International Journal of Emerging Science and Engineering (IJESE)
ISSN: 2319–6378 (Online), Volume-12 Issue-7, June 2024

Reduction of Emissions in a Single Cylinder Diesel Engine using Blends of Diesel & Cotton Seed Oil with Unconventional Catalytic Converter

K. Saikrishna, K. Kishor

Abstract: ***This paper investigates the feasibility of mitigating emissions from diesel engines through the combined application of alternative fuels and an unconventional catalytic converter employing cost-effective catalysts. The dwindling reserves of fossil fuels necessitate the exploration of sustainable power sources for internal combustion engines, thereby reducing our dependence on these finite resources. This study evaluated the performance parameters and emissions of a single-cylinder, four-stroke, stationary diesel engine fueled with blends of 10%, 20%, and 30% cottonseed oil in diesel (by volume). Following the identification of the optimal blend, a performance test was conducted again with the inclusion of a custom-designed and fabricated catalytic converter. Exhaust emissions were subsequently measured with and without the converter in operation. The design of the unconventional catalytic converter considered the engine's specifications, incorporating cerium oxide and sponge iron as oxidation catalysts for CO and hydrocarbon (HC) conversion. Charcoal was employed as a reduction catalyst to specifically target NOx emissions.***

Keywords: Emissions, Cotton seed oil, Unconventional catalytic converter, Cerium Oxide, Sponge Iron, Charcoal.

I. INTRODUCTION

Automobiles have become an essential mode of transportation for both humans and goods. Many forms of vehicular transportation heavily depend on burning gasoline and diesel, resulting in significant emissions of carbon monoxide (CO), unburned hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM). However, with the increasing population, the number of vehicles on the roads has also increased, leading to a rise in pollution which poses a severe threat to the biosphere. It is vital to not only control these emissions but also to reduce them as much as possible to ensure the safe living of future generations. Additionally, the limited availability of fossil fuels serves as a reminder to explore and adopt alternate renewable fuels such as biodiesels.

Manuscript received on 31 May 2024 | Revised Manuscript received on 14 June 2024 | Manuscript Accepted on 15 June 2024 | Manuscript published on 30 June 2024.
**Correspondence Author(s)*

K. Saikrishna*, Student, Department of Mechanical Engineering, Chaitanya Bharathi Institute of Technology, Hyderabad (Telangana), India. E-mail: kathrojusaikrishna1@gmail.com, ORCID ID: 0009-0004-5578-4188

Dr. K. Kishor, Associate Professor, Department of Mechanical Engineering, Chaitanya Bharathi Institute of Technology, Hyderabad (Telangana), India. E-mail: KKishor_mech@cbit.ac.in

When these alternate fuels are derived from plants and its related products, there is a chance of afforestation, energy conservation, sustainable growth, and environmental utilization. Vegetable oils have properties similar to diesel and can either be used as a substitute or an auxiliary fuel to power diesel engines. Among all the vegetable oils available, cottonseed oil is preferred due to its abundance and fast-growing nature, even in drought and poor soil conditions. Several researchers have found that the performance and emission characteristics of diesel engines are improved without any modifications by using cottonseed oil as fuel. Generally, in any engine, the mechanical energy required for the vehicle's propulsion is obtained by the combustion of the fuel. When the fuel undergoes combustion, the chemical energy is converted into thermal energy due to the breakage of the chemical bonds of the fuel. This thermal energy is converted into mechanical energy using piston and cylinder arrangement. In ideal case, combustion is complete, as a result, only carbon dioxide and water vapors are formed from it. In addition, nitrogen and residual oxygen are released into the atmosphere. But practically due to various reasons such as, insufficient residence time, poor mixing of the air and fuel, low total excess air, and insufficient temperature, combustion remains incomplete. Due to incomplete combustion, it produces toxic gases like carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx), which are dangerous for the environment and human life. Although there are various technologies available to reduce emissions, such as alternate fuels, improved engine design, fuel pre-treatment, fuel additives, and better tuning, the use of exhaust gas treatment is the most effective way to produce less toxic exhaust gases. One of the most efficient ways is to incorporate a catalytic converter. A catalytic converter is an accessory placed right after the engine to chemically convert the incomplete combustion products that are toxic into little safe gases, which are then released into the atmosphere. The conventional catalytic converter consists of a stainless steel container, which houses a honeycomb monolith made of ceramic or metal. The monolith is coated with a wash coat and active catalysts, which act as an inert substrate. A mixture of platinum and palladium in a 2:1 mass ratio is commonly used as an oxidation catalyst. It helps in converting carbon monoxide (CO) and hydrocarbons (HC) into carbon dioxide (CO2) and water (H2O). Rhodium, on the other hand, is a NOx reduction catalyst, which significantly reduces NOx to nitrogen (N2).

