine and modified catalytic converter. After which approximating acquired behavior in relation to mathematical equations. Such obtained equations basically represent behavior of concern system. As mathematical equations are obtained, subsequent stage is to implementation of these equations in Simulink platform. The final process is the validation check by the simulation of developed model.

A. Behavioral Modeling of 4-Stroke Engine

This subsection exhibits the complete behavioral modeling of 4-stroke engine, throughout modeling of engine following parameters are very important and needs to address at the time of modeling.

1) Power of engine.
2) Speed of engine (RPM).
3) Applicable load while in running condition.

Each one of these three essential parameters are mainly independent variable for modeling, which makes it complex to address simultaneously. On the other hand for modeling of 4-stroke engine one of these three parameter can possibly be assumed constant. In these research work horse power of engine is taken as constant.

Following steps gives complete idea of behavioral modeling of 4-stroke engine. Step 1. Define the behavior of 4-stroke engine in terms of input and output variables. As the horse power of the engine is taken as constant hence the input variable are:

TABLE I

Speed In RPM	Load	COWOCC in %	HCWOCC in PPM
1500	0.25	1.4	1000
	0.50	1.1	850
	0.75	1.3	900
	1.0	1.5	1100
1800	0.25	1.3	900
	0.50	0.9	750
	0.75	1.0	800
	1.0	1.4	1050
2000	0.25	1.25	1650
	0.50	0.95	1500
	0.75	1.05	1600
	1.0	1.3	1750
2200	0.25	1.5	1200
	0.50	1.3	950
	0.75	1.4	1050
	1.0	1.6	1300

Step.2 From Table I it is clear that the first independent input variable (speed in RPM) having four different values, i.e. speed conditions, and each speed value consist four different load conditions and hence for proper behavioral analysis of 4-stroke engine, we have to analyse the complete behavior in several parts, based on different RPM.

Step.3 Modeling of 4-stroke engine for speed = 1500 RPM. Table II shows the behavior of engine for 1500 RPM.

TABLE II

Speed In RPM	Load	COWOCC in %	HCWOCC in PPM
1500	0.25	1.4	1000
	0.50	1.1	850
	0.75	1.3	900
	1.0	1.5	1100

Fig.2 and 3 shows plot of CO (in percentage) and HC (in PPM) with respect to Load values for speed of 1500 rpm

