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Experimental Analysis and Modeling of Four Stroke Engine with Nanosized Copper Coated Catalytic Converter

Mukesh Thakur, Dr. N.K. Saikhedkar

Abstract - This paper basically deals with behavioural modeling and analysis of a four stroke engine including a prepared model of catalytic converter. The modeling can be very helpful to analyse the mathematical nature of the process of exhaust emission reduction through catalytic converter and analysis gives pollutant concentration. The basic idea of behavioral modeling starts from analyzing the practical behavior of four 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. AVL-422 gas analyzer was used for measurement and comparison for CO and unburnt hydrocarbon in the exhaust of the engine at various speeds and loads. In the present work, some modifications have been designed to provide more time for its oxidation and thereby to reduce harmful emissions.

Index Terms – Modeling, nano-particles, pollution control, catalytic converter

1 Introduction

THE environmental concern originated by automobile sources is due to the fact that the majority of engines employ combustion of fuels derived from crude oil as a source of energy. Burning of hydrocarbon (HC) ideally leads to the formation of water and carbon dioxide; however, due to improper combustion control and the high temperatures reached in the combustion chamber, the exhaust contains significant amounts of pollutants which need to be transformed into harmless compounds. In this paper, the control strategies and achievements in automotive pollution control using nanoparticles are discussed. Nanotechnology has assumed a very important role today mainly because of its utility and application area. No field is untouched by nanotechnology [2]. The increasing demand for a quality poduct in the market has forced the industries to move from macro to micro to nano level. Every aspect of the product is analyzed in detail [3]. 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 [4].

Additionally, visions of ‘’nano in cars’’ reach from contributions for carbon di-oxide free engines, safe driving, quiet cars, self-healing body and windscreens, up to a mood-depending choice of color and a self-forming car body. All this will meet the present society trends and customer demands for improved ecology, safety and comfort, often summarized by the term sustainability. Due to their large number, the automobiles are the major source of pollution. Various improvements in the engine design have been made to prevent the exhaust emission level but they prove to be insufficient. So, an alternative and effective approach is highly recommended [5-6]. Although a two stroke spark ignition engine is compact and light weight as compared to a four stroke engine but it produces a higher level of exhaust emissions than a four stroke spark ignition engine. Instead of chnging the complete design of the engine, the exhaust pipe can be connected to a nano-coated catalytic converter which will reduce the concenteration of exhaust emissions being emitted to the atmosphere. The properties and structure of nanomaterials are very effective in reducing the exhaust emissions primarily due to their small size and high reactivity [7-8].
Thakur and Saikhedkar presented a comprehensive review on the recent trends in application of nano-technology in automotive pollution control was covered. First, the essential aspects of environmental problems due to automotive industry were discussed and then the application of nanotechnology towards the prevention and control of these problems were suggested in detail [9]. The utility of the nano-particles towards automobile pollution control was explained in detail. The nanoparticle 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 [10]. 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 its excellent electrical conductivity and low cost nanoparticles [11]. Thakur and Saikhedkar analysed 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 nanoparticle is inversely proportional to the radius of the nanoparticle. So, on decreasing the radius, this ratio is increased leading to an increased rate of reaction and the concentration of the pollutants is decreased [12]. It involves the use of copper nano-particle which is cheaper than the platinum, palladium and rhodium nano-particles used in automobiles [13]. A microprocessor based analyzer was used for measurement of CO and HC emissions [14]. 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 by Thakur and Saikhedkar. AVL-422

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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 [15]. The conversion efficiency of a catalytic converter mounted on a vehicle with spark ignition engine was evaluated under steady operating conditions [16]. Three way converters have been compared to understand the influence of the substrate on the exhaust gas conversions for many operating conditions of vehicle (Silva and Costa, 2008). Various tests conducted on four stroke engine reveal that the copper coated engine showed a better performance than a normal engine [17]. On using copper powder, the catalytic efficiency was found to increase as the size of the powder decreased [18]. A nano catalytic converter was designed and manufactured to reduce the pollution in the environment [19]. Nano-coatings can be used to reduce surface roughness of engine components and to act as protective coating against wear of components [20]. Experiments were conducted to improve the engine performance and reduce the emissions of HC and CO from vehicle. Thakur and Saikhedkar made some alterations and modifications so as to increase the retention period of exhaust gases to provide more time for its oxidation and thereby to reduce harmful emissions. In the present work, practical behavior of four stroke engine and
designed catalytic convertor was analysed and then approximation of obtained behavior in terms of mathematical equations was done before simulating it [21]. Microchannels in stainless steel were fabricated by using solutions of various concentrations of FeCl , HCl and HNO in water as etchants. This study shows that for obtaining smooth uniform channels on stainless steel substrates, an etchant consisting of FeCl , HCl and HNO is necessary. An increase in the concentration of HCl in the etchant increases the etch rate as well as the etch factor but adversely affects the roughness. Addition of HNO is necessary to obtain smooth uniform channels. The depth and etch factor are significantly affected by the composition of etchant, operating temperature and initial width of opening. In the range of operating conditions studied, an etchant containing 10 wt% FeCl, 10 wt% HCl and 5 wt% HNO at 40 °C and an initial width of 190 μm gave the best results. With this etchant, the channels were smooth and uniform without any cavities on the edges of the channels. Initial width also plays a vital role in obtaining the final desired depth and etch factor [22]. Thakur and Saikhedkar dealt with the behavioral modeling and simulation of two 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 [23]. To control the exhaust emissions from two stroke spark ignition engine, copper nano-particles coated on wire mesh at the junction of improved design as catalytic converter, AVL-422 gas analyzer was used for measurement and comparision for CO and unburnt hydrocarbon in the exhaust of the engine at various speeds and loads. In the present work, an improved design is proposed which is more suitable for implementation along with improved performance and efficiency in reducing the exhaust emissions from two stroke spark ignition engine. [24].