II. LITERATUXRE SURVEY

Mohd Yousuf Ali et al [1] [7] [8] [9] [10] [11] tested cotton seed oil (CSO)-diesel blends ranging from 10% to 50% CSO. The results showed the lower energy content of the blends increased mass flow rate, despite reduced specific energy input. Engine performance and emissions were influenced by differences in properties like heating value, viscosity, and density compared to diesel. Brake thermal efficiency decreased slightly with increasing CSO content, likely due to the higher viscosity degrading fuel spray and leading to incomplete combustion. Soot emissions increased with higher CSO blends due to poor atomization from the viscous oil. The densities and viscosities of the blends were higher, while heating values were reduced by 10% compared to diesel. Minor nozzle tip deposition was observed, but no fuel filter clogging. The researchers concluded blends up to 30% CSO could address short-term fuel shortages without modifications, though low-temperature operability remained challenging.

Radhakrishna et al [2] investigated the performance, emission, and combustion characteristics of a single-cylinder diesel engine using cotton seed oil (CSO) biodiesel blends (B5, B10, and B15) as alternative fuels. The results showed that the B10 blend exhibited a 13.92% improvement in brake thermal efficiency and 16.27% lower hydrocarbon emissions compared to pure diesel, though NOx emissions increased with higher CSO blends. The peak cylinder pressure for the B10 blend was 68 bar at 366° crank angle, and it had the highest heat release rate of 66 J/deg at 365° crank angle. Overall, the authors concluded that the B10 blend could be considered an optimal replacement for diesel in this engine.

The paper given by **Suresh et al [3]** evaluated the performance and emission characteristics of a single-cylinder diesel engine using cotton seed oil (CSO) and its blends with diesel as alternative fuels. The experiments were conducted with CSO-diesel blends ranging from 10% to 60% CSO by volume. The results showed that the CSO blends had lower brake-specific fuel consumption, had lower brake-specific fuel consumption, improved brake thermal efficiency, and increased mechanical and volumetric efficiencies compared to pure diesel. Emissions of carbon monoxide and hydrocarbons also decreased as the CSO percentage in the blend increased. The authors concluded that a 50% CSO blend could be a suitable substitute for diesel in terms of engine performance and emissions, and could be used in existing diesel engines without major modifications.

Mukul. M. Khalasane [4] concluded that among all the types of technologies developed so far, use of Metal Monolith type catalytic converters is the best way to control auto exhaust emission. Three-way catalyst with stoichiometric engine control systems remain the state of art method for simultaneously controlling hydrocarbon, CO and NOx emissions from vehicle. Economic considerations, alongside the finite availability of noble metals like platinum group metals, as well as operational constraints associated with catalytic converters relying on such metals, have spurred research into alternative catalyst materials. These catalytic converters have been designed for application in trucks, buses, motorcycles, as well as in construction equipment, lawn and garden machinery, marine engines, and other off-road engines.

Dillip Kumar and G. Mathiselvan [5] designed and developed a low-cost, non-noble based catalytic converter using titanium oxide (TiO_2) and cobalt oxide (Co_3O_4) as the oxidation and reduction catalysts. The authors designed and modelled the catalytic converter using CREO and SolidWorks, and analysed the flow and pressure drop using ANSYS FLUENT. The catalytic converter was fabricated with the TiO_2 and Co_3O_4 coated wire mesh substrates. The performance of the non-noble based catalytic converter was tested on a DI diesel engine and compared to the conventional noble metal-based catalytic converter. The results showed that the non-noble based catalytic converter reduced NOx, CO, and HC emissions by 27%, 32%, and 37% higher, respectively, compared to the conventional catalytic converter. The authors concluded that the TiO_2/Co_3O_4 oxide-based catalytic converter was effective for direct injection diesel engines and provided a cost-effective alternative to the noble metal-based converters.

