# 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 examines the feasibility of reducing emissions from diesel engines by combining the use of alternative fuels with an unconventional catalytic converter that utilises costeffective 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, this time 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 was tailored to the engine's specifications, incorporating cerium oxide and sponge iron as oxidation catalysts for the conversion of CO and hydrocarbons (HCs). Charcoal was employed as a reduction catalyst to target NOx emissions specifically.

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 alternative renewable fuels, such as biodiesel.

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When these alternate fuels are derived from plants and their related products, there is a chance of afforestation, energy conservation, sustainable growth, and environmental utilisation. Vegetable oils have properties similar to those of diesel and can be used either 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 can be improved without modification 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 a piston and cylinder arrangement. In the ideal case, combustion is complete, resulting in the formation of only carbon dioxide and water vapour. In addition, nitrogen and residual oxygen are released into the atmosphere. However, due to various practical reasons, such as insufficient residence time, poor mixing of air and fuel, low total excess air, and insufficient temperature, combustion remains incomplete. Due to incomplete combustion, it produces toxic gases such as carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx), which are hazardous to the environment and human health. Although various technologies are available to reduce emissions, such as alternative 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 immediately after the engine to chemically convert the incomplete combustion products that are toxic into harmless 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).

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### II. LITERATURE SURVEY

Mohd Yousuf Ali et al [1] tested cotton seed oil (CSO)diesel blends ranging from 10% to 50% CSO. The results showed that the lower energy content of the blends increased the mass flow rate, despite a reduced specific energy input. Differences in properties, such as heating value, viscosity, and density, influenced engine performance and emissions 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 was observed. The researchers concluded that 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 a 366° crank angle, and it had the highest heat release rate of 66 J/°C at a 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 cottonseed oil (CSO) and its blends with diesel as alternative fuels. The experiments were conducted using CSO-diesel blends with volumes ranging from 10% to 60% CSO. The results showed that the CSO blends 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. They could be used in existing diesel engines without significant 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 catalysts with stoichiometric engine control systems remain the state-of-the-art method for simultaneously controlling hydrocarbon, CO, and NOx emissions from vehicles. Economic considerations, alongside the finite availability of noble metals such as platinum group metals, as well as operational constraints associated with catalytic converters that rely on these 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 (TiO2) and cobalt oxide (Co3O4) 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 using TiO2- and Co3O4-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%, respectively, compared to the conventional catalytic converter. The authors concluded that the TiO2/Co3O4 oxide-based catalytic converter was effective for directinjection diesel engines, offering a cost-effective alternative to converters based on noble metals.

The paper given by SengoleRayan et al [6] focused on the design and fabrication of a three-way catalytic converter using aluminium oxide (Al2O3) and silicon dioxide (SiO2) 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 Al2O3 and SiO2 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 SiO2-coated converter reduced nitrogen oxide (NOx) emissions by up to 20.38% at maximum load and 55.22% at minimum load. The Al2O3-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 Al2O3 and SiO2 as catalysts in catalytic converters to reduce harmful emissions from internal combustion engines.

#### **III. DESIGN OF CATALYTIC CONVERTER**

Figure 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



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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 stresses resulting from expansion and contraction. 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 designed to have a circular cross-section for 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 essential 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, thereby reducing emissions. Therefore, it is essential to maintain the volume of the catalytic converter within the engine's swept volume range. Based on the engine's specifications, the catalytic converter must be designed. Table 1 presents the engine specifications necessary for the converter design.

**Table 1: Engine Specifications** 

Parameter	Specification
Engine make	Kirloskar
Engine Speed	1500 RPM
Bore(d)	80mm
Stroke(L1)	110mm

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

Assuming (for single cylinder engine) = 45000 hr<sup>-1</sup>

#### Volume flow rate

Space Velocity =

Catalysts volume

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

$$= \frac{\prod}{4} x d^{2} x L_{1} x (N/2) x 60$$
$$= \frac{\prod}{4} x (0.08)^{2} x 0.11 x 750 x 60$$

Volume flow rate =  $24.88 \text{ m}^3/\text{hr}$ 

Volume flow rate

Catalysts Volume =

Space Velocity

Catalysts Volume = 24.881/45000 = 552.92 cc

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

Volume = 
$$\prod/4 \times D^2 \times I$$

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

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



Figure 2: Model of Catalytic Converter

# **IV. METHODOLOGY**

The present work focuses on reducing emissions in a single-cylinder diesel engine by combining the effects of alternative fuels and a catalytic converter. Blends of cottonseed oil and diesel were obtained in the following proportions. Table 2 shows the 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 an electrical dynamometer for measuring the engine's brake power. A water rheostat wheel is used to apply a load to the engine. The engine is equipped with a pressure-lubrication feed system. Figure 3 indicates the photographic view and schematic diagram of the engine setup.





Figure 3: Photographic View and Schematic Diagram of the Engine

There is no temperature control provided for measuring the temperature of lubrication oil. The governor, which controls the speed of the engine, is pneumatic. The exhaust gas temperature is measured using an

iron-constantan thermocouple.

