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Effect of Using DPF, DOC and NCC Aftertreatment Devices on Emissions of Diesel Engine

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Abstract: To meet more and more stringent emission standards, both the in-cylinder and after-treatment is done in engines by varying the injection pressure, timing, fuel additives, combustion chamber, exhaust gas recirculation; and adopting Diesel particulate filter (DPF), Diesel oxidation catalyst (DOC), Selective Catalytic reduction (SCR), NO_x traps etc respectively. In this study, extensively three aftertreatment devices viz; diesel particulate filter, diesel oxidation catalyst and new catalytic converter were used. Experiments were conducted on a CI engine with neat diesel fuel at all the loads and fixed speed. Test runs were conducted by adopting DPF, DOC, New catalytic converter (NCC) individually and in combinations. At 6 kg loads, the thermal efficiency of engine was found to be 21.45%. Overall comparison of all the results, the least emission level was recorded when engine is operated at sixty percent full load with combined DPF, DOC and new catalytic converter; with emissions values were HC 40 ppm, CO 0.1 %, and NO 332 ppm.

Keywords: *Diesel engine, Catalytic Converter, Diesel Engine Exhaust.*

Introduction

The capability to operate with leaner air fuel ratio and utilization of higher compression ratio are the two integral determinants that validates the immense thermal efficiency and substantial specific power output of the CI engines concurrent with fuel economy that publicizes their deployment as most proficient prime movers in the areas of farming, industries and transportation across the globe. In contrast, diesel engines are the leading benefactor of oxides of nitrogen (NOx) and particulate matter (PM) emissions erupted due to cumulative premixed flame combustion and diffusion flame combustion that ruins the health of an individual. In spite of an injection of water and hydrogen peroxide and Exhaust Gas Recirculation (EGR) in to combustion chamber of a CI engine are the renowned approaches of mitigating the in-cylinder formation of NOx and particulate emission, EGR and water injection routines exceptionally cut down NOx and no sizable betterment in the attenuation of PM could be perceived; while, conflicting sequel is derived with an injection of hydrogen peroxide. Refinements in the engine geometry and revisals of diesel fuel with an addition of oxygenating agents such as biofuels to enhance the cetane number and fuel volatility are the supplementary means that setback to concurrently downsize the in-cylinder formation of NOx and PM. The use of after treatment devices such as Diesel particulate filter (DPF), Selective Catalytic Reduction (SCR), Diesel oxidation catalyst (DOC), NOx traps etc., are the post combustion techniques adopted to reduce the tailpipe emission of NOX and PM.

