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Investigation on Single Cylinder, Four Strokes, Stationary Diesel Engine Using Catalytic Converter

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ABSTRACT

Now a day's use o diesel engine for power generations, stationary engines and small lories in agricultural applica increased. This is due to fuel economy and better performance in agricultural field. This has made rapid raise in use of e increasing emissions. However, increasing emissions causing global warming had made researcher to find emissions co In this present work stationary single cylinder, four strokes, diesel engine is studied. It is coupled with three way catcon with cerium and palladium as catalyst. This helps not only reductions of hydrocarbon (HC) and carbon monoxide (CO) but also nitric oxide (NO) emissions were reduced significantly.
It was noted that, HC and NO emissions were reduced 19% and 17% respectively, while CO emissions was reduced 25%. This emissions reduction was achieved with marginal penalty of 4.4% and 10% in brake thermal efficiency and brake specific fuel consumptions.

Keywords—Emission, catalyst, catalytic converter, Performance.

1. INTRODUCTION

Diesel engines are important power systems for on-road and off-road vehicles. Most heavy-duty trucks and buses are powered by a diesel engine due to the long record of reliability, high fuel-efficiency, and high torque output. Diesel engines are easy to repair, and durable. While diesel engines have many advantages, they have the disadvantage of emitting significant amounts of particulate matter (PM) and oxides of nitrogen (NOx) into the atmosphere.

Diesel engines also emit toxic air pollutants. Health experts have concluded that pollutants emitted by diesel engines adversely affect human health and contribute to acid rain, ground-level ozone, and reduced visibility. Studies have shown that exposure to diesel exhaust causes lung damage and respiratory problems.

Interest in diesel emissions control has grown considerably in recent years as agencies such as the U.S. EPA and California's Air Resources Board (ARB) put forth new regulations and funding to clean up existing and new vehicles. Continuously increasing air pollution, global warming and climate changes have made government to impose stringent emissions norms. India is moving to BS III to BS IV as mandatory option across country.

2. AVAILABLE CONTROL TECHNOLOGIES and EFFECTS

Today, viable emission control technologies exist to reduce diesel exhaust emissions from new engines and vehicles, as well as in-use engines through the use of retrofit kits. The major technologies are listed below.

Technologies designed to control particulate matter (PM) include:

• Diesel oxidation catalysts (DOCs)
• Diesel particulate filters (DPFs)
• Closed crankcase ventilation (CCV)

Technologies designed to control oxides of nitrogen (NOx) include:

• Exhaust gas recirculation (EGR)
• Selective catalytic reduction (SCR)
• Lean NOx catalysts (LNCs)
• Lean NOx traps (LNTs)

