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Investigation of Exhaust Emission Characteristics of Gasoline Fuelled Motorcycles Using Post-Combustor

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Abstract

Exhaust emissions from internal combustion engines are due to incomplete combustion of fuel in the combustion chamber. This incomplete combustion results in a significant increase in the amount of Carbon Mono-oxide and hydrocarbons in the exhaust stream. Several techniques such as catalytic converters, Exhaust gas recirculation, Selective catalytic reduction and etc are used to reduce the emissions. This study proposes a new approach to minimize the amount of pollutant emitted by internal combustion engines using a device known as post-combustor which consist of heating elements known as glow plugs that degrade carbon mono-oxide and hydrocarbons using a high temperature. This post-combustor can be retrofitted in any existing vehicle's exhaust line without any alterations. Moreover, it is designed such that there is no increase in fuel consumption; it only utilizes electrical energy from the vehicle's electrical system. Exhaust emission characteristics were measured using portable emission tester and exhaust gas temperature using a thermometer, it was found that there was an average reduction of 16.35% in the amount of carbon monoxide and 3.8% average reduction in the amount of hydrocarbons whereas there was an average increase of 9.29% in the amount of oxides of nitrogen and there was a slight increase in exhaust gas temperature.

Keywords: Emissions; Exhaust pipe; Glow plug; Pollution; Post-combustor.

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1. Introduction

Researches show a strong connection between emissions from the internal combustion engines and smog which are the reason for severe respiratory diseases in urban cities.[1,2,3] Hazardous chemicals emitted from vehicles result in progressive change in atmospheric temperature and this emission comprises pollutants such as carbon monoxide, Sulphur-dioxide, hydrocarbons, and oxides of nitrogen having different compositions and reaction properties.[4]Strict emission norms were laid and became the base for advanced technologies for reduction of exhaust emissions such as the adoption of biodiesel, [5] non-thermal plasma system,[6,7] selective catalyst reduction,[8] diesel particulate filter, [9,10] split injection,[11] high-pressure fuel injection, [12] partially premixed combustion.[13] However, the challenge of exhaust emission due to incomplete combustion remains which is caused due to low combustion temperature and less air intake. Gao J. in his study demonstrated that more than 50% of exhaust emissions in a driving cycle are during cold startup, which means if the engine does not attain a certain temperature the exhaust emission is higher. [14] Heavy vehicles such as trucks used by municipal corporations run for short distances and may not achieve the minimum exhaust temperature required to cut emissions through catalytic converters. Recent studies have demonstrated that hybrid vehicles also have 30% more NO_X emissions. [15] The manufacturers of internal combustion engines have to tackle a major challenge to meet standards of stringent emission of particulate matter, carbon monoxide and unburned hydrocarbon which are the by-products of increasing performance of engines.

The increasing emission from private and commercial vehicles in developing cities have been reported by policymakers, researchers, and scientists to be a major concern for air quality. Air pollution is one of the major concerns of urban cities where a majority of the population is exposed to poor air quality [16].

The rapid urbanization of the world has resulted in a tremendous increase in motor vehicles. Vehicles are now the main source of pollution in the urban world. [17]

The engineers and researchers have taken several measures for the improvement of air quality in cities these include the improvement of fuel quality, formation of necessary legislation and enforcement of vehicle emission standards, improved traffic planning and etc.

Marc J. Rogoff and Francis screve [18] in their text have clearly stated that products of incomplete combustion are a major concern because carbon monoxide and organic matter such as dioxin are formed even with an excess of air.

Many researchers have reported that in addition to incomplete combustion that is manifested as cold smoke on startup, a misfire can also occur at high-speed light load conditions. The problem is not only associated with high-speed indirect injection engines but also occurs in many high-speed direct injection engines also. [19]

Exhaust emission measurement is done by many researchers using ethanol in CI engine which reduces the NO_X and particulate matter but carbon monoxide and hydrocarbon are higher in this combination. [20]

Many researchers have reported that even after using Diesel exhaust fluid (DEF), it led to a decrease in fuel economy and an increase in $NO_X$and CO emissions. [21]

Much literature and research work from the researchers clearly state that a vast amount of energy, time, money, and capital is being utilized for reducing exhaust emissions. [22-26]

Further, only NO_Xcan be reduced using various methods to some extent and in our research, we have fabricated a post-combustor using glow plugs that burn the carbon monoxide and unburned hydrocarbons at 1600℃.