2 Procedure

2.1 Copper Nano-particle coating (Drop Casting Method)

Drop casting method was used to coat copper nano-particle. Since, the method is very simple and no waste is generated. Cut section model of porous assembly as shown in figure 7 was coated with copper nano-particle in the following manner:

1. Etchening of assembly: The assembly was etched by using a method suggested before [25]. In this method, a mixture of 10 wt % $FeCl_3$, 10 wt % HCl and 5 wt % HNO_3 was used as etchant. The etchant was spread over the assembly surface and kept at stand for 15 minutes and then washed copiously with hot distilled water.
2. Drop casting of copper nanoparticles: Copper nanoparticles were coated on roughened surface using drop casting method. Similar method was adopted before for deposition of polymer nanofilm and semiconductor thin film [26]. With certain modifications in these literatures, it was incorporated in our coating method.

In this method, copper nanoparticles were suspended into an Ethylene glycol and ultrasonically blended for two hours to get a uniform suspension. Then, this suspension was dropped uniformly over porous assembly surface and dried in an oven at 200°C for two hours. After oven drying of first layer, another layer of copper nanoparticles was coated by repeating the dropping procedure and it was dried again at 200°C for two hours. As obtained copper nanoparticle coated porous assembly was then subjected to heat treatment.

3. Heat treatment of copper nanoparticle coated porous assembly: - The heat treatment was carried out by heating the copper nanoparticle coated layer at 800°C for 10 minutes and maintaining inert atmosphere in a furnace. The inert atmosphere was maintained by purging 99.9 % pure nitrogen gas before and during entire heat treatment process. As obtained copper nanoparticles coated plate were then washed with distilled water to remove any loose particle and impurity.

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This section basically deals with the behavioral modeling and simulation of four stroke engine with developed catalytic convertor. The basic idea of behavioral modeling starts from analyzing the practical behavior of four 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.

2.2 Behavioral Modeling of Four Stroke Engine

This subsection presents the complete behavioral modeling of four stroke engine. The engine specifications are as follows:
Four stroke engine (4S)
RPM: 3 HP
FUEL: PETROL
NUMBER OF CYLINDERS: SINGLE
BORE: 70 mm
STROKE LENGTH: 70 mm

These three important parameters are basically independent variable for modeling, and it is difficult to address simultaneously. However among these three on can be assume constant, so for modeling of four stroke 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, the input variables are:

1. i. Speed of engine in RPM.
2. ii. Applicable load during running condition.

Similarly the output variables for our work are

1. i. CO in percentage.
2. ii. HC in PPM.

Table 1: Practical data of load, CO and HC

Speed In RPM	Load	COWOCC in %	HCWOCC 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 four different speed conditions and each speed value consists of four different load conditions. So for proper behavioral analysis of four 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 of 1500 rpm

Table 2 shows the behavior of engine for 1500 RPM.

Speed In RPM	Load	COWOCC in %	HCWOCC in PPM
1500	0.25	1.2	1000
	0.5	1	800
	0.75	1.1	900
	1	1.3	1100

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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. Figure (1) and (2) shows plot of CO and HC with respect to Load values for fixed speed 1500 rpm.

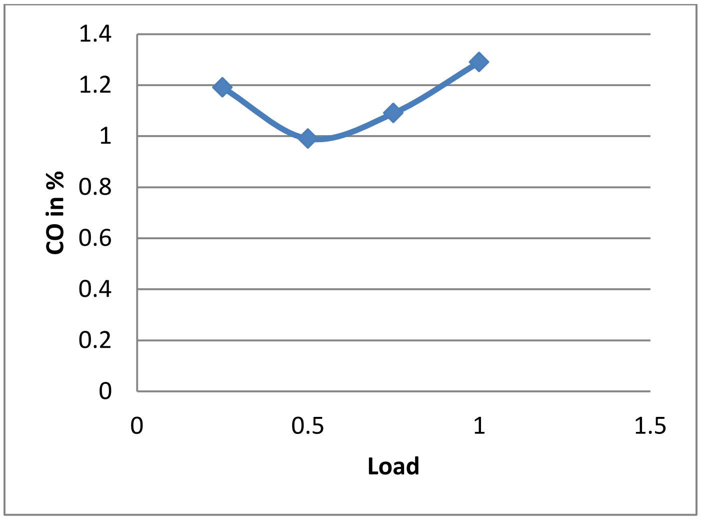

Figure 1. Load versus CO graph

Figure 2. Load versus HC graph

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

$$CO = -2.1333x^3 + 5.6\,x^2 - 4.0667x + 1.89 \quad (1)$$
$$HC = -2.1333x^3 + 5600\,x^2 - 4066x + 1698 \quad (2)$$

Step 4. 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 5. Development of complete model including all four models

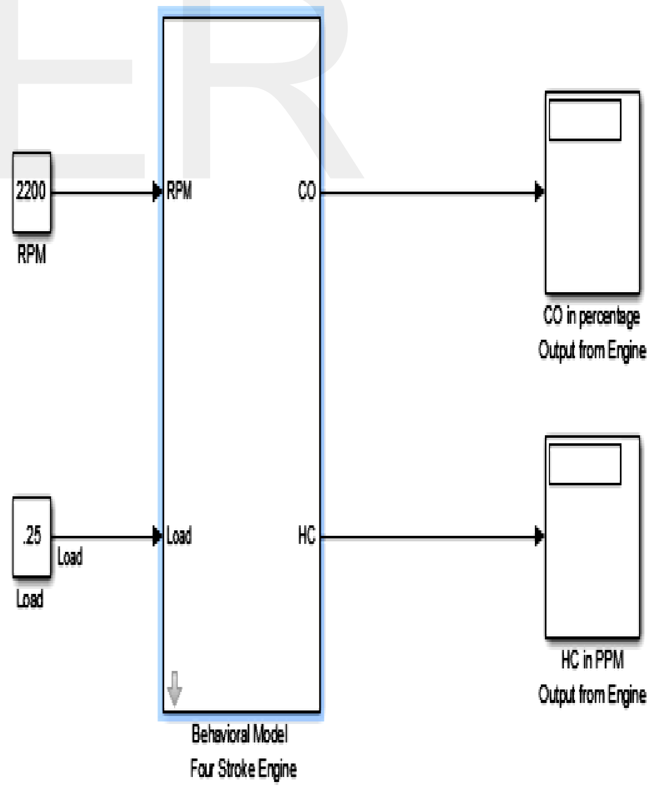

Figure 3. Complete model of Four stroke engine

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2.3 Behavioral Modeling of Catalytic Converter

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.