Diesel engines provide important fuel economy and durability advantages for large heavy-duty trucks, buses, off road equipment and passenger cars. They are often the power plant of choice for heavy-duty applications. While they have many advantages, they also have the disadvantage of emitting significant amounts of particulate matter (PM) and oxides of nitrogen (NOx) and, to a lesser amount, hydrocarbon (HC), carbon monoxide (CO), and toxic air pollutants. Julie Pardiwala et al., (2011) [1] noted that, the three-way catalyst with stoichiometric engine control systems remain the state of art method for simultaneously controlling hydrocarbon, CO and NOx emissions from vehicle. The economical reasons, limited resources of platinum group (noble) metal and some operating limitations of platinum group metal based catalytic converters have motivated the investigation of alternative catalyst materials. Emission Control Technologies for Diesel-Powered Vehicles (2007) [2] in this study number of technologies exist that can greatly reduce emissions from diesel-powered vehicles. Diesel oxidation catalysts, diesel particulate filters, exhaust gas recirculation and crankcase emission controls have been successfully rolled out on new onroad vehicles. These technologies help to reduce emissions of particulate matter and other pollutants like toxic gases. Advanced NOx control technologies are being developed to meet EPA on highway emission standards. Technologies such as lean NOx traps and selective catalytic reduction have been demonstrated to be durable and effective methods of achieving low tailpipe NOx levels from diesel and other lean burn engines. Some of the technologies that reduce particulate matter and NOx are also applicable to the diesel engines already on the road today, offering a cost-effective way to reduce diesel emissions during their remaining life. Advanced sensors are being developed to observe all components of the exhaust control system. These sensors will allow diesel engines to meet the same OBD and emissions requirements already in place for gasoline spark-ignited engines and vehicles. Rajesh Binjwale., et al., (2001) [3] discussed non noble based material for catalyst technology. Alumina wash coating on ceramic substance, scale up technology, catalyst coating was studied. Also, financial calculations were made for project and payback of emission reduction device. The emission reductions were reported for CO and HC 55-60% for four wheeler vehicles and 65-75% for two wheeler vehicle catalytic converter. Benjamin S.F., et al., (2004) [4] used a computational fluid dynamics (CFD) technique for the prediction of uniform conversion efficiency across an automotive catalytic converter. It was noticed variable conversion efficiency across the monolith. The principle of a design methodology has been described that predicts the monolith geometry of a catalytic converter under diffusion-limited regimes so as to provide uniform conversion efficiency across the monolith. The simulations were performed for 2D axi-symmetric systems under steady flow conditions and assumed a monolith resistance given by the Hagen–Poiseuille relationship. Liu X. et al., (2014) [5] reported that power generation of exhaust thermo electric generator (TEG) depends on heat energy and thermoelectric conversion efficiency. It was mentioned about location of TEG among CC and muffler. Three cases were studied. Simulation and experiment were developed to compare thermal uniformity and pressure drop characteristics over the three operating cases. The simulation and experiment showed that heat exchanger in case (TEG in between CC and muffler) obtained more uniform flow distribution, higher surface temperature and lower back pressure than in other cases. At the same time, the CC and muf could keep normal working in case 2, providing a theoretical and experimental basis for the exhaust gas waste heat recovery. Schalwig J. et al., (2004) [6] showed that, filling and regeneration of NOx storage catalysts could be monitored with the help of simple two-sensor arrays consisting of: (i) a SiC-based field-effect gas sensor with a catalytic Pt gate (Pt-MOSiC), and (ii) a resistive thin-film metal oxide gas sensor. It was reported that, two sensors were sufficient and significant for NOx control, filling and regeneration. Larsson G. et al., (2011) [7] studied the effect of three after-treatment options: no retrofit; a diesel oxidation catalyst (DOC)/diesel particulate filter (DPF) system; and a selective catalytic reduction (SCR) catalytic converter. Two vehicle usage patterns were considered, one following the legal test cycle (used for all off-road vehicles) and one corresponding to average agricultural tractor usage. S. Chauhan (2010) [8] Discussed on various materials of catcon. In USA in the years 1975-1980, platinum (Pt) and palladium (Pd) were used as oxidation catalysts in the ratio 5 (Pt) : 2 (Pd) at a typical loading of 50-70 g/ft3. Rhodium (Rh) was introduced with the advent of the three-way catalysts, having considerably better activity than Pt or Pd for the catalytic reduction of the oxides of nitrogen. When sufficient Rh was present the participation of Pt in NO removal was minimum. V.Veeraragavan (2013) [9] Explained that, redesigned catalytic converter was more advantageous for engines that uses Bio-diesel as fuel. Initially, copper as catalyst used to reduce CO, NOx, HC to their corresponding harmless gases. The catalyst was coated on the alumina ball that was contained in the honeycomb. Ling HE et al., (2012) [10] have discussed on dynamic response of 3 way catcon. It was observed that, after lean to rich transitions, emissions reduce with the increase of the exhaust mass flow and turn to be deteriorated till the increase to a value. After rich to lean transitions, the downstream lambda increases linearly with the increase of the exhaust mass flows and inlet lambda amplitudes, since the oxygen storage capacity of the catalytic converter on the ceria increases linearly with the exhaust mass flows and inlet lambda amplitudes.R. Vallinayagam et al., (2013) [11] have utilized pine oil as renewable fuel in the current research work and from the basic experimental investigation, B50 was observed to emit less CO, HC and smoke emission. Though greener to environment, the deleterious NOX emission persisted and hence an after treatment technique, SCR þ CC assembly, was implemented to reduce the overall emissions. By this measure, NOX emission was mitigated, while all other emissions such as CO, HC and Smoke were substantially reduced. Vivek W. Khond et al., (12) [2016] It was reviewed and concluded that broad range of nano fluid additives can be used as additives in diesel and biodiesel due to increased surface area to volume ratio, increased in catalytic activity in nano size metal oxides and metals. Nano fluid increases better combustion due micro explosion phenomenon. Mari Pietikainen et al., (2013) [13] discussed the fuel type had a great impact on the number and chemical composition of particles emitted from the investigated non-road diesel engine. On the view of the health effects the results were contradictory, while the number of particles emitted from the RSO fueled engine was 10e100 times higher compared to DFO implicating to higher health risks caused by RSO. In turn, harmful transition metals were found in notable portions only in the DFO particles. The use of the SCR converter decreased the particle number in general but increased the amount of harmful nanoparticles formed with both fuels. The NOx reduction activity of an SCR converter did not depend on the fuel used but RSO was detected to decrease the converter activity very quickly most probably due to the large amount of trace elements present in the RSO fuel. Thus, further studies in engine and converter performance are required before RSO can be considered as a more sustainable alternative than the common. Thomas Nagel et al., (2014) [14] explained the methodology used to determine the critical stressors and their levels in actual operating conditions which were determined by analyzing a broad range of vehicle test information. Engine manufacturers started as early as the late eighties to develop cleaner diesel engines by employing a number of strategies. These approaches include advanced common rail fuel injection, electronic engine controls, combustion chamber modifications, air boosting, improved air/fuel mixing, and reduced oil consumption. Achieving ultra-low exhaust emission targets requires a systems approach. Engine manufacturers are focusing on ways to control engine operation to reduce engine-out emissions as low as possible and reduce the burden on the exhaust emission control systems.

