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Experimental Investigation into the Effects of Four-Way Catalytic Converter on Four Stroke Diesel Engine Emissions

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Abstract- **The carbon dioxide level in the atmosphere is increasing day by day. The emission from vehicle exhaust is one of the main sources of this pollution. As a greenhouse gas, carbon dioxide emissions from vehicles lead to environmental pollution and global warming. Since CO_2 emissions have an impact on global climate change, remedies should be introduced to reduce pollution. The carbon capture and storage is the mostly proposed method for controlling carbon dioxide emission. This can be achieved with the use of CO_2 adsorbents. The existing catalytic converters in vehicles fail to control carbon dioxide emission to atmosphere. Under no load conditions, the CO_2 emission is increased by 234% while using three-way catalytic converter. This is because of the catalytic effect. The reactions that take place inside the catalytic converter leads in the excess emission of carbon dioxide to atmosphere. The scope of currently available CO_2 adsorbents and their application in four-way catalytic converter are brought out here. The activated carbon and molsieve 13 X are used as CO_2 adsorbents. Both the adsorbents are used in this work and analyzed. When activated carbon is used there is a decrease in CO_2 emission by 86.91% and for molsieve 13 x, it is 69.16%, under no load condition. Thus it is found that activated carbon is 17.75% more effective than molsieve 13 x in reducing CO_2 emission. The adsorption capacity of adsorbents decreases with respect to the increase in temperature. Four-way catalytic converter is effective in reducing carbon dioxide emissions by the adsorption technique. So three-way catalytic converters can be superseded by four-way catalytic converters in future.**

Keywords – Activated Carbon, Adsorption, Four-way catalytic converter. Molsieve 13 X.

I. INTRODUCTION

The catalytic converter was invented by Eugene Houdry, a French mechanical engineer and skilled in catalytic oil refining who lived in United States around 1950. The invention of catalytic converter has a major role in controlling harmful emissions. Houdry first developed catalytic converters for smoke stacks, and then manufactured catalytic converters for warehouse fork lifts which uses low grade non leaded gasoline. Then he began his research to progress catalytic converters for gasoline engines that became used on cars in the mid-1950s.

The catalytic converters were more developed by a series of engineers including John J. Mooney and Carl D. Keith at the Engelhard Corporation by developing the first catalytic converter in 1973. William C. Pfefferle developed a catalytic combustor for gas turbines in 1970s that allows combustion without the formation of carbon monoxide and nitrogen oxides. The catalytic converters are used in exhaust systems for the oxidation and reduction of toxic byproducts of fuel into less harmful gases such as carbon dioxide, nitrogen gas and water vapor. There are two types of catalytic converter; two-way & three-way converters. A two-way (or oxidation) catalytic converter performs two simultaneous tasks:

- The oxidation of carbon monoxide to carbon dioxide:
$$2CO + O_2 \rightarrow 2CO_2$$
- The oxidation of hydrocarbons to carbon dioxide and water:
$$C_xH_{2x+2} + [(3x+1)/2]\ O_2 \rightarrow xCO_2 + (x+1)\ H_2O$$

Since it has limitations, two-way catalytic converters were override by three-way converters in 1981. Most of the modern cars are supplied with three-way catalytic converters. A three-way catalytic converter will help in reduction process in addition to the tasks done by two-way catalytic converters:

- The reduction of nitrogen oxides to nitrogen and oxygen:
$$2NO_X \rightarrow xO_2 + N_2$$

In the work carried out by Robert C. Stempel in the 1970s, automotive catalytic convertors uses precious metals like palladium, platinum and rhodium to raise the reaction of exhaust gases; thus it converts carbon monoxide, nitrous oxides, and unburned hydrocarbons into carbon dioxide, water, and nitrogen gas. Initially, palladium and platinum are used as catalysts for the reduction in hydrocarbon and carbon monoxide emissions. Later, rhodium was included into the catalyst mixture when NO_X standards were added to the rules.

Although the catalytic converter helps to reduce toxic emissions from car engine, it also has some environmental effects. In the conversion of HC and CO, the carbon dioxide is formed. Carbon dioxide is one among the greenhouse gases that contributes pointedly to the global warming. In the recent years, several technologies are applied for the capture of CO_2. These technologies are classified to four main groups: post-

combustion, pre-combustion, oxy-fuel combustion and industrial separation. There are various adsorbent materials for CO_2 capture such as Zeolites, Organic-inorganic hybrids, Calcium Oxides, Lithium Zirconate, Activated Carbons, Graphene, Metal organic framework, Hydrotalcites.