Thus, the purpose of the study is to investigate the exhaust emission characteristics of motorcycle engines after installing a post-combustor. The post-combustor is equipped with glow plugs or heater plugs which are used in diesel engines as preheater, it consumes power from the vehicle's electrical system, and it is universal that is it can be installed in two-wheelers, three-wheelers and four-wheelers running on gasoline diesel CNG and LPG.

Since carbon and carbon monoxide burns in the presence of oxygen to form carbon dioxide according to the following reaction:

$$C + O_2 \rightarrow CO_2 \quad (1)$$
$$2CO + O_2 \rightarrow 2CO_2 \quad (2)$$

Hence after burners or the post combustor will significantly reduce the amount of carbon monoxide present in the exhaust gas. [27]

Similarly, unburned hydrocarbon burns in the presence of oxygen to form carbon dioxide and water [28] according to the following reaction:

$$HC + O_2 \rightarrow CO_2 + H_2O \quad (4)$$

And nitric oxide decomposes to nitrogen oxide according to the following reaction:

$$N_2 + O_2 \rightarrow NO \quad (5)$$
$$NO + ½O_2 \rightarrow NO_2 \quad (6)$$

As a result of which we see a rise in amount of oxides of nitrogen as nitric oxide and nitrogen dioxide constitutes to form oxides of nitrogen.

In our test study, we have fabricated and tested the post combustor on different gasoline engines, further design changes can be done by using a porous heating element for better performance.

2. Experimental methods

2.1 Engine specifications

For the precise and correct analysis of the effect of installing a post- combustor tests were conducted on 4 different types of engines whose specifications are listed in Table 1. Motorcycle gasoline engines were used as they are not equipped with any catalytic converters or exhaust gas recirculation device.

All the test subject engines are derived from different companies and are of different capacities, this will help to analyze the effectiveness of post-combustor on different sizes and types of engines.

2.2 Experimental setup

The post-combustor is placed on the exhaust line and the exhaust gas is treated at a high temperature before releasing it into the atmosphere.

The labeled diagrams of the post-combustor and its position are shown in Figures 1 and 2.

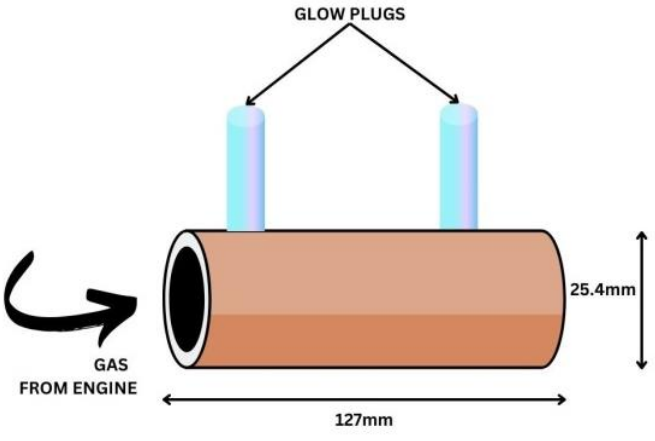

Fig.1. Diagram of post combustor

Table 1. Engine specifications

Motorcycle	Make	Cylinders	Displacement	Stroke length	Bore diameter	Fuel supply	Year	Emission stand-ards
Motorcycle 1	Bajaj	1	150cc	60.7mm	56mmm	Carbureted	2018	Bharat stage 4
Motorcycle 2	Hero motocorp	1	124.7cc	58mm	52mm	Carbureted	2017	Bharat stage 4
Motorcycle 3	Hero motocorp	1	110.95cc	49.5mm	53mm	Carbureted	2018	Bharat stage 4
Motorcycle 4	Hero motocorp	1	97cc	49.5mm	50mm	Carbureted	2018	Bharat stage 4

Glow plugs are heating elements that are installed in diesel engines to produce extra heat while cranking the engine, the same glow plug is used in the post-combustor which attains a temperature somewhere around 1600℃ just by utilizing 12-volt electrical supply from the Motorcycle's alternator or the battery.

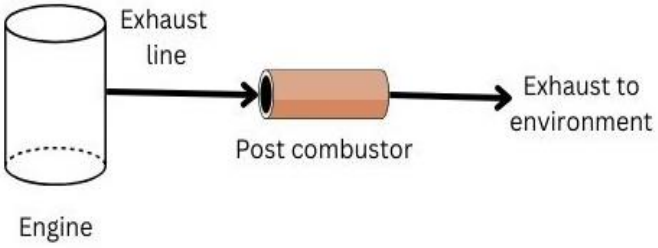

Fig.2. Position of post combustor

A description of the post-combustor is mentioned in Table 2.