Step1. Behavior analysis: table 3 and table 4, shows the practical behavior of physically designed catalytic convertor. Figure 5 and 6 shows corresponding plots.

Table 3. Comparision of COWOCC and COWCC

COWOCC (%)	COWCC (%)
0.7	0.3
0.8	0.4
0.9	0.35
1	0.45
1.1	0.5
1.2	0.6
1.3	0.65
1.4	0.7

Table 4. Comparision of HCWOCC and HCWCC

HCWOCC (PPM)	HCWCC (PPM)
700	500
750	530
800	550
850	600
900	650
950	750
1000	650
1100	750
1150	850

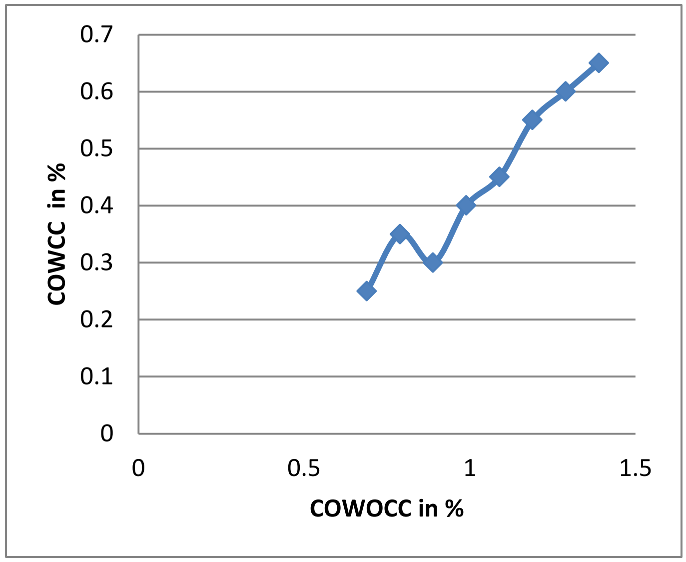

Figure 5. COWOCC versus COWCC graph

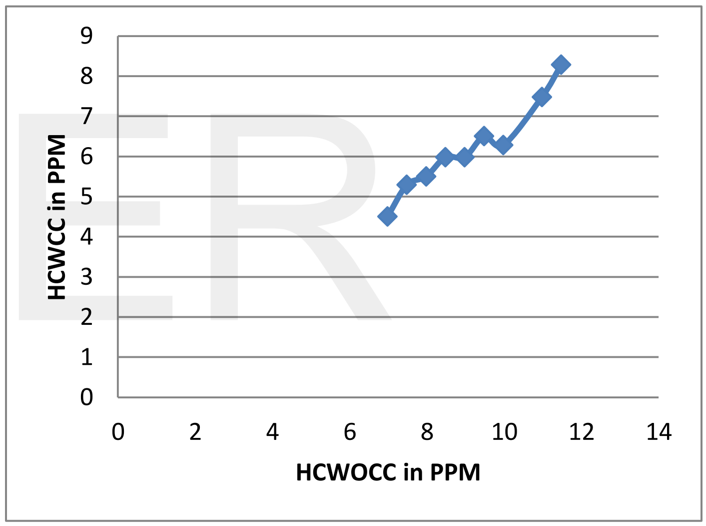

Figure 6. HCWOCC versus HCWCC graph

Step 2. Generation Of mathematical equations: with the help of figure (5) and (6) obtained equations for reduced concemteration of CO and HC are:

$$COWCC = 65.705CO^5 - 350.66CO^4 + 736.8CO^3 - 760.84\,CO^2 + 386.2CO - 76.826 \quad (9)$$

$$HCWCC = 0.0114HC^4 - 0.3188HC^3 + 2.981\,HC^2 - 9.1532HC + 4.5 \quad (10)$$

2.4 Analysis of Engine Alone

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

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Speed In RPM	Load	CO in %			HC in PPM		
		Practical	Simulation	Percentage Error in %	Practical	Simulation	Percentage Error in %
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

Table 5. Comparitive evaluated values

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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.

2.5 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.

Speed In RPM	Load	COWCC in %			HCWCC in PPM		
		Practical	Simulation	Percentage Error in %	Practical	Simulation	Percentage Error in %
1500	0.25	0.6	0.56	6.45	700	639.8	8.60
	0.5	0.42	0.38	9.76	600	554.64	7.56
	0.75	0.52	0.48	8.52	650	599.67	7.74
	1	0.62	0.60	2.90	750	713.67	4.84
1800	0.25	0.41	0.38	7.56	600	599.67	0.06
	0.5	0.4	0.39	2.50	550	512.569	6.81
	0.75	0.48	0.44	8.33	580	554.64	4.37
	1	0.52	0.49	5.77	630	629.8	0.03
2000	0.25	0.4	0.38	5.00	550	549.64	0.07
	0.5	0.3	0.27	8.53	500	453.43	9.31
	0.75	0.35	0.33	5.46	530	512.569	3.29
	1	0.45	0.41	8.89	600	582.239	2.96
2200	0.25	0.65	0.60	7.38	800	726.67	9.17
	0.5	0.5	0.48	4.86	650	592.239	8.89
	0.75	0.6	0.56	6.45	715	646.949	9.52
	1	0.7	0.67	4.49	850	804.689	5.33

Table 6. Comparision performance table

From table 6, it is clearly observable, that the maximum percentage error obtained for CO is 9.76% and for HC is 9.52%, 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.

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3 RESULTS AND DISCUSSION

The majority of the environmental pollution is due to the two-wheeler automobiles due to their large number. Many environmentalists are interested in using precious metal nanoparticles as exhaust filters, both for vehicles and for power plants. In vehicles, particularly those that are diesel-powered, the nanoparticles have been shown to be effective in oxidizing harmful hydrocarbon compounds that are released in their exhaust, thereby reducing their negative impact on the atmosphere. Platinum, gold and palladium are the most commonly used when it comes to diesel filtering. There are two methods of control of pollution namely, pre-pollution control and post pollution control. This paper is based on the post pollution control method in two-wheeler automobiles using nano-particle as a catalyst. 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.