The paper given by **SengoleRayan et al [6]** focused on the design and fabrication of a three-way catalytic converter using aluminium oxide (Al_2O_3) and silicon dioxide (SiO_2) as catalysts. The existing catalytic converter was analysed, and its dimensions were measured to create a wire mesh replica. The wire mesh was coated with Al_2O_3 and SiO_2 using an epoxy resin binder, heated, and arranged inside the catalytic converter. The fabricated converters were tested, and the emission characteristics were analysed. The results showed that the SiO_2-coated converter reduced nitrogen oxide (NOx) emissions by up to 20.38% at maximum load and 55.22% at minimum load. The Al_2O_3-coated converter reduced carbon monoxide (CO) emissions by up to 75% at maximum load and 80% at minimum load, and hydrocarbon (HC) emissions by up to 88.88% at maximum load and 80% at minimum load. The study demonstrated the potential of using cheaper and more readily available Al_2O_3 and SiO_2 as catalysts in catalytic converters to reduce harmful emissions from internal combustion engines.

III. DESIGN OF CATALYTIC CONVERTER

Fig 1 shows that the catalytic converter is composed of three main sections:

i) Divergent section, ii) Central shell, and iii) Convergent section.

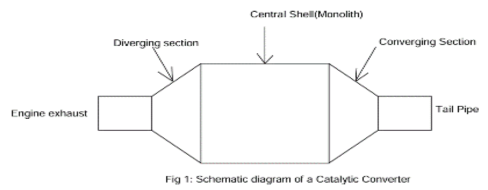

Fig 1: Schematic Diagram of Catalytic Converter Shape of Catalytic Converter

Retrieval Number: 100.1/ijese.F450213060824
DOI: 10.35940/ijese.F4502.12070624
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As the catalytic converter is placed right after the engine, it is exposed to high temperatures at one end and atmospheric or lower temperatures at the other end. Due to this sudden and high-temperature difference, the converter is subjected to uneven expansion and contraction stresses. The Divergent and Convergent sections are considered in the design to withstand these uneven expansion and contraction stresses.

The central shell of the converter is considered to be in a circular cross-section for the ease of manufacturing, and fabrication. Due to the circular cross-section thermal conductivity is increased and a considerable amount of back pressure is reduced.

A. Dimensions of Catalytic Converter

The size of the catalysts is an important factor to consider when designing the dimensions of a catalytic converter. The volume of the catalytic converter should be between 0.5 and 1 times that of the engine's swept volume. The volume of the catalytic converter also depends on the engine's swept volume and is inversely proportional to the space velocity. If the volume of the catalytic converter is less than half the engine's swept volume, the space velocity will increase significantly. This will prevent the reaction between the catalyst and exhaust gases, leading to an increase in emissions. Therefore, it is important to keep the volume of the catalytic converter within the range of the engine's swept volume. Based on the specifications of the engine, the catalytic converter has to be designed. Table 1 shows the engine specifications required for design of converter.

Table 1: Engine Specifications

Parameter	Specification
Engine make	Kirloskar
Engine Speed	1500 RPM
Bore(d)	80mm
Stroke(L_1)	110mm

Space Velocity: The space time necessary to process one reactor volume of fluid. It is also called as holding time or residence time.

Assuming (for single cylinder engine) = 45000 hr^{-1}

$$\text{Space Velocity} = \frac{\text{Volume flow rate}}{\text{Catalysts volume}}$$

Volume Flow Rate = Swept volume x number of intake strokes per hour

$$= \frac{\prod}{4} \times d^2 \times L_1 \times (N/2) \times 60$$

$$= \frac{\prod}{4} \times (0.08)^2 \times 0.11 \times 750 \times 60$$

Volume flow rate = 24.88 m^3/hr

$$\text{Catalysts Volume} = \frac{\text{Volume flow rate}}{\text{Space Velocity}}$$

Catalysts Volume = 24.881/45000 = 552.92 cc

Let length of the catalyst is equal to twice the diameter of the catalyst L = 2D

$$\text{Volume} = \prod/4 \times D^2 \times L$$

$$0.00055292 = \prod/2 \times D^3$$

Then D = 7 cm and L = 14 cm, where D is the diameter of the catalyst and L is length of the catalyst. Fig 2 indicates the modelling of obtained dimensions.

