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Enhancing diesel engine sustainability using paradise seed oil as an alternative fuel

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Abstract

In this article, a four-stroke, single-cylinder, direct injection, water-cooled diesel engine's performance, combustion, and emissions are computed using the influence of raw Paradise seed oil (PSO). In this investigation, several substances were used: diesel, PSO 10 (10% PSO + 90% diesel), PSO 20, PSO 40, PSO 60, and PSO 100 (100% PSO). The experiment was performed with four loading conditions such as 0, 1.75, 3.5, and 5 kW, a constant engine speed of 1500 rpm, and a compression ratio of 17.5:1. Investigations proved that without engine modifications, a CI engine may operate on raw oil blends adequately. The results indicated that with higher blends, the result was some loss of performance and a lack of combustion. As compared to diesel, the results indicate that at higher loads, brake specific energy consumption (BSEC) increased by 4-9%, and brake thermal efficiency (BTE) reduced by 4-9% for PSO blends. Considering PSO and its diesel mixtures to diesel, both of them reduced cumulative heat release rate (CHRR) by 1.8-15.7 percent and a net heat release rate (NHRR) by 15-48 percent. PSO mixtures slightly shoot the emissions of hydrocarbons and reduced nitrogen oxide emissions by approximately 20 percent compared to diesel fuel.

Keywords: Performance, combustion, sustainability, oxides of nitrogen, raw oil

1. Introduction

The manufacturing as well as consumption of energy determine a nation's growth and its rate of progress. The worldwide trend toward growth in industrialization and automation has led to a significant rise in the overall consumption of energy [1]. The total quantity of energy spent internationally is rising every year as in 2019 carbon dioxide emissions from burning fossil fuels exceeded 38 billion tons. By 2040, the global use of energy is predicted to have grown by over 25 percent [2]. Automotive fuel takes approximately 24% of the energy consumed by transportation, manufacturing, and energy production, and diesel makes up 66%. The primary concerns consist of a rapid reduction of fossil fuel savings, increasing awareness of environmental challenges to the security of energy, variations in consumers availability of energy, and high costs of gasoline and diesel. Considering it is renewable and environmentally friendly, has an improved thermal value, has lower sulfur, dissolves in nature, and has fewer carbon effects than petroleum fuels, Vegetable oil is an effective substitute for these fuels [3]. Many eating and non-edible vegetable oils along with oils produced from bioenergy have recently been the focus of various investigations for use in diesel engine applications. On the other hand, engines that depend on vegetable oils could develop problems with performance as the oils are not as unstable and have more viscosity [4]. Among all of the vegetable oils offered, PSO, called paradise seed oil (Simarouba Glauca), acts as an unusable oil containing a high concentration of oil content [5]. The entire surface of unused lands in India was 55.76 million acres, among which 17.95 million acres can be found in Tamil Nadu [6].

The most economical to grow Simarouba in these places is to yield biofuel for a long period. Also, the food and pharmaceutical industries neglect PSO's value [7]. This is a versatile tree that grows effectively under low-quality soil. It can be grown in dry places and sustain heat as high as 45°C. Over 60 percent of oil can be extracted from paradise seed, and an adequate tree can yield 5 kg of oil from approximately 22 kg of nutlets, and an equal quantity of various by-products.

Every acre of land, every single tree yields approximately 2000 kg of oil with an equivalent volume of oil cake [8]. Utilizing 50% paradise oil biodiesel, investigators [9, 10] were able to minimize smoking and hydrocarbons (HC) pollutants by 22% and 33%, respectively, using a single-cylinder diesel engine. Then the results of a 50% combination of eucalyptus and paradise oil in another investigation [11], then reached their conclusion of reduced emission levels enhanced performance and ignition properties. According to recent studies, PSO represents an exciting starting point for biodiesel synthesis and an excellent option for replacing diesel fuel in a few years. The potential of utilizing raw PSO and its blends as an alternative fuel in the CI engine, however, hasn't been tested. This investigation seeks to offer a comprehensive understanding of PSO's potential, then its feasibility of applying it for a diesel engine alternative fuel, and the most effective composition for an engine to operate effectively and make modifications.

2. Resources and Procedures

2.1 Vegetable oil Extraction

While being collected from Gujarat, India, paradise seed oil seeds were exposed to the sun and embellished. Figure 1a illustrates how the roasted simarouba fruit was skinned by hand; Figures 1(b) and 1(c) show when the shells and seeds were extracted. A motorized screw pump was utilized to remove the oil. The pollutants in this PSO will make it more challenging to make biodiesel from glycerol. During the introduction of hexane and stirring for 10 to 25 minutes, PSO was heated to 25 to 45 degrees Celsius and departed to cool down to 30 minutes. The impurities that accumulated at the bottom were extracted. It allowed for hexane to dissipate. Free fatty acids, or FFA, are defined as a percentage of oleic acid. PSO has approximately 4 percent FFA, therefore an initial treatment and main transesterification were carried out.