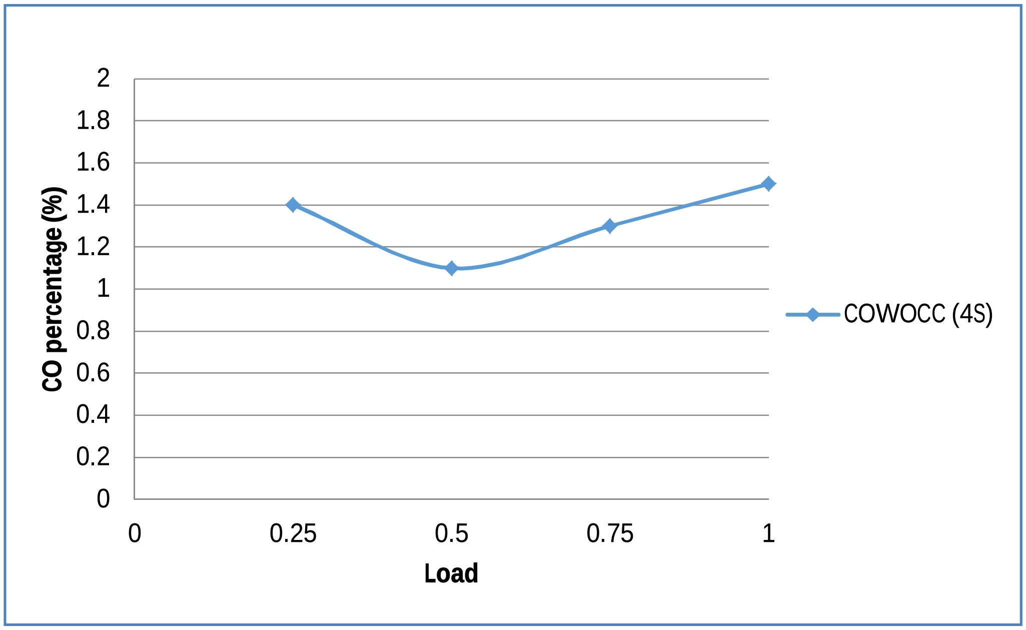

Fig.2 Load versus CO Graph

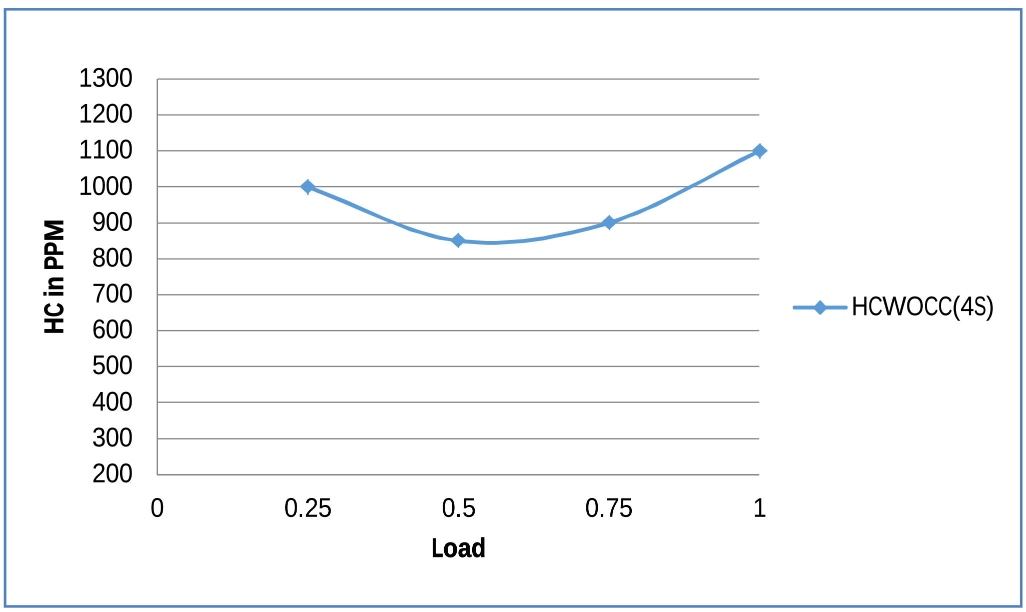

Fig.3 Load versus HC Graph

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

$$COWOCC = -5.333x^3 + 12\,x^2 - 7.866\,x + 2.7 \quad (1)$$

$$HCWOCC = -533.3\,x^3 + 2400\,x^2 - 2166x + 1400 \quad (2)$$

Where x = Load values.

Step4. Modeling of equation 1 and 2: After getting the equation (1) and (2) the next step is to make Simulink model of the equation in MATLAB Simulink.