4 CONCLUSION

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 which is cheaper than the platinum, palladium and rhodium nano-particles used in automobiles. To achieve this objective, an innovative design of catalytic converter for two-wheeler automobiles is proposed using nano-particle as a catalyst. The converter uses two different types of catalyst, reduction and oxidation catalyst. 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. This paper basically deals with modeling 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.

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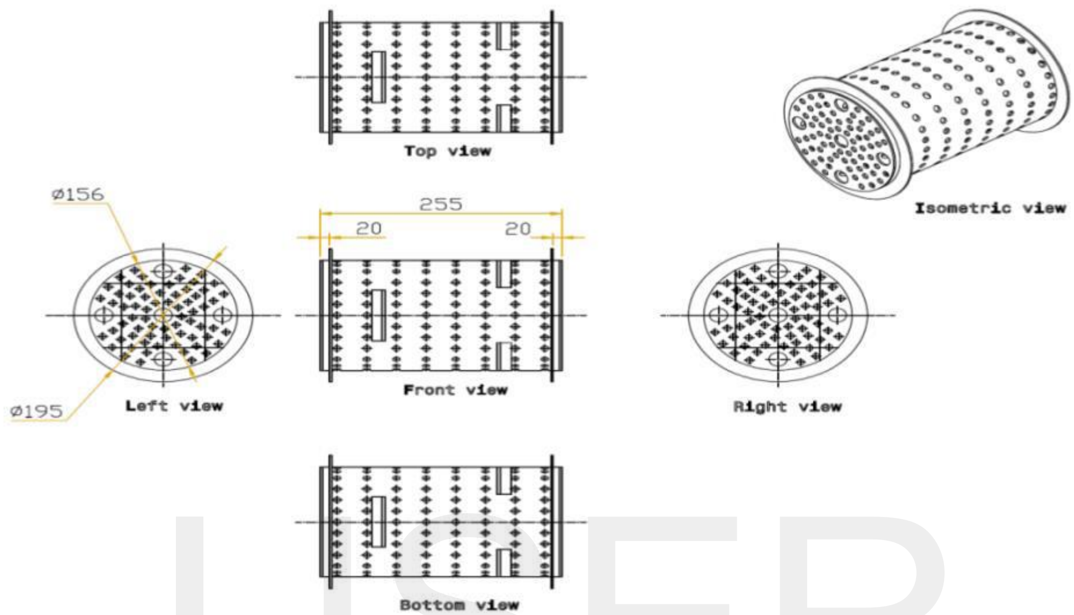