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For measuring the fuel consumption, the burette method is used. The air-box method is used to measure the engine's air consumption. 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 a catalytic converter involves the procurement of raw materials and the joining of the individual parts that have been developed.

# 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, 2 mm thick and 2500 x 3100 mm 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 oxidising properties that enable them to oxidise carbon monoxide (CO) and hydrocarbons (HC) into carbon dioxide (CO2) and water (H2O). Charcoal has reducing properties and reduces 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, allowing the substrate to 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 a 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, an epoxy resin —a type of adhesive —was used. Catalyst slurries were prepared by mixing 100g of each catalyst with the adhesive individually. The wire meshes were immersed in the slurries and then maintained at 50 °C for four hours. These catalystdeposited substrates are then placed inside the central shell of the converter, and welding is carried out. Figures 4A, B, and 4C represent the respective catalysts on the substrate.





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



Figure 5: D and E represent the Fabricated Catalytic Converter

Fig. 5 D and E represent the images of the 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 or blends mentioned. After recording the observations of Diesel, the fuel tank is emptied, and Blend 1 is introduced. This process is repeated for the succeeding blends. The readings required for calculating performance parameters, such as brake thermal efficiency, brake specific fuel consumption, air-fuel ratio, and volumetric efficiency, were taken. Based on the experimental parameters, the performance parameters were calculated and evaluated for each blend. Those performance parameters were compared with each other, and the required effective blend was identified among these blends.

# G. Testing of Catalytic Converter:

A test is now conducted again by removing the effective blend from the previously carried out blends. Firstly, emissions were analysed at no-load conditions without a catalytic converter. Next, a Catalytic converter was incorporated into the engine's exhaust, and the emissions produced by the catalytic converter were analysed. The same procedure is repeated at 25%, 50%, 75%, and 100% loads,

and the emissions with and without a catalytic converter are carefully noted.



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The average of those obtained values was taken to get the 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 the catalytic converter using a gas analyser and smoke meter.



Figure 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

Retrieval Number: 100.1/ijese.F450213060824 DOI: <u>10.35940/ijese.F4502.12070624</u> Journal Website: <u>www.ijese.org</u> 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 the performance of blends in terms of BSFC, the calorific value stands out prominently. A higher calorific value generally indicates a lower BSFC, as a decrease in calorific value means more fuel consumption for a given power output. CSD20 exhibits a significant reduction in BSFC, thereby increasing its fuel efficiency. 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 presented in Fig. 9. The graph's pattern shows that the air-fuel ratio declined as the load increased. This condition is caused by the increased fuel requirement necessary to maintain engine speed at 1500 rpm when the load is 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 the lower fuel requirement resulting from 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% increase in air-to-fuel ratio was observed in CSD20 compared to 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 the Catalytic Converter	After the Catalytic Converter
CO	0.087%	0.035%
$O_2$	18.42%	18.51%
CO <sub>2</sub>	3.348%	3.785%
HC	67 PPM	56.8 PPM

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A significant decrease in CO and HC values was observed. This decrease in percentages of CO and HC indicates that the oxidation of CO and HC was successfully carried out by the oxidation catalysts, namely Cerium oxide and Sponge Iron, which were incorporated into the catalytic converter. A 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 see the decrease in smoke meter values after incorporating the catalytic converter. Fig. 10 A, B represents the results of the smoke meter before and after placing the catalytic converter.



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



		8
	Without a	With a Catalytic
	Catalytic	Converter
	Converter	
HSU	28.80	1.28

Table 5 presents the results of the smoke meter before and after the installation of the catalytic converter. A significant decrease in HSU values is observed after incorporating the catalytic converter, due to the presence of wire mesh and charcoal, which possess both adsorption and 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 the lower fuel requirement resulting from 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% increase in air-to-fuel ratio was observed in CSD20 compared to diesel.

2. A higher calorific value generally indicates a lower BSFC; a decrease in calorific value means more fuel consumption for an equivalent power output. CSD20 exhibits a significant reduction in BSFC, thereby increasing its fuel efficiency. CSD20 exhibits a substantial decrease in BSFC, thereby increasing its fuel efficiency. There is an 8.03% decrease in brake-specific fuel consumption for the CSD20.

3. In the case of every blended fuel tested, the pressure rises as the load is increased. 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, a slight increase in  $CO_2$  and  $O_2$  was observed. The percentage increments were 13.05% and 5.23%, respectively.

6. A significant decrease in HSU values can be observed after incorporating the catalytic converter, due to the presence of wire mesh and charcoal, which possess both adsorption and absorption properties. A 95.5% decrease in HSU values was seen when the catalytic converter was incorporated.

In conclusion, the project's objective was to improve the engine performance and reduce emissions. By conducting the experiments and studies, we can conclude that performance improvement and emission reduction can be achieved through the combined effect of using alternative fuels and a catalytic converter. The inexpensive catalysts, including Cerium oxide, Sponge Iron, and Charcoal, are found to be effective in reducing emissions.

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Availability of Data and Materials	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 wrote the paper. Dr. K. Kishor evaluated the paper.

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