Although, the usage of water-in-diesel emulsions for diesel engine applications exhibited optimistic consequences, showed trade-off in terms of efficiency and NOx emissions. The blends of diesel-biodiesel 80:20 by volume have shown favourable sequels in terms of engine emissions and performance parameters. The outcome of the experimentation with a fuel composed of blend of Diesel-Neem biodiesel (80:20) supplemented with 5% water (by volume) and 1% surfactant (by volume) along with 0.5% Di-tertiary butyl peroxide (by volume) unveiled the improved performance with diminished specific energy consumption and attenuated NOx emission of 45% and 29% compared to that of diesel-biodiesel blend and diesel fuel respectively [1]. The exertion of DPF instigated in the diminishment of soot by 40% was noticed at full loading conditions [2]. The experimentation with the utilization of low-cost catalyst composed of silica, alumina and activated charcoal on single cylinder engine under full loading conditions ascertained that emission of NOx shortened by 21% in contrary to the engine operation with catalyst of noble metals [3]. The demonstration on diesel engine fuelled with the blends of diesel-biodiesel with electrochemically activated cells composed of CuO–YSZ electrolyte and CuO–YSZ electrolyte with BaO coating has concluded the considerable NOx adulteration with coincidental decrement of emissions of HC and PM [4]. The engine ran with blend of 40% biodiesel extracted from chicken skin-diesel incorporated with copper doped zeolite coated catalyst at 4.3 kW load have shown explored the slashed emissions of HC, CO, NOX and smoke 9.71%, 5.32%, 11.3%, and 34.9% analogous to the catalysts available commercially [5]. The exploitation of urea -water SCR system with an engine operated with a blend of 25% madhuca indica bio-diesel -diesel blend shown-off declined emissions of HC and NOx by 5.8% and 1.2% in contrast to base diesel fuel [6]. Exertion of nanoparticles in the biodiesel-diesel blends results in better atomization of the fuel, reduced ignition delay and hence accelerates the combustion and inevitably decline the particulate emission. The deployment of Al_2O_3 nanoparticles 25-100 ppm in steps of 25 ppm with 20% microalgae biodiesel-80% diesel blend has shown positive impact on the thermal efficiency and considerable decrement in the NOx emission with 50 ppm of Al_2O_3 nanoparticles in the blend compared to the biodiesel-diesel blend [7]. Addition of 25 ppm zirconium oxide (Zr2O3) nano additives in B20 spirulina microalgae biodiesel blend (20% spirulina microalgae biodiesel + 80% diesel fuel) revealed that inhabitance of Zr2O3 nano additives in B20 blend effectuated in lowering BSEC by 4.9%, elevated BTE by 7.9% and adulterated NOx emissions by 9.4%. [8]. The adoption of multiwalled carbon nano-tubes in the mass fraction of 25 ppm palm methyl ester/ jatropha methyl ester on the diesel engine exhibited a considerable betterment in performance and minute attenuation in terms of emissions [9]. The trials on the diesel engine with the nanoparticles unveiled the substantial decline in the emissions of NOx and CO compared to that with the base diesel operation alone [10].

1. Objectives

1. To conduct test runs on existing diesel engine having Diesel Particular Filter and Diesel Oxidation Catalyst being the two after treatment devices.
2. To analyze the reduction in emissions of the same diesel engine by adopting these devices alone and/or together and record the least emission values.
3. To model and fabricate a new aftertreatment devices so as to tackle NOx emission.
4. To conduct test runs on the diesel engine with this new device so as to check the feasibility of using it.
5. To compare the performance and emission tests on diesel engine adopted with all the three devices and evolve the optimum condition leading to least emissions.

2. Experimental Setup

Fabrication of New Catalytic Convertor

Catalytic converter consisted of platinum, paladium and rhodium metals with the composition of 3:1:1. Platinum was dissolved in the solution of hexa hydrated aluminium chloride ($AlC_3.6H_2O$). The prepared solution was washed, coated to the ceramic substrate, which is honeycomb structure. Two-dimensional design and three-dimensional model of catalytic convertor is shown in figure 1 and 2 respectively. The photograph of cutting process and welding of catalytic convertor during the fabrication is shown in figure 3 and 4 respectively.