Figure 7 Cut section model of Porous Assembly

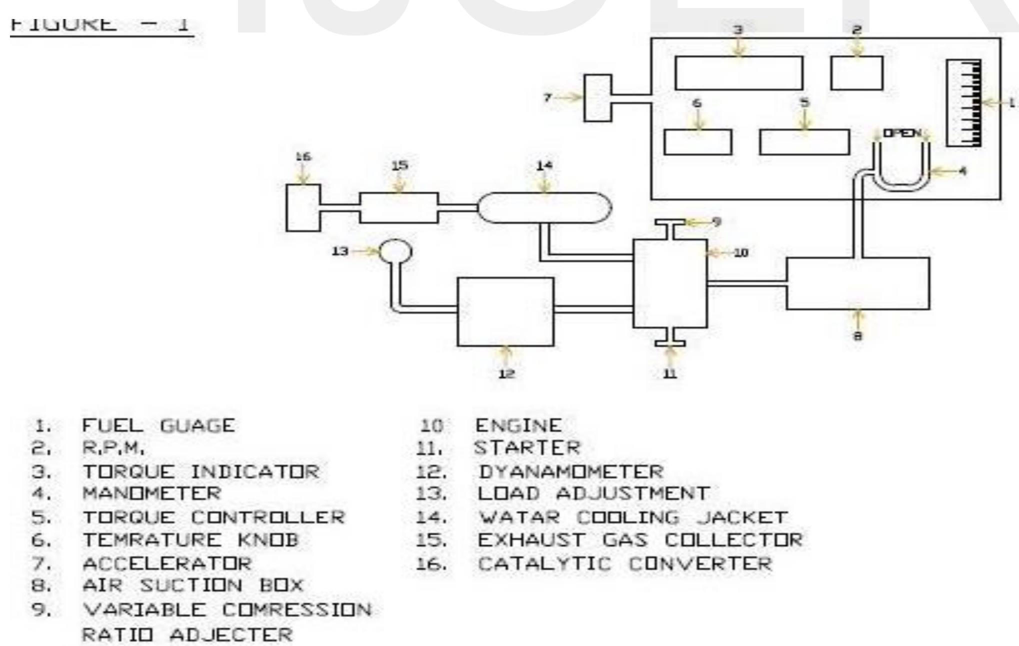

Figure 8 Complete arrangement

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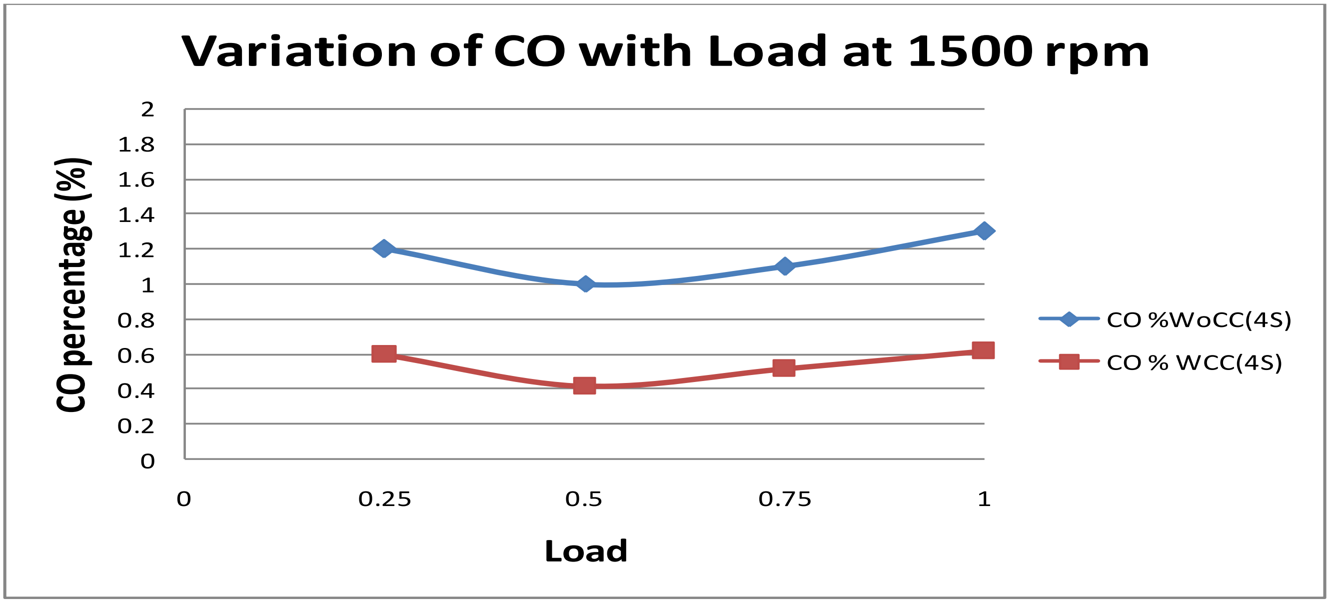