The main objective of this work is to investigate the effects of four-way catalytic converter on a single cylinder four stroke diesel engine emissions, using the CO_2 adsorbents such as molsieve 13 x and activated carbon. The existing catalytic converters are not able to reduce CO_2 gases from vehicle exhaust. Four-way catalytic converter is capable in reducing the CO_2 emissions by the physical adsorption method. So three-way catalytic converters will be superseded by the newly introduced four-way catalytic converters.

II. EXPERIMENTAL SETUP AND PROCEDURE

The first and foremost step is to design a four-way catalytic converter as in figure 1. It mainly consists of a diesel engine test rig, three-way catalytic converter, aluminium chamber filled with adsorbents such as molsieve 13 x, and activated carbon.

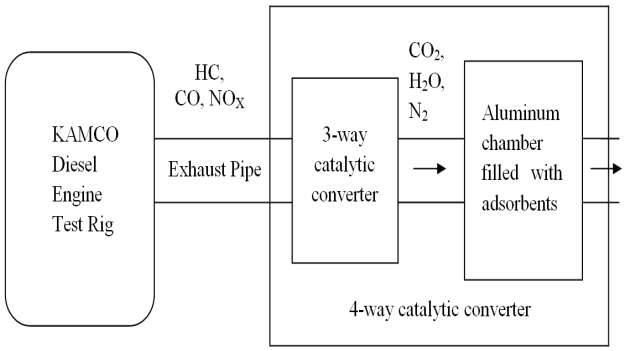

Fig.1. Block diagram of the experimental setup

In this experimental setup, a KAMCO Diesel engine test rig is used and is connected with the four-way catalytic converter. Some modifications are made in the diesel exhaust line by introducing a four-way catalytic converter. The four-way catalytic converter is the combination of a three-way catalytic converter and aluminium chamber filled with adsorbents. These adsorbents may help in reducing the carbon dioxide emissions from the tail end of exhaust pipe. After combustion, harmful gases like HC, CO, NO_X is released from the diesel exhaust. It is then converted to less harmful gases such as CO_2, H_2O, and N_2 with three-way catalytic converter. The excess CO_2 is to be reduced by connecting the aluminium chamber to the three-way exhaust end. So the CO_2 emission may be controlled with the introduction of four-way catalytic converter in the exhaust end.

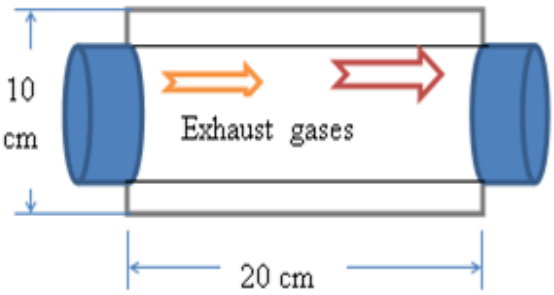

Fig.2. Structure of aluminium chamber

The structure of aluminium chamber is shown in the figure2. For the installation of four-way catalytic converter in vehicles, the chamber of reduced size is made; so that it is better comparable and applicable in real case. The aluminium chamber is built for filling of adsorbents, as shown in figure 3. The adsorbents are filled in the gap between cylindrical and rectangular wire mesh structure. 1kg of adsorbent pellets is filled in the mesh gap for the experiment setup. Then the outlet end of chamber is closed by aluminium sheet cover and tightens the screws carefully. Thus we can make sure that there is no air leakage through this end. Inlet end is connected to catalytic converter and readings are measured from exhaust end with the help of an exhaust gas analyzer (IMR Inc.USA).

Fig.3. Cross sectional view of aluminium chamber with wire mesh

The four-way catalytic converter consists of a three-way catalytic converter and an aluminium chamber, which reduces CO_2 emissions. The additional component includes CO_2 adsorbents for carbon capture and storage from exhaust. The three-way converter can perform the oxidation and reduction reactions. Oxidation-reduction (redox) reaction is a type of chemical reaction that involves a transfer of electrons between two species, in which the oxidation number of a molecule, atom, or ion changes by gaining or losing an electron. This will helps in reducing harmful emissions into less harmful emissions. Along with the tasks of oxidation and reduction, it may also reduce CO_2 level by adsorbing gas before the exhaust to atmosphere. Molsieve 13 X and activated carbon can be chosen as adsorbent materials and is filled in the aluminium chamber as in figure 4.