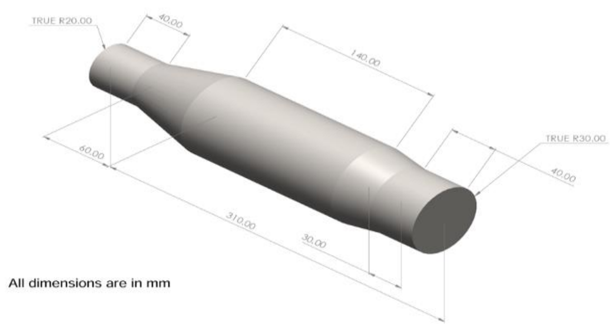

Fig 2: Model of Catalytic Converter

IV. METHODOLOGY

The present work focuses on the reduction of emissions in a single-cylinder diesel engine using the combined effect of alternate fuels and catalytic converter. Blends of cotton seed oil and diesel were obtained in the following proportions. Table 2 shows the proportions of fuels in blends.

Table 2: Proportions of Fuels in Blends

Blend	% of Cotton Seed Oil in Volume (ml)	% of Diesel in Volume (ml)
CSD10	10	90
CSD20	20	80
CSD30	30	70

The engine is coupled with electrical dynamometer for measuring the brake power of the engine. Water rheostat wheel is used to apply the load on the engine. The engine is provided with a pressure- lubrication feed system. Fig 3 indicates the photographic view and schematic diagram of the engine setup.

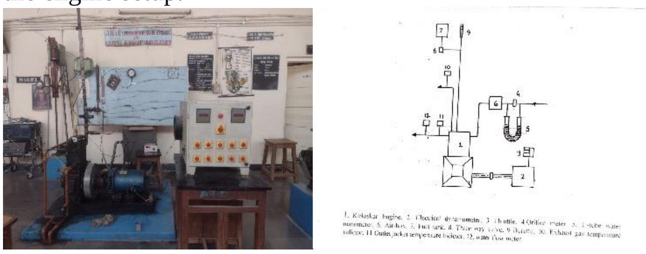

Fig 3: Photographic View and Schematic Diagram of Engine

There is no temperature control provided for measuring the temperature of lubrication oil. The governor, which controls the speed of the engine is a pneumatic governor. The exhaust gas temperature is measured with an iron and iron-constantan thermocouple.

For measuring the fuel consumption, burette method is used. Air-box method is used for measuring air consumption of the engine. Table 3 represents complete engine specifications.

Table 3: Engine Specifications

Engine Make	**Kirloskar**
No of Strokes	4
No of cylinders	1
Cylinder arrangement	Vertical
Compression ratio	16:1
Bore	80mm
Stroke	110mm
Cooling arrangement	Water cooled
Brake power	3.68 kW at the rated speed of 1500 rpm

A. Fabrication of Catalytic Converter:

Fabrication of catalytic converter involves the procurement of raw materials and joining the individual developed parts.

B. Outer shell:

The converter operates at a temperature above 600°C and below 800°C. Considering the mechanical and physical properties at a low cost, SS 304 is suitable for this application. A sheet of SS-304, 2mm thick and 2500 x 3100mm in size, was selected. The inlet, diverging section, central shell, converging portion, and outlet were marked on the sheet according to their dimensions. The marked pieces were then cut with an angle grinder, filed, bent into cylindrical shapes, and welded at the joining edges.

C. Catalysts:

Powders of Cerium oxide, Sponge iron, and Charcoal are used as the catalysts. Cerium oxide and Sponge iron have oxidizing properties to oxidize carbon monoxide(CO) and hydrocarbons(HC) into carbon dioxide(CO2) and water(H2O). Charcoal has reducing properties and reduces the Nitrogen oxides(NOX) to Nitrogen(N2).

D. Substrate:

SS-304 wire mesh is used as the substrate for its high temperature resistance and durability.

E. Fabrication Process:

The bent and welded individual outer parts were joined by the welding process except for one side so that the substrate could be inserted. The SS-304 wire mesh was cut into circular pieces of 7 cm diameter with a nipper. Those cut pieces were immersed in 10% HCL solution for one hour, rinsed in distilled water, and dried for 2 hours. Catalyst deposition was carried out using the dipping technique. For the sake of permanent bond formation, epoxy resin which is an adhesive was used. Catalyst slurries were prepared by mixing 100g of each catalyst with the adhesive individually. The wire meshes were dipped into the slurries and were kept at 50oC for four hours. Now these catalyst-deposited substrates are placed inside the central shell of the converter and welding was carried out. Below Fig 4 A, B, C represents the respective catalysts on the substrate.