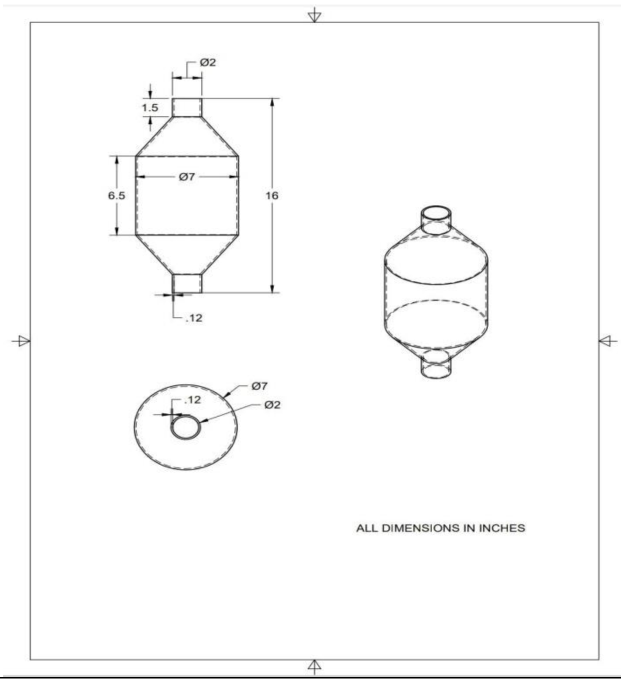

Figure 1 Two-dimensional design of Catalytic Converter

Figure 2 Three-dimensional design of Catalytic Converter

Figure 3 Cutting of sheet metal

Figure 4 Welding of New Catalytic Converter

Experiments were conducted on a diesel engine having three after-treatment devices. The engine specifications are shown in the table 1. All tests were conducted at different loads like, zero, sixty percent and eighty percent full load. The engine speed was maintained at 1500 rpm. After every load, the engine was allowed to attain steady state for 15 minutes. The specification of DPF, DOC and Catalytic Convertor is given in table 2, 3 and 4 respectively. Figure 5 shows the Diesel Engine used for the test runs. The three aftertreatment devices are shown in Figure 6, 7 and 8 respectively. The photograph of Diesel engine's exhaust having DPF, DOC and Catalytic converter and Diesel engine's exhaust having Catalytic converter only shown in figure nine and ten respectively.

Figure 5. Diesel engine test rig

Table 1 Specifications of Compression Ignition Engine

Type of Ignition	CI
No. of Cylinders	1
Rated Power	3.68 kW
Rated Speed	1500 RPM
Bore x Stroke	80 mm x 110 mm
Compression ratio	18:1

Figure 6 Diesel Particulate Filters

Table 2 Specifications of Diesel Particulate Filter

DPF Core	150 mm x 150 mm
Volume	2 Liters
Cell Density	100 cPsi
Material	Cordierite
Chemical Composition	$AI_2O335.2 \pm 1.5\%$
Compressive Strength	10 MPa
Porosity	45%
Maximum Use Temperature	1200ºC
Average of Pore Diameter	7-10 µm
Can Thickness	1.2 mm
Total Length	400 mm
PGM	15gm/ft Pt/Pd = 3/1
PGM Loading	15 gm/ft^3

Figure 7 Diesel Oxidation Catalyst

Figure 8 Catalytic Converter

Table 3 Specifications of Catalytic Converter

Cell Density	500 cPsi
Material	Mild Steel
Total Length	375 mm
Ceramic Substrate	Honey Comb Structure

Figure 9 Diesel engine exhaust having DPF, DOC and Catalytic converter

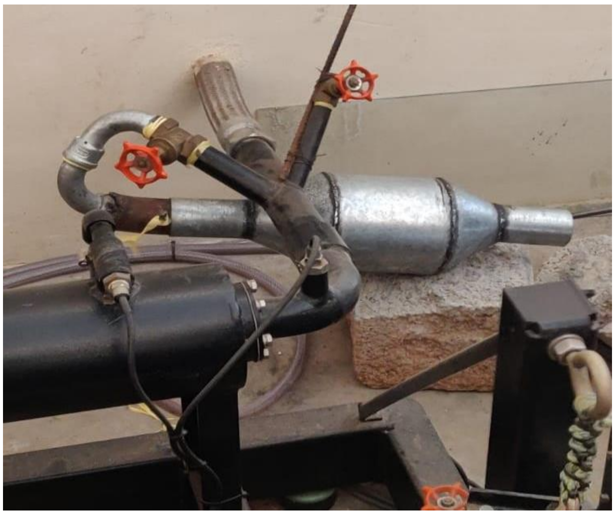

Figure 10 Diesel engine exhaust having Catalytic converter only

3. Results and Discussion

Experimentations were carried out on a CI engine with diesel fuel and speed is maintained at 1500 rpm. The IP is 205 bar, IT is 23° BTDC, having HCC and three hole injector; each hole being 0.3 mm diameter as specified by manufacturer were adopted.