Figure 9 Variation of CO with load at 1500 rpm

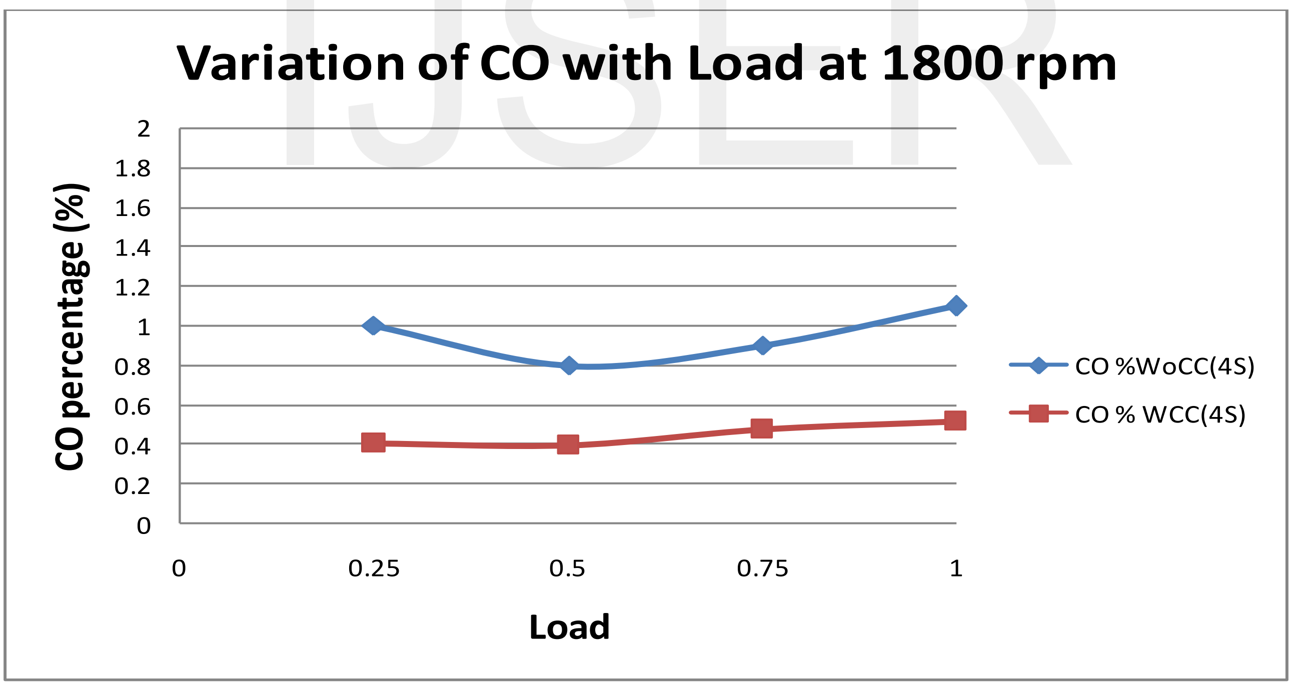

Figure 10 Variation of CO with load at 1800 rpm

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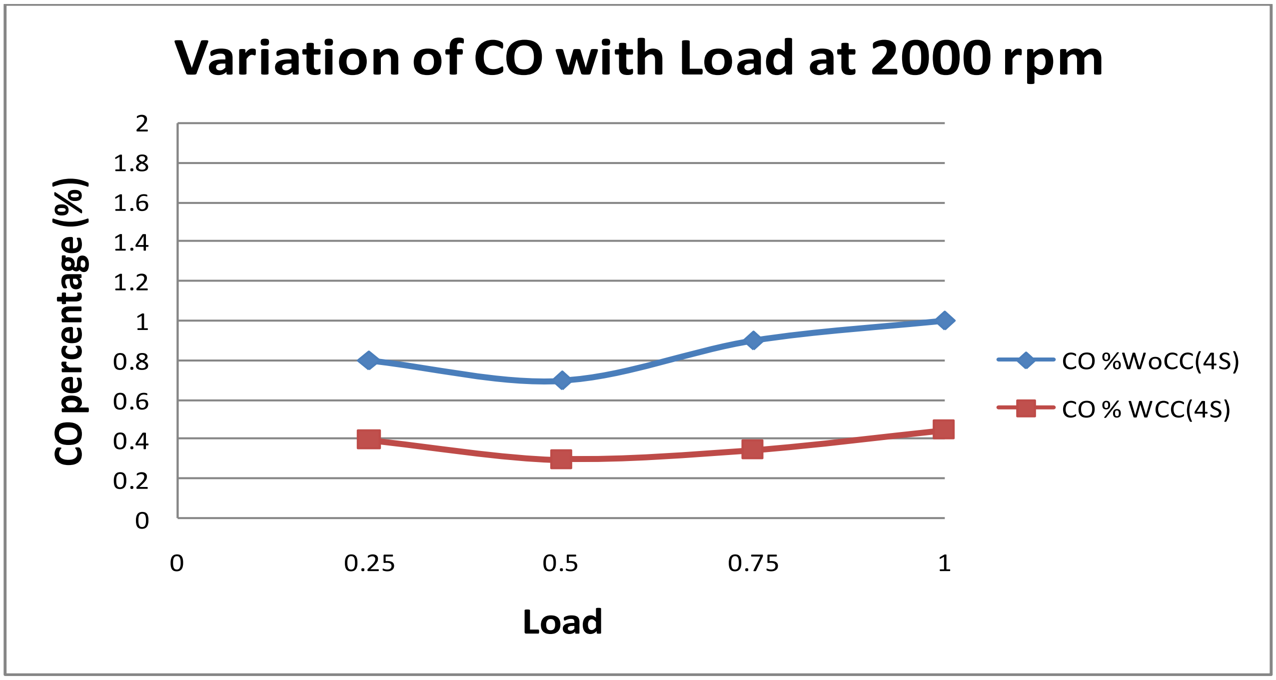