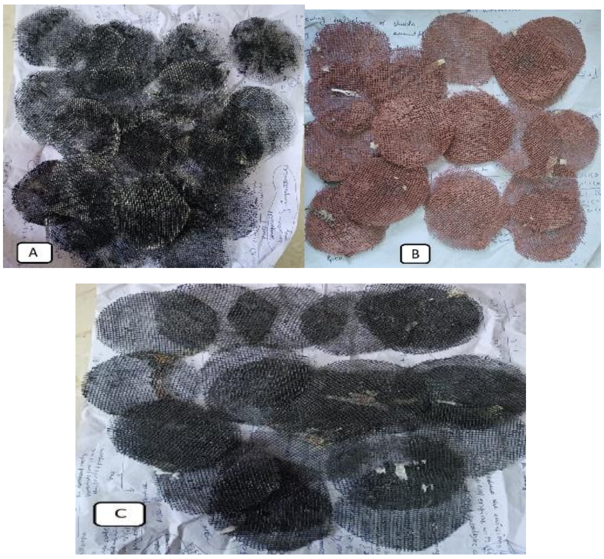

Fig 4: A) Charcoal Deposited Mesh B) Cerium Oxide Deposited Mesh C) Sponge Iron Deposited Mesh

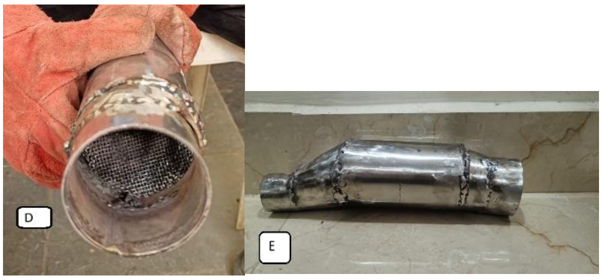

Fig 5: D and E Represents Fabricated Catalytic Converter

Fig 5 D and E represents the images of fabricated catalytic converter.

F. Operating the Engine:

Initially, the engine is operated by using Diesel at various loading conditions. Subsequently, Diesel is replaced by the different experimental samples/blends that are mentioned. After recording the observations of Diesel, the fuel tank is emptied and Blend 1 is introduced. This process is carried out again for the succeeding blends. The readings required for the calculation of performance parameters such as brake thermal efficiency, brake specific fuel consumption, air-fuel ratio, and volumetric efficiency were taken. Now based on the experimental parameters, the performance parameters were calculated and evaluated for every blend. Those performance parameters were compared with each other and the required effective blend out of these blends was found.

G. Testing of Catalytic Converter:

Now a test is again conducted by taking the effective blend out of the blends that were carried out. Firstly, emissions were analyzed at no load conditions without catalytic converter. Next, Catalytic converter was incorporated at the exhaust of the engine, and the emissions obtained from the catalytic converter were analyzed. The same procedure is repeated at 25%, 50%, 75%, and 100% loads and the emissions with and without catalytic converter were carefully noted down.

Retrieval Number: 100.1/ijese.F450213060824
DOI: 10.35940/ijese.F4502.12070624
Journal Website: www.ijese.org

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Average of those obtained values were taken to obtain final values of emissions. Next, a smoke meter is used to find out the HSU values obtained from the emissions. HSU values of emissions with and without the catalytic converter were taken. Fig 6 indicates the testing of catalytic converter using gas analyzer and smoke meter.

Fig 6: Testing of Catalytic Converter

V. RESULTS

A. BTE vs BMEP

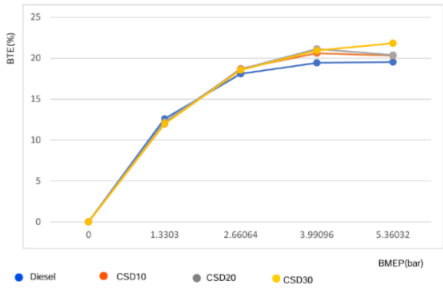

Fig 7: Graph between Brake Thermal Efficiency (%) and Brake Mean Effective Pressure (Bar)

The brake thermal efficiency indicates the proportion of power extracted by the engine crankshaft from the total power generated through fuel combustion. Across all tested blended fuels, this efficiency improves with increasing applied load. This phenomenon can be attributed to reduced heat loss and heightened power output in response to increased load. Comparing the baseline brake thermal efficiency results between diesel and blends, it is found that the brake thermal efficiency for CSD20 was higher than for diesel runs. From figure 7, an 8.7% increment in brake thermal efficiency of CSD20 over diesel was observed.