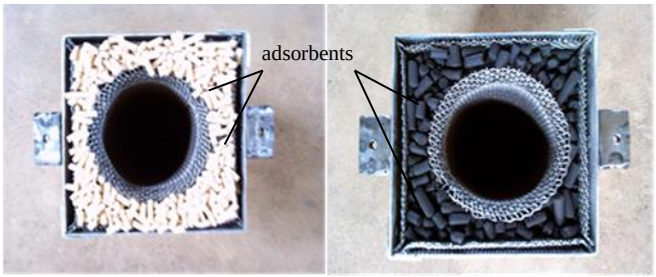

Fig.4. Molsieve 13 X (left) and activated carbon (right)

The four-way catalytic converter is connected to the diesel engine exhaust as shown in figure 5. The aim is to conduct test on the diesel engine under no load and load conditions and to analyze the change in CO_2 emission level. The water cooled single cylinder diesel engine is coupled with a belt pulley arrangement. Spring balance is used to apply load on the brake drum. Suitable cooling water arrangement for the brake drum is provided.

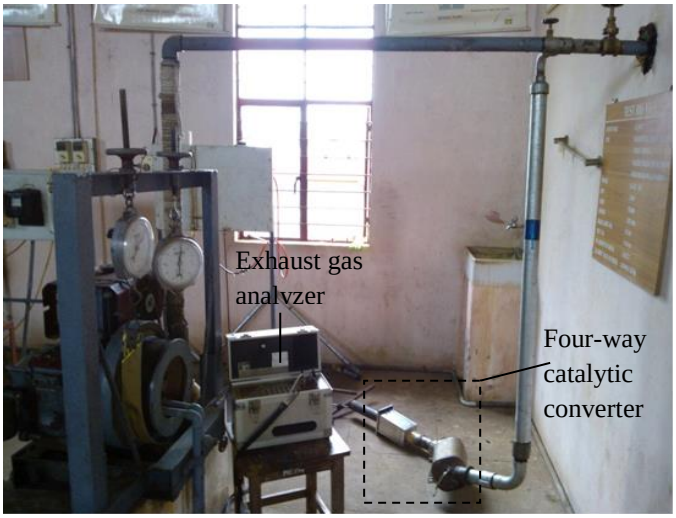

Fig.5. Diesel engine with four-way catalytic converter for experimental set up

After combustion process, the engine emissions come out and these gases are highly pollutant. Hence three-way catalytic converter is placed for converting these gases into less pollutant. This three-way catalytic converter is connected to an aluminium chamber where the adsorbents (molsieve 13 x or activated carbon) are placed in between the meshes. The entire setup is called as four-way catalytic converter. The exhaust gas level is determined by the help of an exhaust gas analyzer. The emission percentage of the different gases can be noted down with the help of this analyzer. A sensor connected with the analyzer is kept in front of the gas outlet pipe. This is used for sensing the gas percentage, temperature. The exhaust gas analyzer shows the level of emissive gases to the atmosphere. This will varies in different load conditions and with respect to the temperature. These results can be analyzed and compared for both adsorbents. Thus most suitable adsorbent can be selected among these for the fabrication of real four-way catalytic converter. So that the catalytic converter can do better performance by trapping the CO_2 and reducing harmful exhaust gas emissions.

III. EXPERIMENTAL RESULTS

Experimental tests have been carried out with different experimental setup and results are analysed. The CO_2 exhaust emission level without any catalytic converter and with three-way catalytic converter is noted as in figure 6. At first, the gas emission level after the combustion process is considered. The observations are made on different load conditions. This can be achieved with the help of spring balance. It is shown that the level of CO_2 emission increases with the increase in load. It is clear from the graph that the three-way catalytic converter connected to the engine exhaust will lead to the increase in CO_2 emission though it decreases carbon monoxide emission. This may be due to the redox reaction takes place inside the catalytic converter by the catalysts. The CO_2 emission level increases with increase in load conditions.