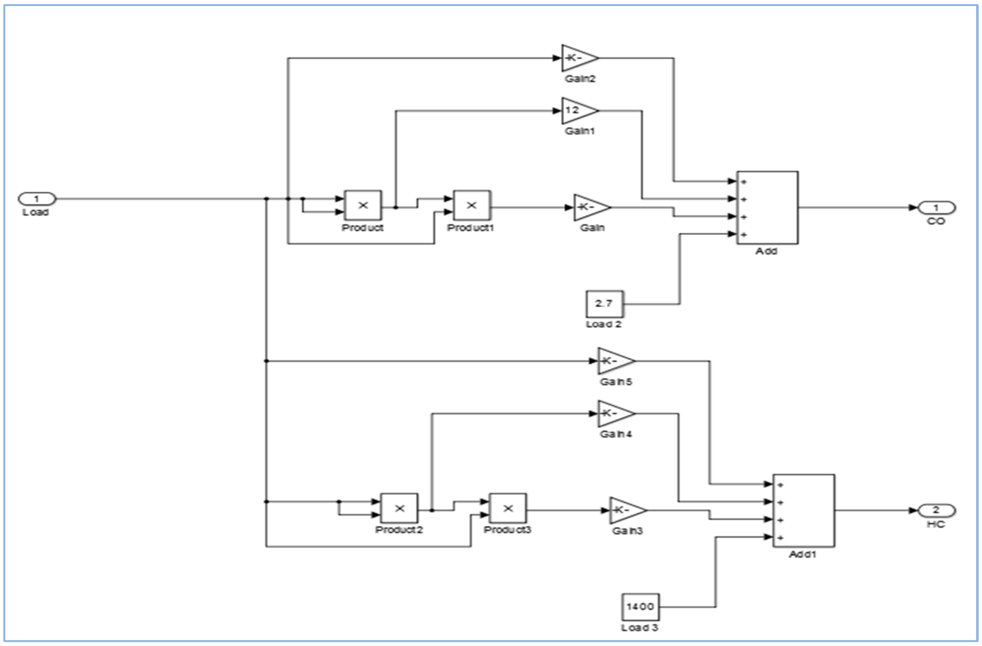

Fig.4 Actual Simulation Model of 4-Stroke Engine for 1500 rpm

Step5. Similarly we can get equations for CO and HC for speed of 1800, 2000 and 2200 rpm.
The equations are as follows:

For Speed = 1800 rpm.

$$COWOCC = -2.133x^3 + 7.2\,x^2 - 6.066\,x + 2.4 \quad (3)$$

$$HCWOCC = 5 \times 10^{-11}\,x^3 + 1600\,x^2 - 1800x + 1250 \quad (4)$$

For Speed = 2000 rpm.

$$COWOCC = -2.666x^3 + 7.2\,x^2 - 5.433\,x + 2.2 \quad (5)$$

$$HCWOCC = -2133\,x^3 + 5200\,x^2 - 3566x + 2250 \quad (6)$$

For Speed = 2200 rpm.

$$COWOCC = -2.133x^3 + 5.6\,x^2 - 4.066\,x + 2.2 \quad (7)$$

$$HCWOCC = -2133\,x^3 + 6000\,x^2 - 4566x + 2000 \quad (8)$$

B. Behavioral Modeling of Catalytic Converter for 4-Stroke Engine

This subsection exhibits the complete behavioral modeling of 4-stroke engine newly designed Cu nano particle coated catalytic converter for the reduction of CO and HC in the exhaust of 4-stroke engine. For this purpose following steps are followed.

Step.1 Table III and Table IV, shows the practical behavior of newly designed Cu nano particle coated catalytic converter.

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TABLE III

COWOCC in %	COWCC in %
1.4	0.9
1.1	0.75
1.3	0.73
1.5	1
1.3	0.95
0.9	0.7
1.0	0.8
1.4	1
1.25	1.06
0.95	0.75
1.05	0.8
1.3	1
1.5	1
1.3	0.9
1.4	0.95
1.6	1.05

TABLE IV

HCWOCC(in PPM)	HCWCC(in PPM)
1000	900
850	750
900	800
1100	1000
900	850
750	700
800	800
1050	1000
1650	1500
1500	1400
1600	1480
1750	1650
1200	950
950	800
1050	900
1300	1050

Fig.5 and 6 shows plot of CO (in percentage) and HC (in PPM) with respect to Load values for speed of 1500 rpm.

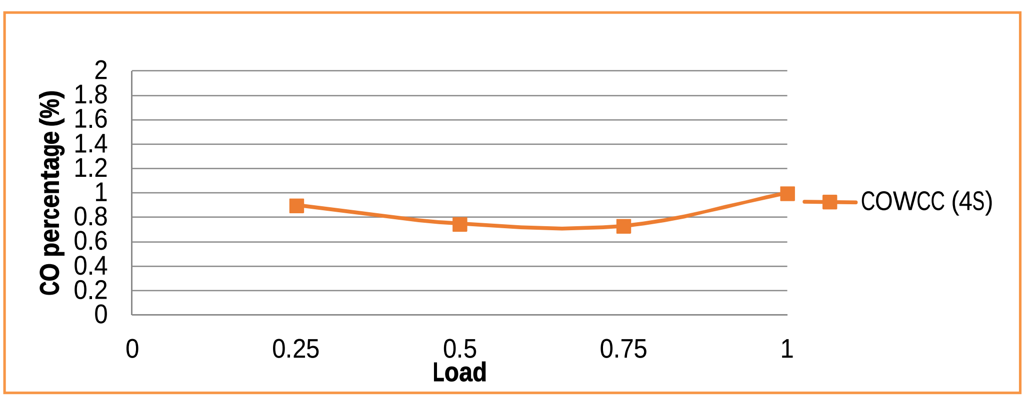

Fig.5 Load versus COWCC

Step.2 Generation of mathematical equations with the help of Fig.5 and 6. Acquired equations for reducing CO and HC are follows: For Speed = 1800 rpm.