Table 2. Specification of post combustor

Material of post-combustor	Aluminium
Length of post-combustor	127mm
Diameter of post-combustor	25.4mm
Shape of post-combustor	Hollow cylindrical
Number of glow plug	2
Voltage rating of glow plug	12-Volts
Ampere rating of glow plug	3 Amp
Resistance of glow plug	4 Ohm
Length of glow plug	30mm
Diameter of glow plug	7mm

The ambient temperature during the test conducted was 24ºC, humidity 36%, and pressure 1012 mbar.

The main measuring instrument used was a PET (portable emission tester) whose specifications are mentioned in Table 3and Table 4.

Actual image of apparatus (Namtech-GA-954) is mentioned in Figure 3.

Fig.3. Namtech-GA-954

The actual image of the post-combustor is shown in Figure 4 which is installed on different Motorcycles which are mentioned in table 1.

PETs are equipment used by pollution test centers authorized by the government of India for providing pollution under-control certificates. The principles used for CO sensors (and other types of gas) are infrared gas sensors and chemical gas sensors. Carbon monoxide sensors are used to assess the CO.

And for the measurement of exhaust gas temperature digital thermometer was used. Which uses thermocouple for temperature measurement in degree Celsius.

Fig. 4. Positioning of post combustor

Table 3. Operating condition for PET

Temperature	+5ºC to +50ºC
Relative humidity	5-95%
Atmospheric pressure	70kPa-106kPa

Table 4. Measuring range of PET

HC(Hexane equivalent)	0 ppm-10,000 ppm
CO	0%-10%
NO_x	0 ppm- 5000 ppm

2.3 Experimental procedure:

The experiment parameter, unburned hydrocarbons, carbon monoxide, and nitrogen oxides are measured using the above test equipment twice, once without the post-combustor and once with the post-combustor.

Test conditions were designed to investigate the effect of installing a post-combustor on emission characteristics.

The test was conducted on no load condition at a constant speed of 1200 RPM as exhaust emission is maximum at initial temperature and at lower RPM. Consistency and repeatability of engine operating conditions were ensured.

Each test specimen engine was first run for 30 seconds to ensure stable temperature then the exhaust gas sensor was installed after the post-combustor and the test parameters were noted, the same was repeated for every test specimen engine.

3. Results

The test results of different engine specimens are mentioned in Tables 5 when no post-combustor was installed.

Table 5. Emission characteristics when Post combustor was not installed.

Motorcycle	Carbon monoxide	Oxides of nitrogen	Hydrocarbons	Temperature
Motorcycle 1	2.8%	235ppm	585ppm	75 ℃
Motorcycle 2	1.7%	137ppm	502ppm	78 ℃
Motorcycle 3	1.5%	113ppm	564ppm	70 ℃.
Motorcycle 4	1.5%	113ppm	564ppm	70 ℃

The prime objective of the result is to investigate emission parameters affected by the use of post-combustor. In which the values of carbon monoxide, oxides of nitrogen, and hydrocarbons were mainly measured. Oxides of nitrogen and hydrocarbons are measured in parts per million whereas Carbon monoxide is measured in percentage.

Exhaust gas temperature was also a major concern and hence it was also measured in degree Celsius.

After the installation of the post-combustor following data was interpreted as mentioned in Table 6.

Table 6. Emission characteristics when post combustor was installed

Motorcycle	Carbon monoxide	Oxides of nitrogen	Hydrocarbons	Temp.
Motorcycle 1	2.5%	270ppm	570ppm	87 ℃
Motorcycle 2	1.46%	148ppm	481ppm	91 ℃
Motorcycle 3	1.2%	122ppm	540ppm	88 ℃
Motorcycle 4	1.2%	122ppm	540ppm	77 ℃

The effect of installing a post-combustor on emission characteristics is studied using different test engines which are derived from different manufacturers and are of different sizes.