- **The oxidization catalytic converter**

An oxidation catalyst is a device placed on the tailpipe of a car. it is the second stage of the catcon. It reduces the unburned HC and CO by oxidizing over a platinum and palladium catalyst. This catalyst aids the reaction of the CO and hydrocarbons with the remaining oxygen in the exhaust gas

$$HC + O_2 \rightarrow CO_2 + H_2O \quad (1)$$

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

- **A reduction catalyst to control**

NOx can be used as separate system in addition to the oxidation catalytic converter. The reduction catalyst is fitted upstream of the oxidation system. The reduction catalyst is the first stage of the catalytic converter. It uses platinum and rhodium to reduce the nitrogen oxide emissions.

$$2NO \rightarrow N_2 + O_2 \quad (1)$$

- **The three-way catalytic converter (TWCs)**

TWCs have the advantage of performing the oxidation of carbon monoxide (CO), hydrocarbons (HC) and the reduction of nitrogen oxides (NOx) simultaneously. Noble metals are usually used as the active phase in TWCs. Pd catalysts are especially attractive since Pd is by far the cheapest noble metal in the market and has better selectivity and activity for hydrocarbons. Rhodium the other essential constituent of three-way catalysts is widely recognized as the most efficient catalyst for promoting the reduction of NO to N2. The TWCs performance in the emission control can be affected by operating the catalyst at elevated temperatures (> 600 °C). Reactions occurring on the automotive exhaust catalysts are very complex as listed below. The major reactions are the oxidation of CO and HC and the reduction of NOx. Also, water gas shift and steam reforming reaction occur. Intermediate products such as N2O and NO2 are also found. The NOx storage concept is based on incorporation of a storage component into the three-way catalyst (TWCs) to store NOx during lean conditions for a time period of minutes.