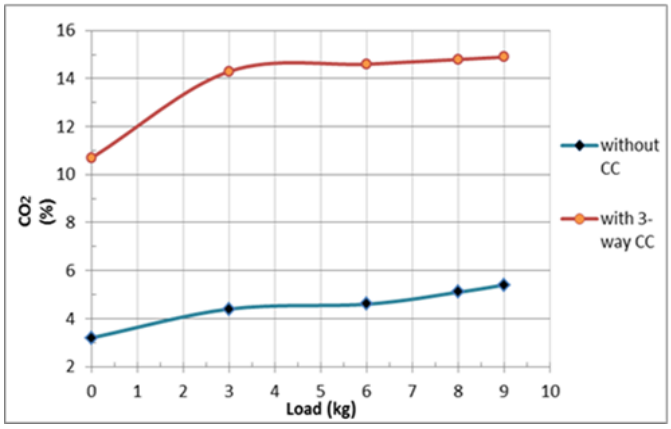

Fig.6. The CO_2 emission level without catalytic converter and with three-way catalytic converter

Sl No	LOAD (kg)	CO_2 EMISSION WITHOUT CATALYTIC CONVERTER (%)	CO_2 EMISSION WITH 3-WAY CATALTIC CONVERTER (%)	PERCENTAGE INCREASE IN CO_2 EMISSION (%)
1	0	3.2	10.7	234
2	3	4.4	14.3	225
3	6	4.6	14.6	217
4	8	5.1	14.8	190
5	9	5.4	14.9	176

Table 1. Percentage increase in CO_2 emission level with the effect of three-way catalytic converter

From the table 1, the percentage increase in the carbon dioxide emission is discussed. Under no load conditions, the CO_2 emission is increased by 234% while using three-way catalytic converter and it decreases while applying load. This is due to the catalytic action takes place inside the catalytic converter with the help of catalysts such as Rh, Pt and Pd.

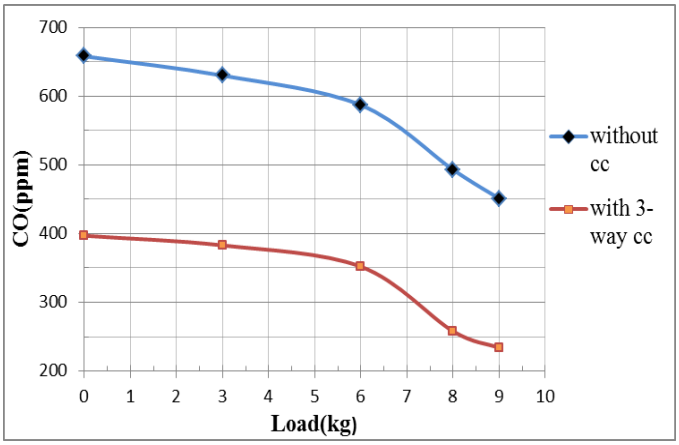

Fig.7. The CO emission level without catalytic converter and with 3-way catalytic converter

The variation in CO emission level without catalytic converter and with three-way catalytic converter is shown graphically in the above figure 7. The emission level of CO reduces with the effect of three-way catalytic converter. Here, the oxidation reaction takes place inside the catalytic converter. The CO emission reduces with the increase in load and becomes almost steady with slight variation after certain load.

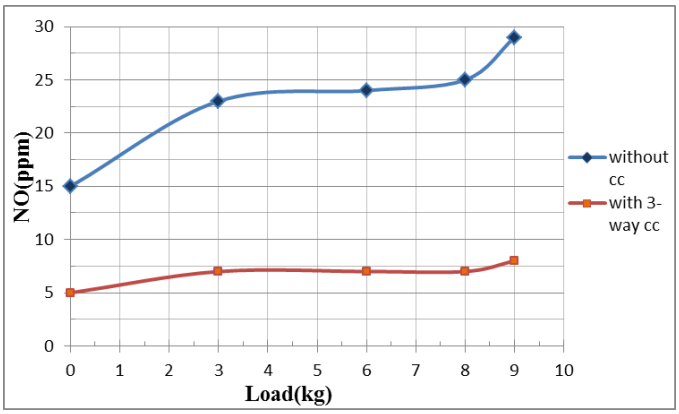

Fig.8. NO emission level without catalytic converter and with three-way catalytic converter.

Figure 8 depicts the graphical representation of variation in NO emission level without catalytic converter and with three-way catalytic converter. The exhaust emission level of NO gases reduces with the effect of three-way catalytic converter. Table 2 provides the percentage reduction values of CO and NO exhaust gas emission levels with the effect of three-way catalytic converter. This may be due to the catalytic action takes place inside the converter. By the effect of three-way catalytic converter, the NO emission remains almost steady after maximum load.