$$COWCC = 2.977\,x^2 - 7.064\,x + 4.912 \quad (9)$$
$$HCWCC = 1x - 100 \quad (10)$$

Where x = HCWOCC values.

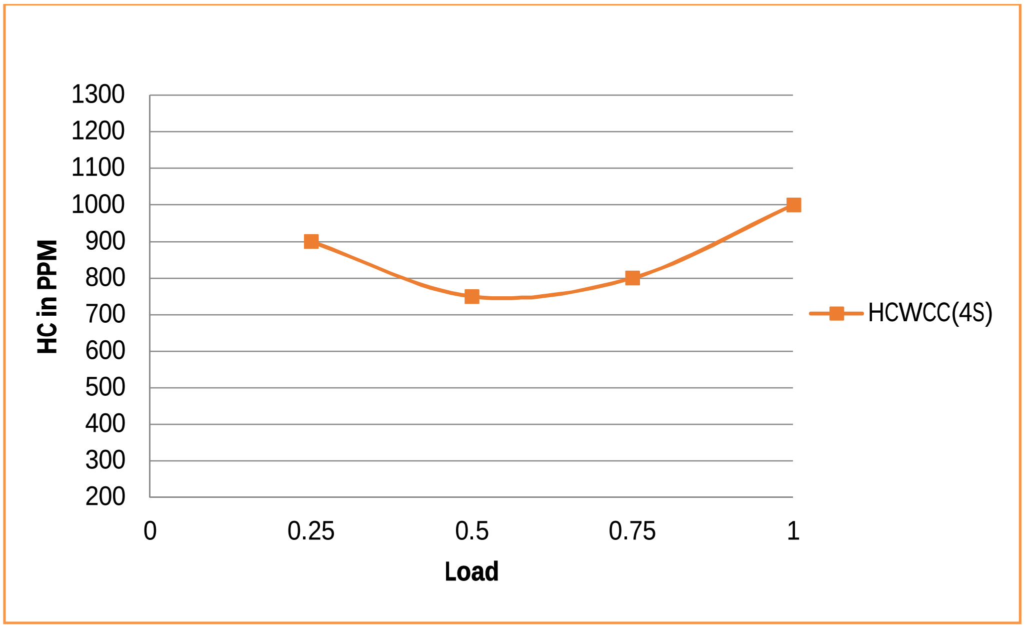

Fig.6 Load versus HCWCC

1) For Speed = 1800 rpm.

$$COWCC = 2.5x^3 - 9.25\,x^2 + 11.8\,x - 4.25 \quad (11)$$
$$HCWCC = 4 \times 10^{-5}\,x^3 - 0.108\,x^2 + 97.3x - 28400 \quad (12)$$

2) For Speed = 2000 rpm.

$$COWCC = -13.33x^3 + 46\,x^2 - 51.46\,x + 19.56 \quad (13)$$
$$HCWCC = 0.0013\,x^2 - 3.3\,x - 3400 \quad (14)$$

3) For Speed = 2200 rpm.

$$COWCC = 2 \times 10^{-12}x^3 - 8 \times 10^{-12}x^2 + 0.5\,x + 0.25 \quad (15)$$
$$HCWCC = 0.655\,x + 187.9 \quad (16)$$