The results are summarized below:

We noticed a reduction in the amount of Carbon Monoxide present in the exhaust emissions, as it gets reduced to Carbon dioxide in the presence of heat. In Motorcycle 1 which is derived from Bajaj Pulsar 150, we noticed a reduction in CO level from 2.8% to 2.5%. Similarly, In Motorcycle 2 which is derived from Hero Motocorp Super Splendor, we noticed a reduction from 1.7% to 1.46%. In Motorcycle 3 which is derived from Hero Motocorp Passion Pro, we noticed a reduction from 1.5% to 1.2%. For Motorcycle 4, which is derived from Hero MotocorpHf- Delux, we noticed a reduction from 1.5% to 1.2%. A comparative graphical representation is shown in Figure 5.

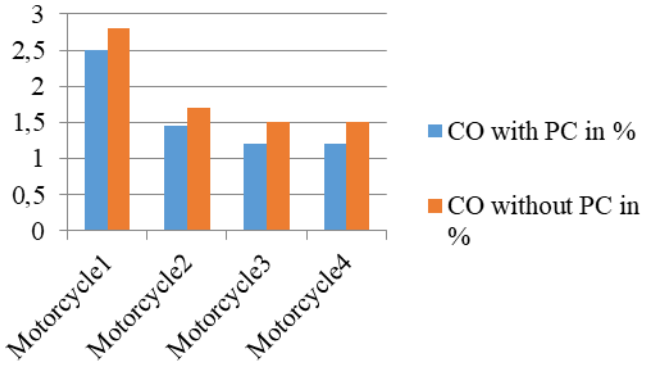

Fig. 4. Comparison of CO emission with and without post combustor.

We noticed a reduction in the amount of hydrocarbons present in the exhaust emissions, as it gets reduced to water and carbon dioxide in the presence of heat. In Motorcycle 1 which is derived from Bajaj Pulsar 150, we noticed a reduction in HC level from 585ppm to 570 ppm. Similarly, for Motorcycle 2, which is derived from Hero Motocorp Super Splendor, we noticed a reduction from 502ppm to 481ppm. For Motorcycle 3, which is derived from Hero Motocorp Passion Pro, we noticed a reduction from 564ppm to 540ppm. For Motorcycle 4, which is derived from Hero MotocorpHf- Delux, we noticed a reduction from 564ppm to 540ppm. A comparative graphical representation is shown in Figure 6.

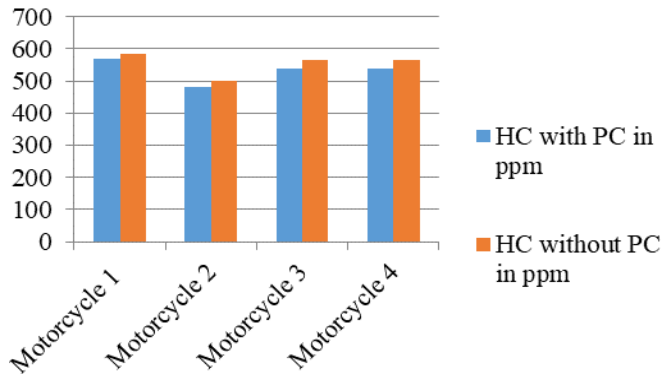

Fig 5. Comparison of HC emission with and without post combustor

We noticed an increase in the amount of oxides of nitrogen present in the exhaust emissions. In Motorcycle 1 which is derived from Bajaj Pulsar 150, we noticed an increase in NO_x level from 235ppm to 270ppm. Similarly, for Motorcycle 2, which is derived from Hero Motocorp Super Splendor, we noticed an increase from 137ppm to 148ppm. For Motorcycle 3, which is derived from Hero Motocorp Passion Pro, we noticed an increase from 113ppm to 122ppm. For Motorcycle 4, which is derived from Hero MotocorpHf- Delux, we noticed an increase from 113ppm to 122ppm. A comparative graphical representation is shown in Figure 7.

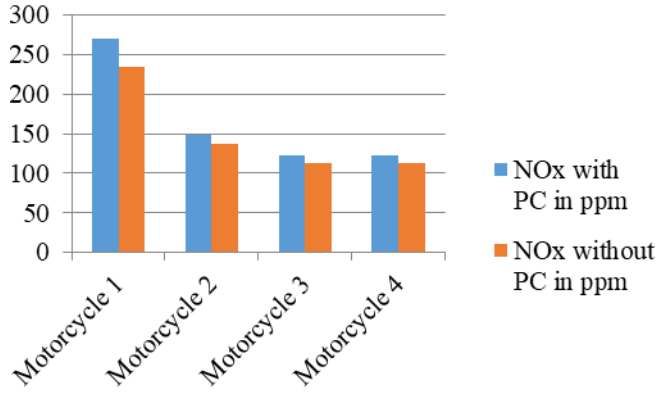

Fig. 7. Comparison of NOx emission with and without post combustor.