BTE of the engine with/without devices was found to be 15.77 % and 16.47 % at 4 kg and 6 kg loads respectively. In addition, the measured emissions are HC is 91 ppm, CO is 0.14 %, CO_2 is 6.62 % and NO is 435 ppm at 4 kg load.

4.1 HC emissions

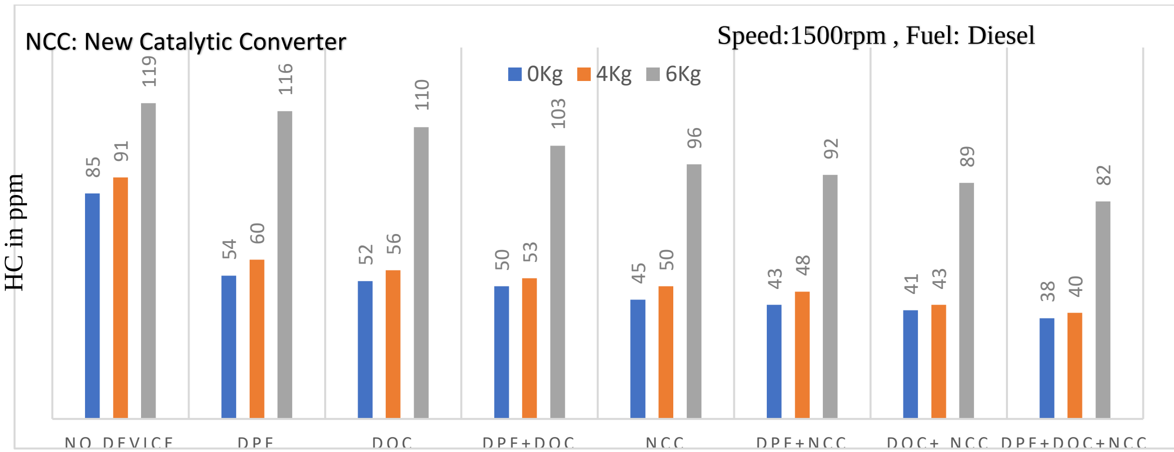

Figure 11 HC emissions at 0 kg, 4 kg and 6 kg load

Without incorporating any post treatment devices, HC emissions was found to be 85 ppm in the exhaust at no load condition as shown in figure 11. It reduces further to 54 ppm with DPF only, 52 ppm with DOC only, 50 ppm with both DPF and DOC; 45 ppm with new catalytic converter only, 43 ppm with both DPF andCatalytic converter, 41 ppm with both DOC and new catalytic converter and 38 ppm with combination of all three devices viz; DPF, DOC and new catalytic converter. Emissions were reduced because of New Catalytic Converter has been used. Emissions, which are released from diesel engine, were reacted with Platinum Group Metals (Platinum, Palladium, and Rhodium) which is coated inside the New Catalytic Converter. Platinum and Palladium are acts as oxidation process while Platinum and Rhodium are acts as Reduction process [6]. Emissions are decreased more when the combination of these three aftertreatment devices.

4.2 CO emissions

At 6 kg load and without incorporating any devices, CO emission is 0.26 % in the exhaust as shown in figure 12. It reduces further to 0.24 % when DPF is used, 0.22 % when DOC is used, 0.19 % when DPF and DOC used, 0.17 % New Catalytic Converter is used, 0.148 % when DPF and Catalytic converter is used,0.138 % when DOC and Catalytic converter is used and 0.13 % when combination DPF, DOC and Catalytic Converter is used.