B. BSFC vs BMEP

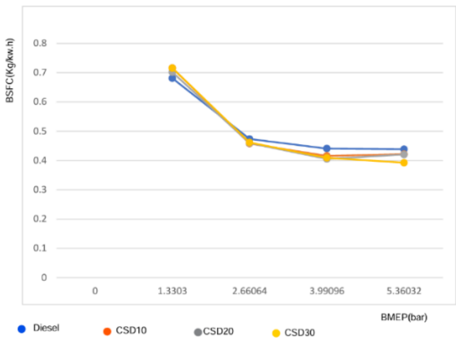

Fig 8: Graph Between Brake Specific Fuel Consumption (Kg/hr) and Brake Mean Effective Pressure (Bar)

Brake Specific Fuel Consumption is a measure of the fuel efficiency of any engine that burns fuel and produces rotational power output. BSFC serves as a crucial parameter for assessing the fuel efficiency of engines utilizing combustible fuel to generate rotational power. Among the factors influencing blends' performance in terms of BSFC, the calorific value stands out prominently. A higher calorific value generally indicates lower BSFC, as a decrease in calorific value means more fuel consumption for equivalent power output. CSD20 has a significant decrease in BSFC making it more fuel efficient. From figure 8 an 8.03% decrement in brake specific fuel consumption for CSD20 was observed.

C. A:F Ratio vs BMEP

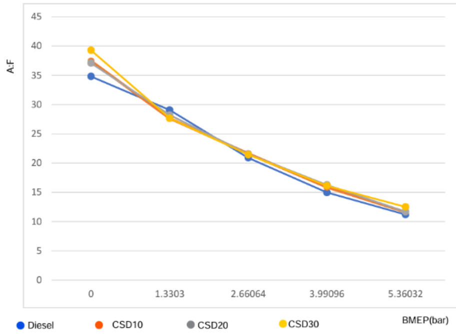

Fig 9: Graph between Air-Fuel Ratio and Brake Mean Effective Pressure (Bar)

For diesel engines as the load increases, the brake power increases and the air-to-fuel ratio decreases. The results of the air-fuel ratio for all runs are given in Fig.9. The pattern of the graph shows that the air-fuel ratio declined when the load was increased. This condition is due to the requirement of more fuel to maintain the engine speed at 1500 rpm while the load was increased. Comparing the baseline air-fuel ratio results between diesel and blends, it is found that the air-fuel ratio for CSD20 was higher than for diesel runs. This is due to less fuel requirement owing to the high calorific value of blend CSD20. Among all blend models, the highest air-fuel ratio was recorded with the CSD20 model especially at higher loads due to the effectiveness of the CSD20 model which resulted in better combustion. A 6.54% increment of air-to-fuel ratio was observed in CSD20 when compared with diesel.

D. Gas Analysis Results

The following table shows the values of gas percentages obtained from the gas analyser on testing of the diesel engine at various loads, before and after incorporating the catalytic converter. The change of values was carefully observed and taken. Table 4 indicates the gas analyzer readings.

Table 4 Gas Analyser Readings

Gases	Before Catalytic Converter	After Catalytic Converter
CO	0.087%	0.035%
O_2	18.42%	18.51%
CO_2	3.348%	3.785%
HC	67 PPM	56.8 PPM

Retrieval Number: 100.1/ijese.F450213060824
DOI: 10.35940/ijese.F4502.12070624
Journal Website: www.ijese.org

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A significant decrease in CO and HC values was observed. This decrement in percentages of CO and HC indicates that the oxidation of CO and HC was successfully carried out by the oxidation catalysts Cerium oxide and Sponge Iron, that were incorporated in the catalytic converter. Slight increase in CO2 and O2 values was observed because of the conversion of HC and CO to CO2 and O2 by oxidation processes.

E. Smoke Meter Results

The Hartridge Smoke Unit (H.S.U) is a measure of smoke opacity. A value of 0 indicates perfect transmission with no smoke, while a value of 100 indicates complete opacity with total absorption of smoke. The following figures show the change in smoke meter values before and after incorporating the catalytic converter. We can clearly see the decrease in smoke meter values after incorporating the catalytic converter. Fig 10 A, B represents results of smoke meter before and after placing the catalytic converter.