Figure 11 Variation of CO with load at 2000 rpm

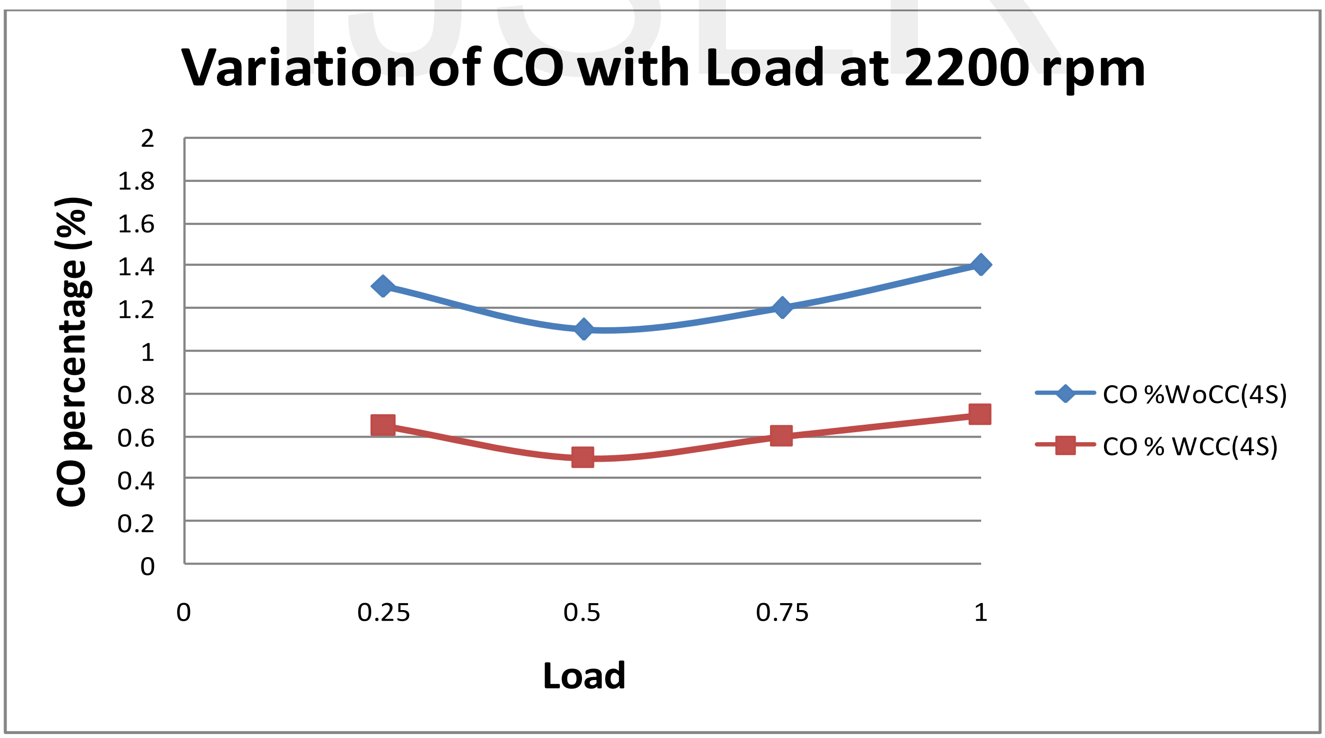

Figure 12 Variation of CO with load at 2200 rpm

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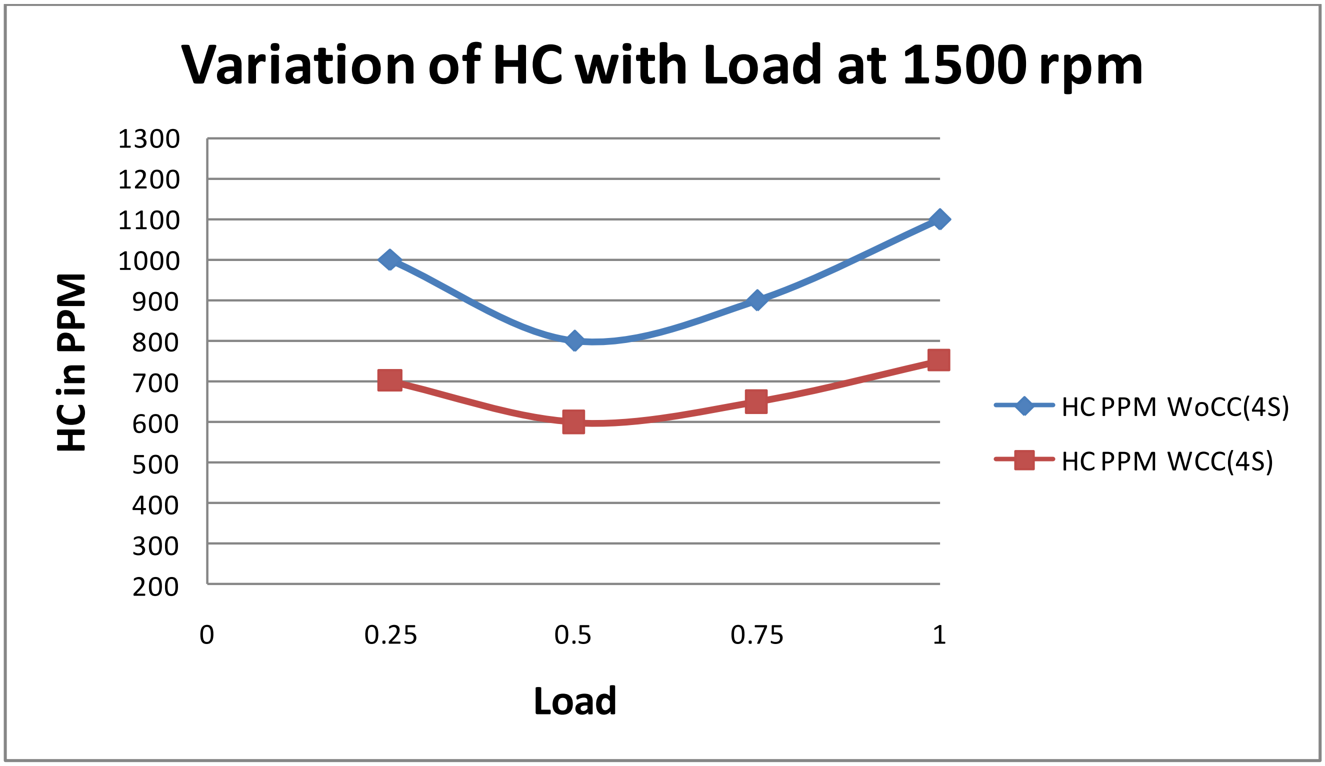