Reactions in Catalytic Converter

Oxidation $2CO + O_2 \rightarrow 2CO_2$ (1)

$HC + O_2 \rightarrow CO_2 + H_2O$ (2)

Reduction/three-way $2CO + 2NO \rightarrow 2CO_2 + N_2$ (3)

HC +NO →C $O_2 + H_2O$ + N2 2 $H_2 + 2NO \rightarrow 2H_2O + N_2$ (4)

Water Gas Shift $CO + H_2O \rightarrow CO_2 + H_2$ (5)

Steam reforming $HC + H_2O \rightarrow CO_2 + H_2$ (6)

The literature work so far studied comprises of emission reduction techniques for on road vehicle. However, CFD, mathematical modeling, experimental investigation have been carried out systematically. Emissions so far discussed are HC & CO. The emission reduction techniques for diesel engine for on road vehicles have been studied. However, key technology for development of Catalytic Converter along with its effect for off road applications has been not discussed. Further, limited studies on emissions have been carried out. It is required to find best possible device common to reduce major emissions. It should be noted that, limited work is done so far on emission reduction of (off road) stationary diesel engine. Hence, “Investigation on Single Cylinder, Four Strokes and Stationary Diesel Engine Using Catalytic Converter” is thoroughly studied in present work.

3. EXPERIMENTAL SET-UP

A 3.5 kW,1500 rpm, Kirloskar stationary diesel engine is used in this investigation as shown in figure. The detailed specification is given in table no 1. Fuel consumption is measured using burret. A differential pressure manometer (air box) is used to measure airflow rate. Engine is coupled with alternator dynamometer to control engine torque through manual handling. Engine speed and load are controlled by varying the load to alternator. However, this AC generator works at constant rpm. Smoke head Monitor exhaust gas analyzer is used to measure emission parameters.

- **Catalytic convertor:**

A catalytic convertor is an emissions control device that converts toxic pollutants in exhaust gas to less toxic pollutants by catalyzing a redox reaction (oxidation or reduction). Catalytic convertors are used with internal combustion engines fueled by either petrol or diesel. In this present work three way catalytic convertor is used as shown in Fig. 2 for observing the effect of emission reduction and backpressure on diesel engine.

Table: 1. Specification of Engine

1	Make	Kirloskar-TV1
2	Power and speed	3.5 kW and 1500 rpm
3	Type of engine	Single cylinder, 4 stroke DI Stationary Diesel Engine
4	Compression ratio	17.5:1
5	Bore and stroke	87.5 and 110 mm
6	Method of loading	Alternator dynamometer of max rated 2.5 kVA@ 1500 RPM
7	Method of cooling	Water
8	Type of ignition	Compression ignition
9	Speed type	Constant
10	Lube oil	SAE40

Table:2. Specification of exhaust gas analyzer

1	Manufacturer	Crypton Ltd., U.K.
2	Power requirement	230V AC , 50-60 Hz
3	Response time	11 seconds to 95% of final reading
4	Warm up time	<10 minutes (self controlled) at 20^{o}
5	Range	CO : 0 to 10% $CO_{2:}$ 0 to 20% HC : 0 to 10000 ppm O_2 : 0 to 25% NO:0 to 5000 ppm
6	Resolution	CO : 0.01% CO_2 : 0.01% HC : 1 ppm O_2 : 0.01% NO:1 ppm
7	Master calibration	Six month once