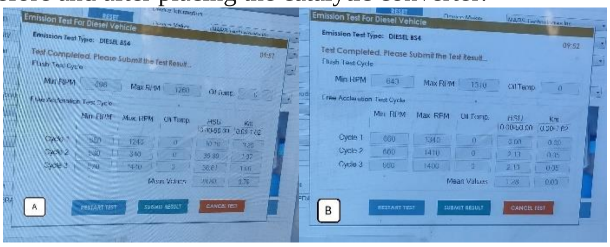

Figure 10 A) Without Catalytic Converter B) with Catalytic Converter

Table 5 HSU Readings

	Without Catalytic Converter	With Catalytic Converter
HSU	28.80	1.28

Table 5 indicates the results of smoke meter before and after placing the catalytic converter. A major decrement of HSU values can be seen after incorporating the catalytic converter due to the presence of wire mesh and charcoal which has great adsorption as well as absorption properties.

VI. CONCLUSIONS

1. Comparing the baseline air-fuel ratio results between diesel and blends, it is found that the air-fuel ratio for CSD20 was higher than for diesel runs. This is due to less fuel requirement owing to the high calorific value of blend CSD20. Among all blend models, the highest air-fuel ratio was recorded with the CSD20 model especially at higher loads due to the effectiveness of the CSD20 model which resulted in better combustion. A 6.54% increment of air-to-fuel ratio was observed in CSD20 when compared with diesel.
2. A higher calorific value generally indicates lower BSFC, a decrease in calorific value means more fuel consumption for equivalent power output. CSD20 has a significant decrease in BSFC making it more fuel efficient. CSD20 has a significant decrease in BSFC making it more fuel efficient. There is an 8.03% decrement in brake specific fuel consumption for CSD20.
3. In the case of every blended fuel that was tested, it rises as the amount of load that is applied. This can be explained by a decrease in heat loss as well as an increase in power output in response to an increased load. Comparing the baseline brake thermal efficiency results between diesel and blends, it is found that the brake thermal efficiency for CSD20 was higher than for diesel runs. An 8.7% increment in brake thermal efficiency of CSD20 over diesel was observed.
4. Due to the oxidation of CO to CO_2, HC to CO_2, and O_2 by the oxidation catalyst Cerium oxide, the CO and HC emissions were decreased by 58.8% and 15.21% respectively.
5. Due to the oxidation processes, slight increase in CO_2 and O_2 was observed. The percentages of increment were 13.05% and 5.23% respectively.
6. A significant decrement of HSU values can be seen after incorporating the catalytic converter due to the presence of wire mesh and charcoal which has great adsorption as well as absorption properties. 95.5% decrease in HSU values were seen when the catalytic converter was incorporated.

In conclusion, the project's objective was to improve the engine performance and reduce emissions. By performing the experiments and conducting the studies, we can finally conclude that performance improvement and emission reduction can be obtained by the combined effect of using alternate fuels and a catalytic converter. The inexpensive catalysts Cerium oxide, Sponge Iron, and Charcoal are found to be good enough to reduce the emissions.

DECLARATION STATEMENT

Funding	This work is funded by DOST - ERDT, a government scholarship grant.
Conflicts of Interest	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material	Not relevant.
Authors Contributions	Each author has made an independent contribution to the article. The individual contributions of each author are presented below for clarity and transparency. Kathroju Saikrishna carried out the necessary research, fabrication, testing, and writing the paper. Dr. K. Kishor evaluated the paper.

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AUTHORS PROFILE

Dr. K. Kishor, is working as associate professor at Chaitanya Bharathi Institute of Technology in Mechanical Engineering Department. Fluid Principles and Hydraulic Machines (FPHM), Thermo dynamics (TD), Hydraulic Machinery & Systems (HMS), Applied Thermodynamics (ATD), Turbo Machinery (TM), Renewable Energy Sources (RES), Power Plant Engineering (PPE), Engineering Graphics (EG), Mechanical Technology (MT), Mechanical Engineering (ME), Advanced IC Engines (AICE), Turbo Machines (TM) are some of the subjects handled.

Kathroju Saikrishna, completed his B.E in Mechanical Engineering in 2024 from Chaitanya Bharathi Institute of Technology and areas of interest are I.C Engines, Sustainable development, Emissions treatment.