Sl No	LOAD (kg)	Percentage Reduction of CO (%)	Percentage Reduction of NO (%)
1	0	39.06	66.66
2	3	39.21	69.56
3	6	40.03	70.83
4	8	47.67	72.01
5	9	48.11	72.41

Table 2. Percentage reduction of CO and NO emission levels with the effect of three-way catalytic converter.

Under null load conditions, there is a percentage reduction in CO emission by 39.06% and for NO it is 66.66%.The value increases while applying loads for both gases.

The CO_2 emission of activated carbon is 1.4% and Molsieve 13 X is 3.3% as in figure 9. The emission through three-way is well reduced under both cases. Also the activated carbon shows better adsorption rate than Molsieve 13 X. The readings are graphically plotted and analyzed. Thus these adsorbents can be used for controlling the harmful vehicle exhaust in four-way catalytic converter. It has its high performance under no load condition. Under load conditions, the gas temperature will be increased and at the high temperatures, the adsorption process will not be much effective. The Physical adsorption process is better results at low temperatures.

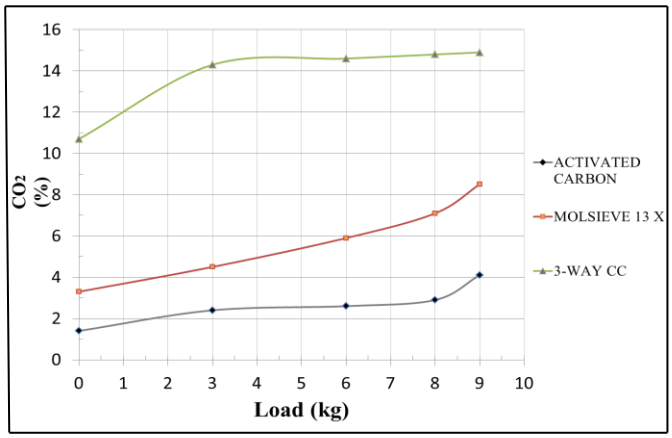

Fig.9. CO_2 emission level under adsorbents and three-way catalytic converter

From the table 3, it is found that there is a decrease in CO_2 emission of activated carbon by 86.91%, and for Molsieve 13 X by 69.16% under no load condition. Thus activated carbon is 17.75% more effective than Molsieve 13 x in reducing carbon dioxide emissions. With the increase in the load, the CO_2 emission also increases.

Sl No	LOAD (kg)	MOLSIEVE 13 X (%)	ACTIVATED CARBON (%)
1	0	69.16	86.91
2	3	68.53	83.21
3	6	59.58	82.19
4	8	52.02	80.41
5	9	42.95	72.48

Table 3. Percentage of reduction in CO_2 emission using adsorbents while comparing it with three-way catalytic converter

Hence it is found that activated carbon has good CO_2 adsorption rate and it is performed well among all cases. Also when considering the case of availability, activated carbon is cheaply available. So it can be considered as better adsorbent among these materials. Activated carbon is not harmful while placing in the open condition. It has good performance at high temperatures. These all factors provide a better privilege for the selection of activated carbon. Molsieve 13 X and activated carbon can be heated for separating CO_2 and can be reused. These experimental setup will not make any change in vehicle efficiency because it doesn't blocks the exhaust emission flow.

The benefit of this work is that the CO_2 emission to the atmosphere can be reduced by adopting this method.

IV. CONCLUSION

From the analysis of the results the following conclusions can be made:

- Under no load conditions, the CO_2 emission is increased by 234% while using three-way catalytic converter. This is due to the catalytic effect.
- It is found that the percentage of reduction in CO_2 for activated carbon is 86.91% and molsieve 13 x is 69.16% under no load condition.
- The activated carbon is about 17.75% more effective than molsieve 13 x in reducing carbon dioxide emissions.
- The adsorption capacity of adsorbents decreases with increase in temperature.
- Molsieve 13 X has better adsorption rate over activated carbon in case of adsorbing NO and HC.
- Adsorption technique is one of the effective method to control carbon dioxide emission.
- The four-way catalytic converter can be fabricated with activated carbon for the better performance.
- The carbon capture and storage can be introduced as a new method to reduce CO_2 emission from vehicles.

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