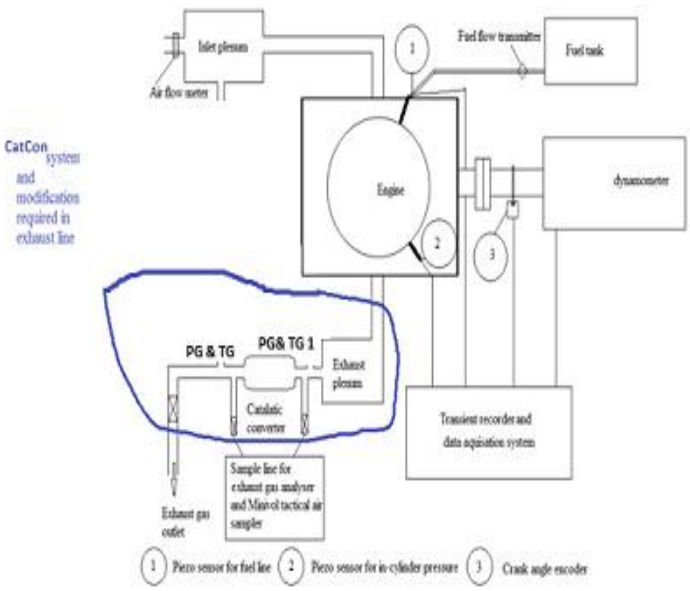

Fig. 1: Experimental Set-up

Fig 2: Catalytic convertor

Fig 3: Photo of experimental set-up

4. RESULT AND DISCUSSIONS

4.1 Performance characteristics

The performance studies comprise of brake thermal efficiency (BTHE), volumetric efficiency, and mechanical efficiency. In additions exhaust gas temperature and brake specific fuel consumption were also studied. Fig. 4 sheds light on effect on various efficiency of engine with and without use of catalytic converter.

The volumetric efficiency remains higher among all efficiency. It is amount of air consumed per cycle capacity. It slightly decreases with increase in load. It should be noted that, volumetric efficiency for engine without catcon remains marginally higher due to consumptions of air spontaneously and less obstacles (residue) in tail pipe due to use of catcon. At no load 10.79% volumetric efficiency difference is present between with and without catcon. Mechanical efficiency increases with increase in load. It was observed 71.01% highest mechanical efficiency without use of catcon. This value is slightly 2.9% more compared to mechanical efficiency with use of catcon. This marginal difference may be due to almost same frictional losses of engine. The vital results of brake thermal efficiency showed that, inferior loss in thermal efficiency was observed with use of catcon. The brake thermal efficiency for engine with catcon is 4.4% lesser than engine without catcon. This slightly loss may be due to more consumption of fuel and back pressure produced in tail pipe. The brake thermal efficiency 24.51% and 23.01% were obtained without and with catcon operations to engine.

The effect on brake specific fuel consumptions without and with catcon is shown in fig.5. The fig.6 shows effect on exhaust gas temperature. It should be noted that, brake specific fuel consumptions increases with catcon. The BSFC 0.39 and 0.35 kg/kWhr were noted with and without catcon at peak load operations. This % 10.25increase in BSFC may be due to presence of back pressure and residuals in tai pipe. Hence, locations of catcon are vital to reduce residuals and backpressure in tail pipe. Hence, design development and location of catcon attracts serious concern. It should be noted that, the exhaust gas temperature decrease by use of catcon. Almost 16.7% decrease in exhaust gas temperature was observed at peak load operations with used of catcon. This may be due to decrease in after burning process.