We noticed an increase in exhaust gas temperature after the installation of the post-combustor, which is due to the extra heat added by the glow plugs. For Motorcycle 1, which is derived from Bajaj Pulsar 150, we noticed an increase in temperature level from 75℃ to 87℃. Similarly, for Motorcycle 2, which is derived from Hero Motocorp Super Splendor, we noticed an increase 78 ℃ to 91 ℃. For Motorcycle 3, which is derived from Hero Motocorp Passion Pro, we noticed an increase from 75 ℃ to 88 ℃. For Motorcycle 4, which is derived from Hero MotocorpHf- Delux, we noticed an increase from 70 ℃ to 77 ℃. A comparative graphical representation is shown in Figure 8.

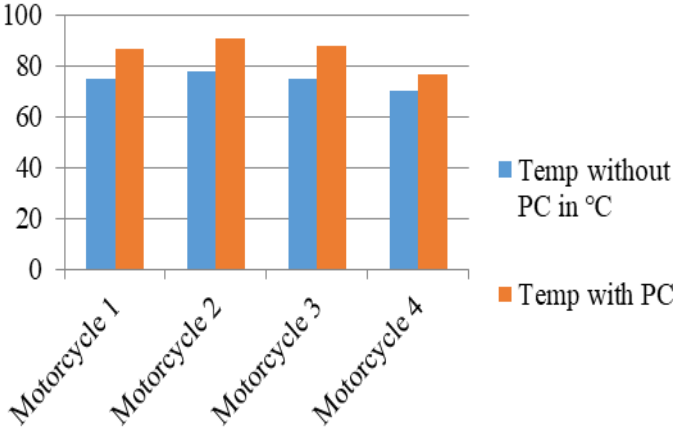

Fig. 8. Comparison of exhaust gas temperature with and without post combustor.

Hence, It can be concluded that Post-combustor is effective in reducing the Carbon Monoxide and Hydrocarbon using thermal energy to reduce the pollutants in other forms. And hence it can be applied to existing Motorcycles to reduce pollution that occurs due to incomplete combustion and at cold startups.

The post-combustor works efficiently on different sizes of engines and with different numbers of cylinders and can be retrofitted to any Motorcycle's exhaust pipe after the catalytic converter. Moreover, the cost of production of post-combustor is also very less. There is a slight increase in exhaust gas temperature which can be neglected.

4. Conclusions

Various technologies such as catalytic converters, Exhaust gas recirculation, Selective catalytic reduction and etc are already being used for reduction of exhaust emission in four wheelers and heavy motor Motorcycles. Motorcycles are equipped with mufflers to reduce the noise pollution and no arrangements are done for reduction of emissions. In such case post combustor or an after burner can be used to reduce amount of carbon monoxide and hydrocarbons as it does not increase any fuel consumption or reduce the performance of engines and hence can be installed in smaller engines also.

We have seen a reduction of a maximum reduction of 20% of carbon monoxide emission in Motorcycle 3, a maximum of 4.38% reduction in hydrocarbon emission but an increase of 14.89% in oxide of nitrogen when post combustor was installed in Motorcycle 1. Exhaust gas temperature also increases significantly with an average of 17.07%.

In order to further reduce the emission a porous heating element can be used or recirculation can be equipped as to give maximum time and surface area for heating the exhaust gases. And to reduce oxides of nitrogen water injection technique can be applied which will also reduce the exhaust gas temperature.

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Nomenclature:

NO_X	: Oxides of nitrogen
CO	: Carbon monoxide
DEF	: Diesel exhausts fluid
CNG	: Compressed Natural Gas
LPG	: Liquid petroleum gas
HC	: Hydrocarbons
NO	: Nitric oxide
PET	: Portable emission tester
PPM	: Parts per million
RPM	: Revolution per minute
EGR	: Exhaust gas recirculation
SCR	: Selective catalyst reduction

Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

CRediT Author Statement

Arpit Kumar Singh: Conceptualization, Writing-original draft and Data curation.
Mohammad Rehan: Conceptualization and Supervision.
Sandeep Kumar Singh: Formal analysis and Validation.

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