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

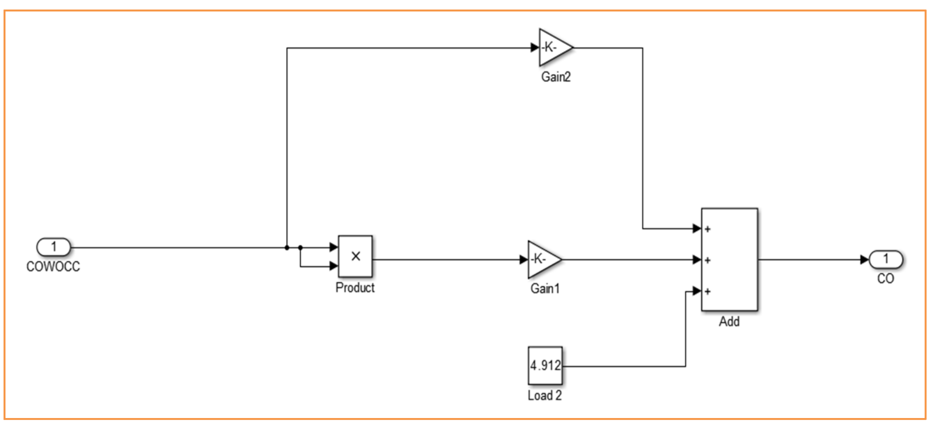

Fig.7 Simulation Model for COWCC

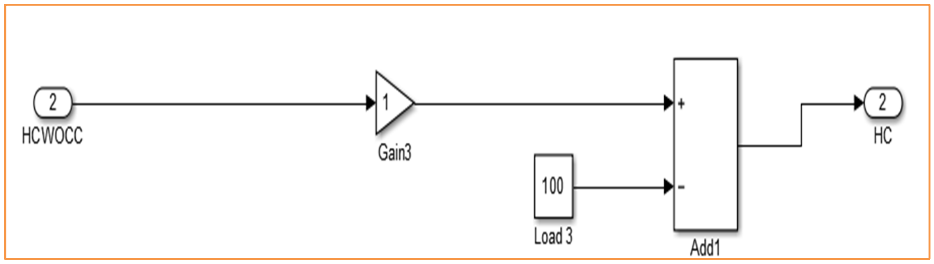

Fig.8 Simulation Model for HCWCC

C. Simulation of Complete System

The complete simulation model of this research work has been successfully executed and shown in Fig.9