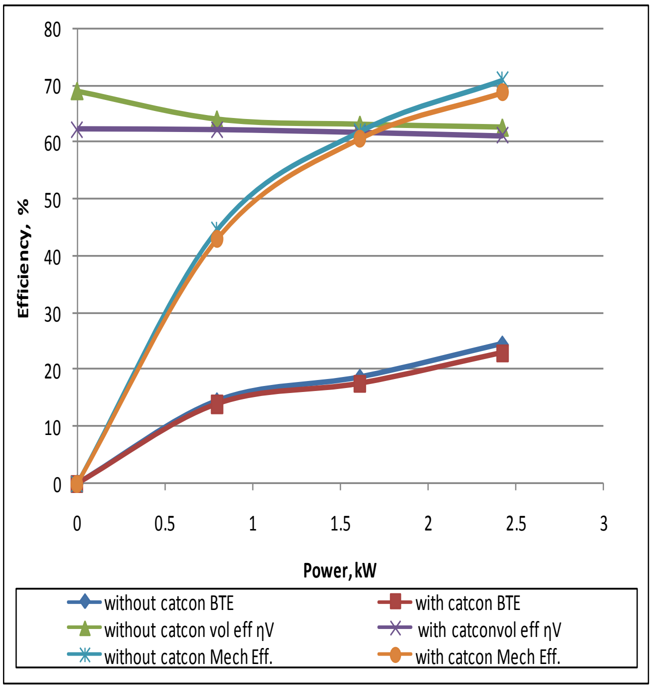

Fig. 4. Various efficiency (η) vs brake power kW

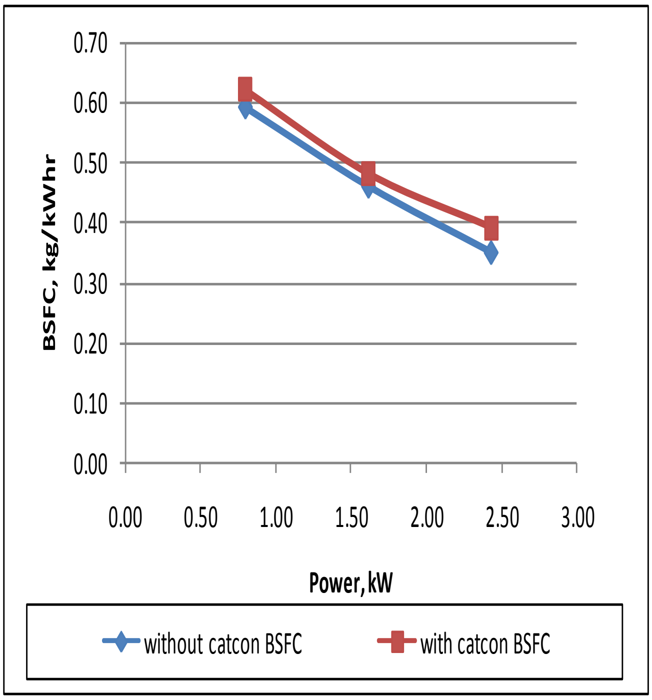

Fig. 5. Brake specific fuel consumptions (kg/kWhr) vs brake power, (kW)

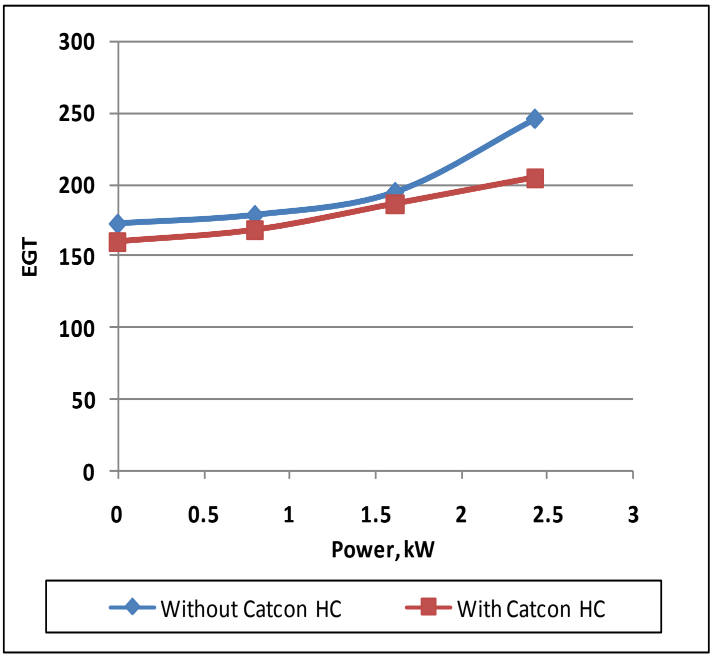

Fig. 6. Exhaust gas temperature (EGT) vs brake power

4.2 Emissions characteristics

Investigation on emissions reduction using catcon can be seen in Fig.7, 8 & 9. The emissions so far studied are un-burnt hydrocarbon (HC in ppm), carbon monoxide (CO in % Vol.) and nitric oxide (NO in ppm) respectively.

The HC emissions for peak load operation without catcon remains highest 37 ppm compared to 31 ppm of with catcon. This reduction of 19.3% in HC emissions with catcon is significant. Further, CO emissions and NO emissions showed decreasing nature with use of catcon.

The CO emissions were reduced from 0.04%vol to 0.03%Vol. with use of catcon. This 25% reduction in CO emissions attracts vital role of catcon. This reduction in emissions may be due to oxidation reaction of cerium catalyst in catalytic converter.