Figure 13 Variation of HC with load at 1500 rpm

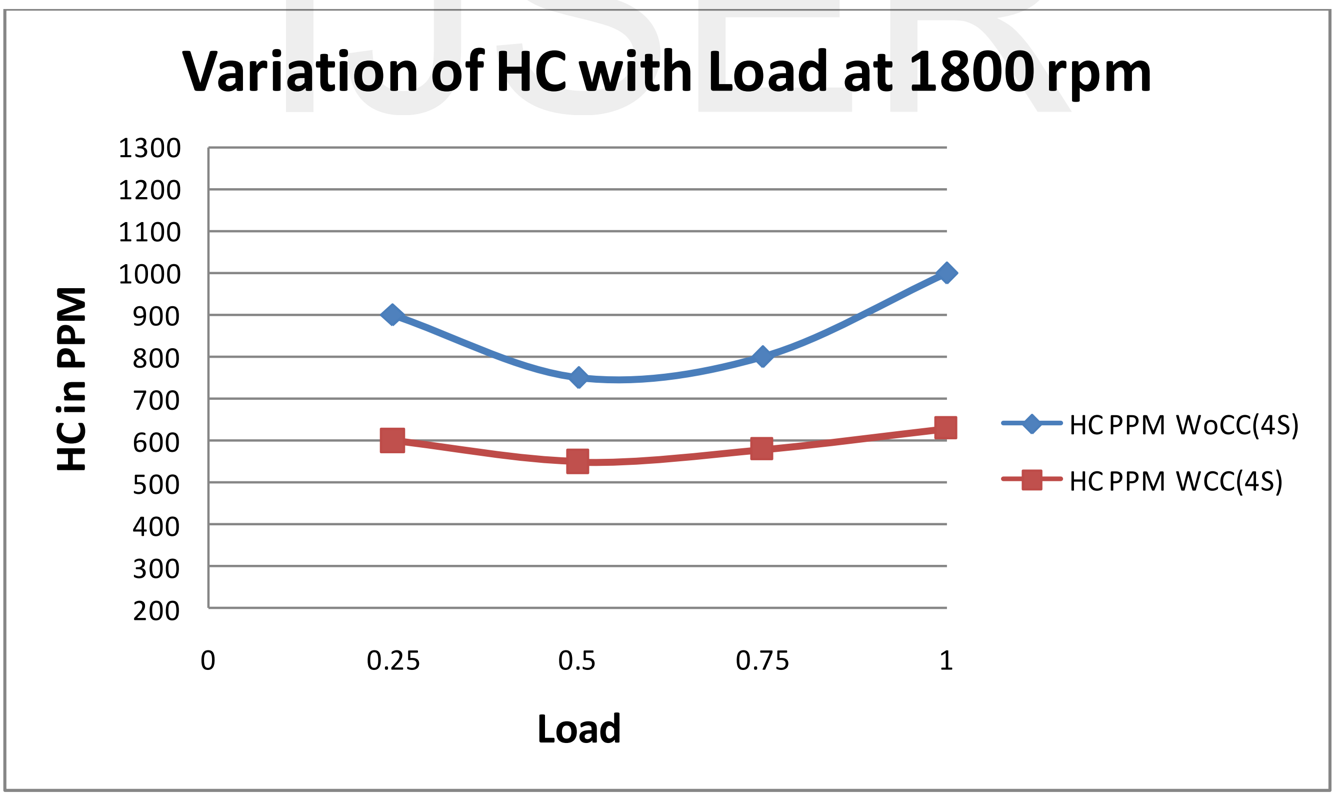

Figure 14 Variation of HC with load at 1800 rpm

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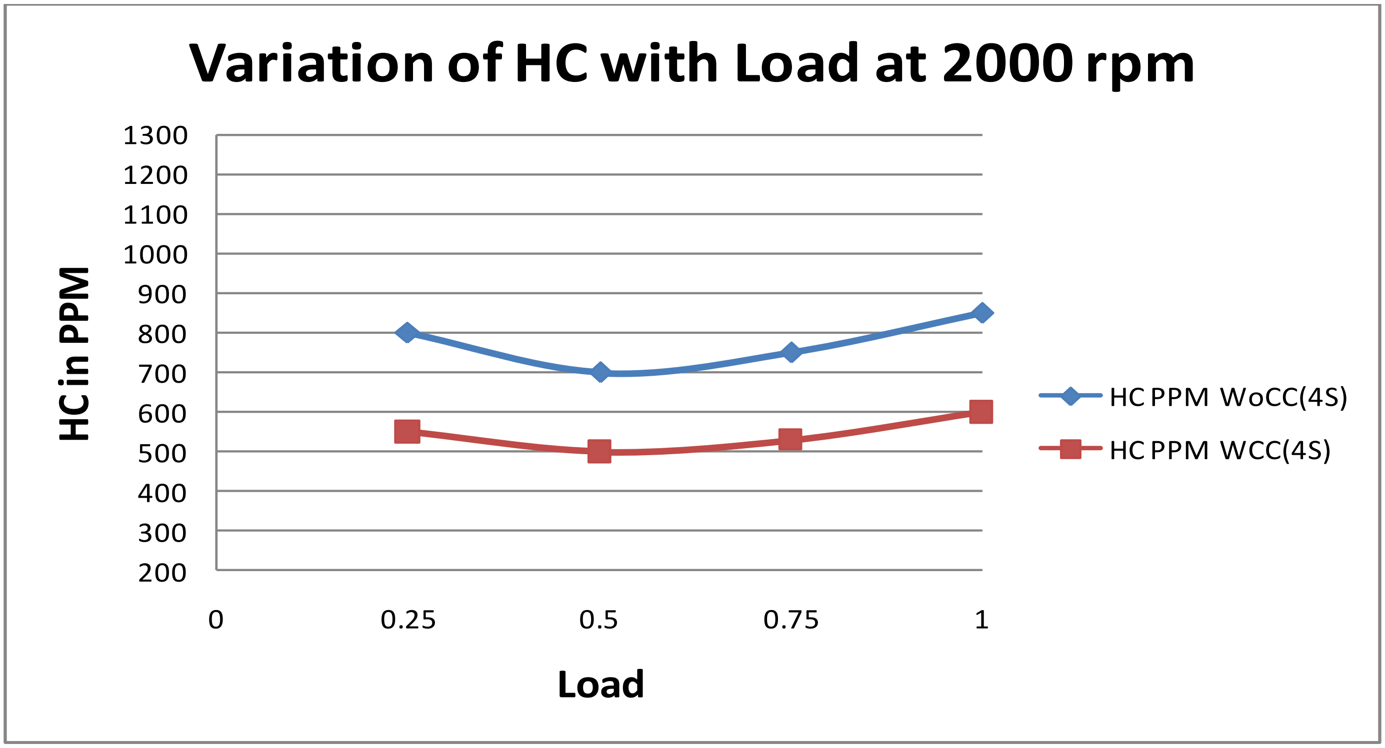

Figure 15 Variation of HC with load at 2000 rpm

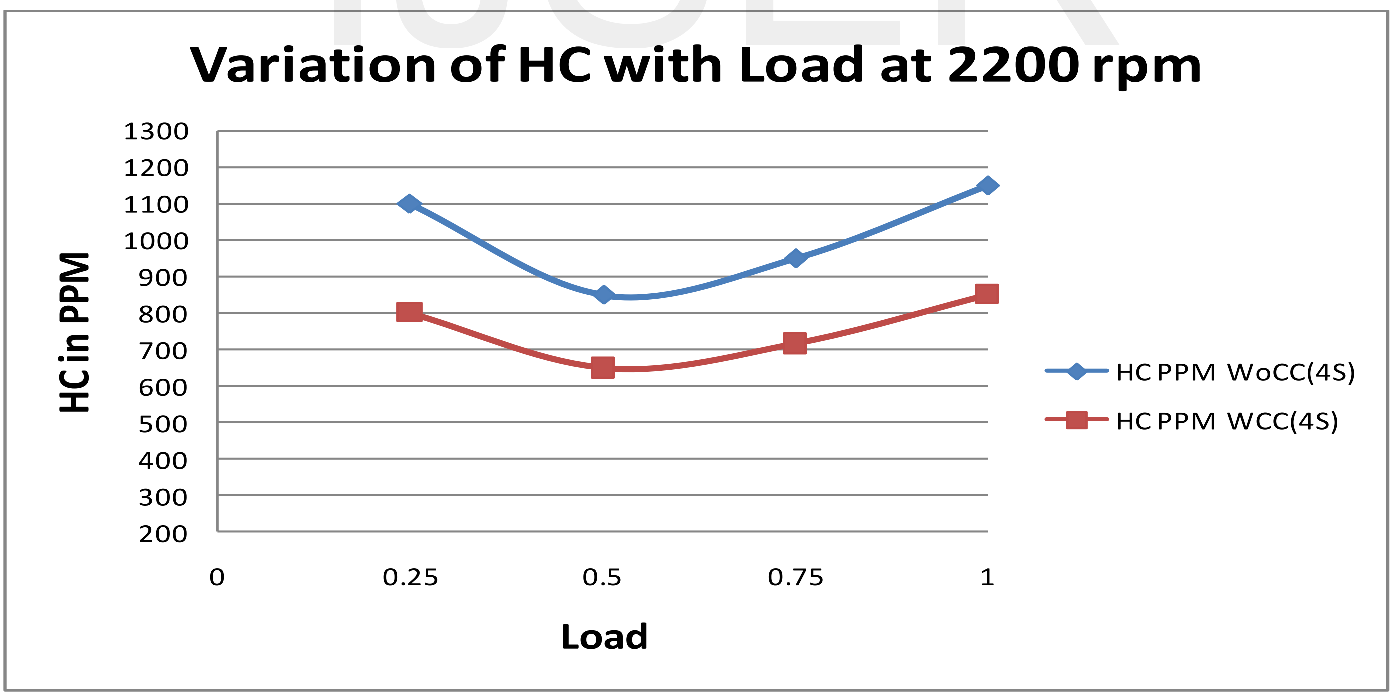

Figure 16 Variation of HC with load at 2200 rpm