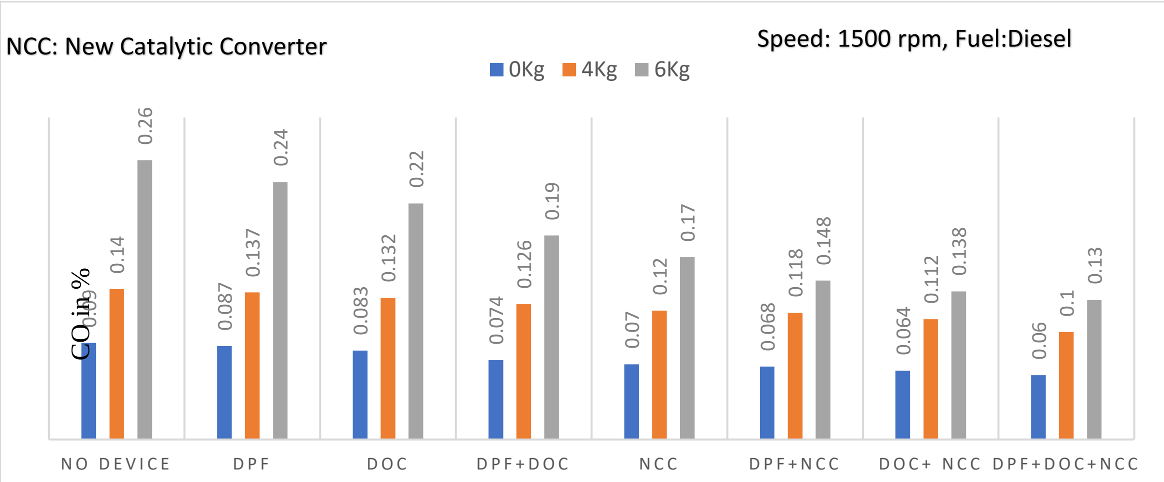

Figure 12 CO emissions at 0Kg, 4Kg and 6Kg

4.3 NO emissions

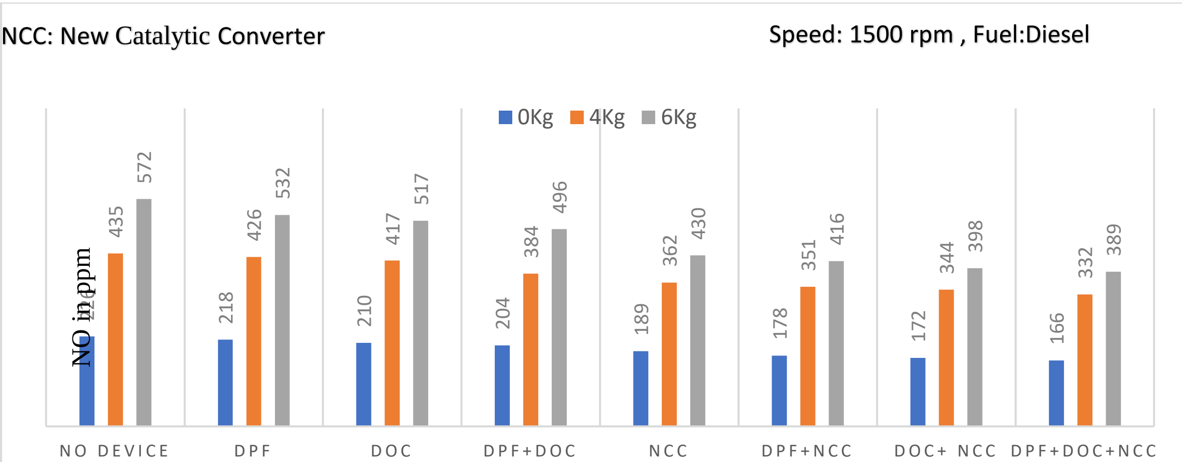

Figure 13 NO emissions at 0Kg, 4Kg and 6Kg

At 4 kg load and without incorporating any devices is 435 ppm of NO emissions present in the exhaust as shown in figure 13. It reduces further to 426 ppm when DPF is used, 417 ppm when DOC is used, 384 ppm when DPF and DOC used, 362 ppm New Catalytic Converter is used, 351ppm when DPF and Catalytic converter is used,344 ppm when DOC and Catalytic converter is used and 332ppm when combination DPF, DOC and Catalytic Converter is used.