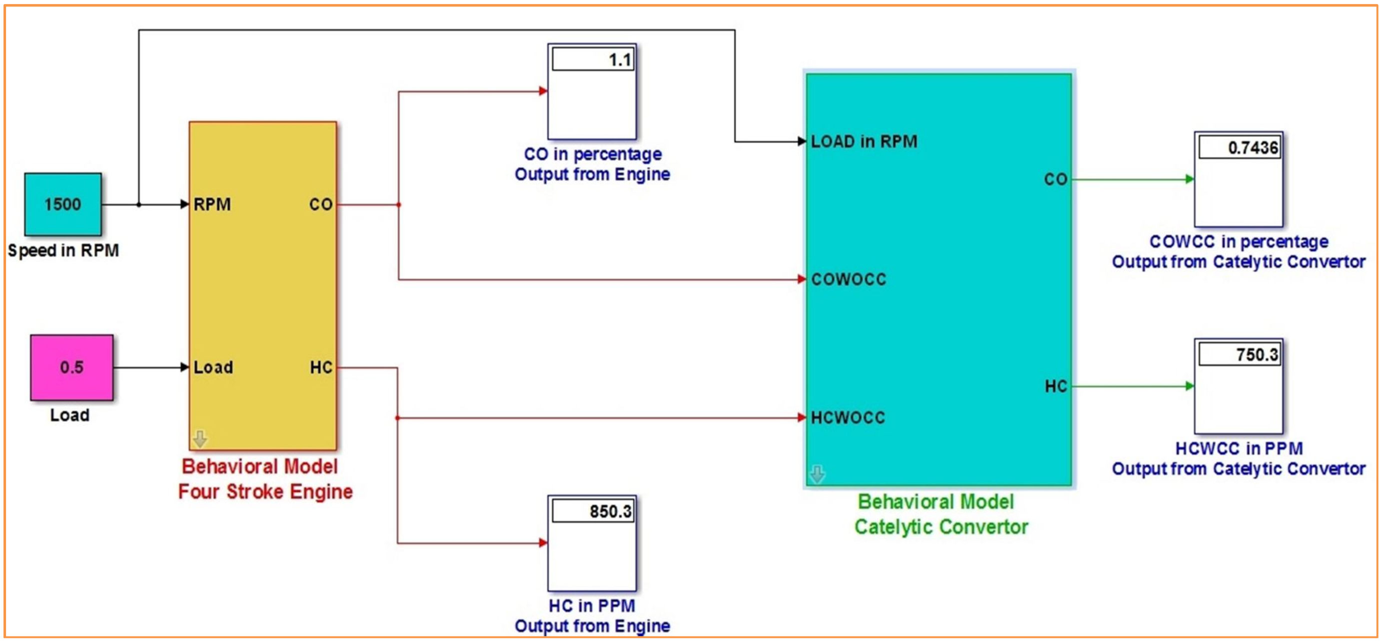

Fig.9 Complete simulation model of 4-strock engine with proposed catalytic converter

D. Analysis of Developed Simulation Model of complete Engine with Catalytic Converter

After development of simulation model for a system, it must go through testing. This subsection presents an entire statistical analysis of practically examined engine with catalytic convertor and developed simulation model. For the appropriate analysis of designed Catalytic Converter model, comparative analysis values for the Catalytic Converter are given in Table V.

TABLE V

Speed In RPM	**Load**	**CO in %**			**HC(in PPM)**		
		Practical	Simulation	Percentage Error	Practical	Simulation	Percentage Error
1500	0.25	0.9	0.8575	4.72	900	900.2	0.02
	0.50	0.75	0.7436	0.85	750	750.3	0.04
	0.75	0.73	0.7604	4.16	800	800.5	0.06
	1.0	1	1.016	1.60	1000	1001	0.10
1800	0.25	0.95	0.9501	0.01	850	850	0
	0.50	0.7	0.7004	0.05	700	700	0
	0.75	0.8	0.8004	0.06	800	800	0

	1.0	1	1	0	1000	1000	0
2000	0.25	1.06	1.075	1.42	1500	1494	0.40
	0.50	0.75	0.7592	1.23	1400	1375	1.78
	0.75	0.8	0.8114	1.42	1480	1449	2.09
	1.0	1	1.117	11.7	1650	1608	2.54
2200	0.25	1	1	0	950	974	2.52
	0.50	0.9	0.9002	0.02	800	810.4	1.30
	0.75	0.95	0.9503	0.03	900	876.1	2.65
	1.0	1.05	1.05	0	1050	1040	0.95

From Table V it is visible that the highest % error received for the CO is 11.7% and for HC is 2.65%, which are not so large and hence the advanced simulation model of complete engine with the catalytic converters is the exact replica of the 4-stroke engine with the catalytic converter, which was taken into consideration for this research.

III. RESULT AND CONCLUSION

The purpose of this research is to give a complete perspective of the application of nanotechnology to resolve potential issues of climate toxins. Many researchers put their efforts to develop the new ideas to minimizing the amount of emission. One is, the use of nano-catalyst with increasing surface area for chemical reactions. The function of the catalyst is to accelerate chemical reactions that convert poisonous emission from automobile into harmless gases. At present, the catalysts which is in use include a catalyst composed of Nobel metal such Palladium (Pd), Platinum (Pt), and Rhodium (Rh). Also a nanofiber catalyst made of manganese oxide is used that eliminates volatile organic compounds from automobile exhaust. Further techniques still remain in development. Since the Noble metal Pd, Pt, and Rh is too expensive because of their unavailability, copper metal was designated for the current experiment work. Due to its excellent catalytic behaviour, superior compatibility and surface improved Raman scattering activity, Cu nanoparticles have drawn the eye of scientists for use as vital aspect within the future nano-devices. In this research work, modeling as well as simulation has been carried out for a 4- stoke spark ignition engine with copper nano particle coated catalytic converter. It reveals that substantial reduction in emission could be achieved by Cu nano -particle coating. This article opens a gateway to research the alterations in the level of exhaust emissions because of the nano -particle coating.

Nomenclature

COWCC – CO emission with catalytic converter

COWOCC – CO emission without catalytic converter

HCWCC – HC emission with catalytic converter

HCWOCC – HC emission without catalytic converter

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