The NO emissions are 410 ppm with catcon compared to 496 ppm of without catcon operation at peak load. NO emissions observed to be increase with increase in load for both conditions. However, 17.3% lessen NO emissions was noted with use of catcon compared to without catcon. These noteworthy reductions in emissions may be due to lowered oxygen content and reduced post combustion causing increase in tail pipe gases temperature. compared to without. Further, cerium and dual bed catcon gives prominent results for emissions reductions.

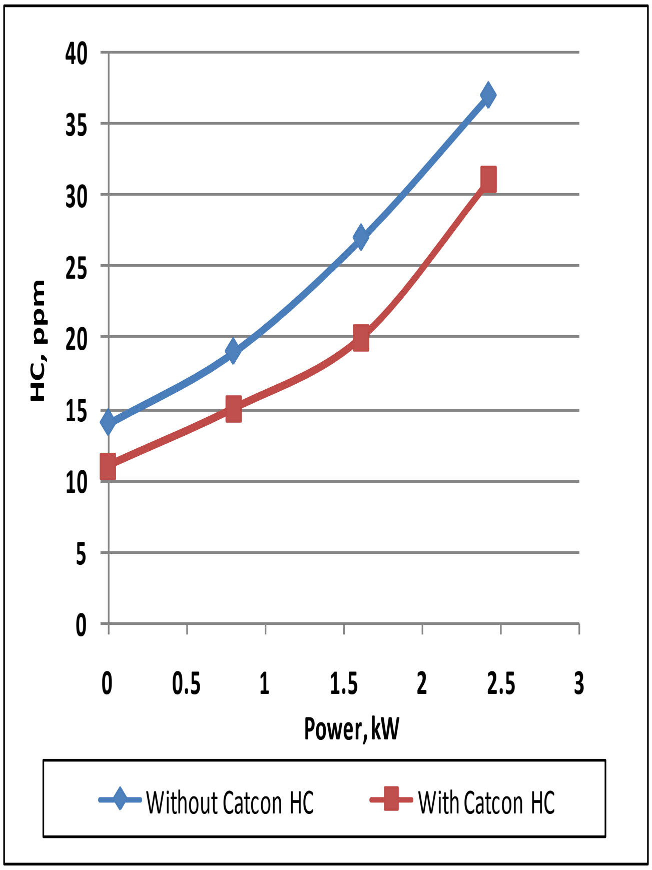

Fig. 7. Un burnt Hydrocarbon, HC (ppm) vs brake power€ (kW)

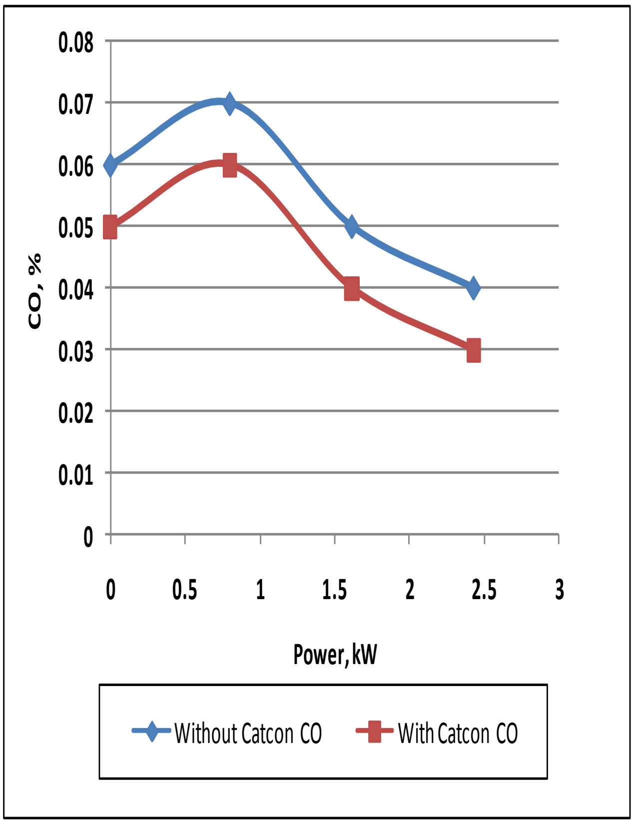

Fig. 8. Carbon monoxide, CO (%Vol) vs brake power (kW)