5. Conclusion

The effects of diesel engine fitted with DPF, DOC and New Catalytic Converter on engine emissions were investigated. Overall comparison of all the test runs, the least emission values were recorded when engine is loaded with sixty percent full load and having combined three aftertreatment devices including new catalytic converter. At this load, the emissions are HC is 40 ppm, CO is 0.1 %, and NO is 332 ppm. Hence, combined DPF, DOC and new catalytic converter for diesel engine provides reduction in exhaust gas emission.

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References

[1] Sridharan G, Chandramouli R, Mohamed MM and Ashok KT. Performance, combustion and emission characteristics of a single cylinder CI engine running on diesel-biodiesel-water emulsion with additive. Energy Sources, Part A:

[2] Recovery, Utilization, and Environmental Effects, Taylor & Francis, 2019, https://doi.org/10.1080/15567036.2019.1704948, Pages 1-14

[3] Barbara Apicella, Ezio Mancaruso, Carmela Russo, Antonio Tregrossi, Maria Maddalena Oliano, Anna Ciajolo and Bianca Maria Vaglieco, Effect of after-treatment systems on particulate matter emissions in diesel engine exhaust, Experimental Thermal and Fluid Science. 116 (2020) 110107, 1-8.

[4] V Chintala, Amit Kumar, Ashish Karn, Swapnil S. Bhurat and Ayush Kumar Mishra, Development of an after-treatment device with low cost catalysts for NOx emission reduction from diesel engines. Proceedings of 7th International and 45th National Conference on Fluid Mechanics and Fluid Power (FMFP), 2018. 1-8.

[5] S Jenoris Muthiya and Senthilkumar Pachamuthu. Electrochemical NOx reduction and oxidation of HC and PM emissions from biodiesel fuelled diesel engines using electrochemically activated cell. International Journal of Green Energy, Taylor & Francis, 2018; 15(5): 314–324.

[6] Lee, J., Yang, S., Muniandi, B., Chien, M., Chen, K., Lin, Y., Lin, S., & Tsai, T. (2021). Multiphase active energy recycling technique for overshoot voltage reduction in Internet-of-Things applications. IEEE Journal of Emerging and Selected Topics in Power Electronics, 9(1), 58–67. https://doi.org/10.1109/jestpe.2019.2949840

[7] G. Elavarasan and Rajneesh Kaushal, Investigation of Metal doped-ZSM5 coated catalyst for emission reduction in a diesel engine fueled with biodiesel–diesel blends. International Journal of Ambient Energy, Taylor & Francis. 2022. https://doi.org/10.1080/01430750.2022.2056913.

[8] C Solaimuthu and P. Govindarajan. Performance Evaluation of a Urea-water Selective Catalytic Reduction (SCR) for a Diesel Engine with Mahua Bio Diesel. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. Taylor & Francis, 2015; 37(13):1424–1431.

[9] Praveen, V. Lakshmi Narayana, K. Ramanaiah. Influence of nano-additive Chlorella vulgaris microalgae biodiesel blends on the performance and emission characteristics of a DI diesel engine. International Journal of Ambient Energy, Taylor & Francis. 2020, 1-8.

[10] Harish Venu, Prabhu Appavu. Effect of nano additives in spirulina microalgae biodiesel–diesel blends in a direct injection diesel engine. International Journal of Ambient Energy, Taylor & Francis.2021, 1-9.

[11] R. V. S. Madhuri, A. Swarna Kumari, Comparative analysis on diesel engine fuelled with biodiesels blended with multi walled carbon nano tubes. International Journal of Ambient Energy. Taylor & Francis. 2021, 1-10.

[12] R. Sam Sukumar, Muralidhara Rao Maddula, A. Gopala Krishna, Experimental investigations with zinc oxide and silver doped zinc oxide nanoparticles for performance and emissions study of biodiesel blends in diesel engine. International Journal of Ambient Energy, Taylor & Francis.2013, 1-10.