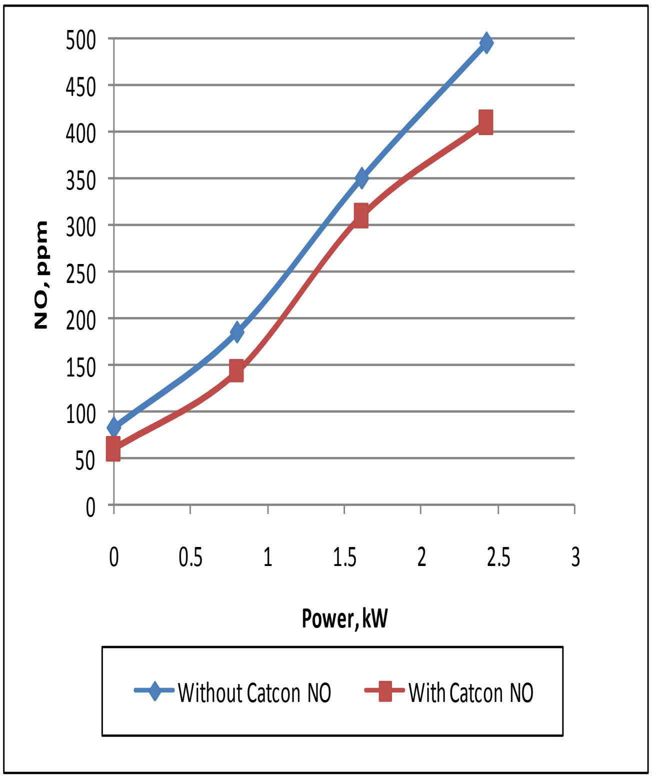

Fig. 9. Nitric Oxide, NO (ppm) vs brake power (kW)

5. Conclusions

➢ The volumetric efficiency remains higher among all efficiency. Mechanical efficiency increases with increase in load. It was observed 71.01% highest mechanical efficiency without use of catcon. This value is slightly 2.9% more compared to mechanical efficiency with use of catcon. This marginal difference may be due to almost same frictional losses of engine. The brake thermal efficiency for engine with catcon is 4.4% lesser than engine without catcon. This slightly loss may be due to more consumption of fuel and back pressure produced in tail pipe. The brake thermal efficiency 24.51% and 23.01% were obtained without and with catcon operations to engine.

➢ The BSFC 0.39 and 0.35 kg/kWhr were noted with and without catcon at peak load operations. This % 10.25increase in BSFC may be due to presence of back pressure and residuals in tail pipe. Almost 16.7% decrease in exhaust gas temperature was observed at peak load operations with used of catcon. Hence, locations of catcon are vital to reduce residuals and backpressure in tail pipe. Hence, design development and location of catcon attracts serious concern. It should be noted that, the exhaust gas temperature decrease by use of catcon.. This may be due to decrease in after burning process.

➢ The HC emissions for peak load operation without catcon remains highest 37 ppm compared to 31 ppm of with catcon. This reduction of 19.3% in HC emissions with catcon is significant. The CO emissions were reduced from 0.04%vol to 0.03%Vol. with use of catcon. This 25% reduction in CO emissions attracts vital role of catcon. NO emission was 410 ppm with catcon compared to 496 ppm of without catcon operation at peak load. NO emissions observed to be increase with increase in load for both conditions. However, 17.3% lessen NO emissions was noted with use of catcon compared to without catcon.

➢ This reduction in emissions may be due to oxidation reaction of cerium catalyst in catalytic converter. In additions these noteworthy reductions in emissions may be due to lowered oxygen content and reduced post combustion causing increase in tail pipe gases temperature.

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