Fig 1: a) Simarouba Tree Broken Fruits, Shells, and Kernels, b) Simarouba Tree Seed Before, c) After Decortication

2.2 Fuel Properties

Simarobuba seed oil serves as an extremely viscous and non-edible oil which is incorporated in various ratios with diesel to determine the engine's efficiency in a single-cylinder diesel engine. As shown in Table 1, the characteristics of the fuel mixes were assessed using ASTM (American Standard for Testing Materials) standards.

Table 1: Properties of Paradise Oil

Fuel Property	ASTM D975 Diesel	PSO	ASTM D6751 (Biodiesel)	ASTM Method Used
Density at 30°C (gm/cc)	0.830	0.909	0.86 - 0.90	D 4052
Kinematic Viscosity at 40°C (cSt)	1.9 - 4.1	45.75	1.9 - 6.0	D 445
Heating Value(kJ/kg)	43,000	39,229	-	D240
Flash Point (°C)	45 - 60	258	100 - 170	D93
Fire Point (°C)	72	342		D92
Cloud Point (°C)	-15 to 5	25	-3.0 to 12	D2500
Pour Point (°C)	-35 to -15	19	-15 to 16	D 97
Acid Value (mg KOH/g)	0.05	6.9348	0.8 max	D664
Carbon Residue wt. (%)	0.35	1.56	0.050 max.	D 2500-05
Sulfur wt. (%)	0.045	0.016	0.050max.	D 2622
Ash Content wt. (%)	0.01	0.005	<0.02	D 482
Boiling point(°C)	197	271	37 - 285	D86

The primary properties of fuel mixtures are density, flash, fire point, kinematic viscosity, and calorie content. Essential variables to take into consideration include the pH value, cloud, flow point, and so on. Table 1 shows PSO is a more stable fuel than diesel due to its reduced flash and fire point. However, such fuels' viscous properties can be helpful for lubrication and it leads to a lack of atomization and inadequate combustion [12]. PSO contains a molecular weight of 600-900, which is approximately 12 times that of diesel fuel, causing its raised viscosity. Diesel fuel contains a specific gravity that varies from 0.80 to 0.86. PSO has a density that is approximately 7.8% more than diesel due to its considerable viscosity. A higher boiling point provides inadequate combustion and petroleum invasion, which extends the impact. The thermal energy of combustion values of PSO and diesel are shown in Table 1. It is compatible with [13], which suggests that fuel heating power can be measured by a level of saturation. Approximately 8% less energy is present in PSO compared to diesel. Fuel-bound oxygen and lubricated characteristics will be utilized to make up for this loss. The meaning of "acid values" refers to the quantity of potassium hydroxide that is needed to destroy one gram of lipid acid; the official process of the American Oil Chemists Society (AOCS) specifies the highest possible value at 0.5 mg KOH/g. A lubricant's lifespan and state of health are indicated by this, which is often referred to as the neutralization number (NN), and it signifies the lifetime of the oil and its fitness whereas oil is in service. NN of PSO is 6.9348 mg KOH/g [14].

Design of Experiments in CI Engine: A water-cooled, single-cylinder diesel engine was utilized for the tests, as shown in Figure 2. Most of the engine's parameters are given in Table 2. An AVL 437 smoke meter was used to detect smoke, and an AVL Di-gas 4000 gas analyzer was used to determine the substance of exhaust gases. In the beginning, diesel fuel serves to run the engine until it reaches a steady condition. In each fuel sample, engine exhaust emission levels, torque, speed, fuel, and air feeds, and the temperature of the exhaust gases (EGT) were determined and averages at three separate points. A computational data collection system (DAQ; AVL INDISMART 612) serves for collecting data, particularly the cylinder pressures. A maximum of 1000 cycles of data can be computed and stored using DAQ.

Table 2: Engine Conditions

Make	Kirloskar
Type	Single Cylinder, Four stroke, Direct Injection
Displacement (cm^3)	661
Number of Cylinders	1
Compression Ratio	17.5: 1
Bore & Stroke (mm)	87.5 x 110
Connecting Road Length (mm)	185
Dynamometer Type	Eddy Current
Speed (rpm)	1800
Rated Power (kW)	5.9
Cooling System	Water cooling
Injection Timing	23° bTDC
Injection pressure (bar)	200
Lubrication System	Forced Feed system

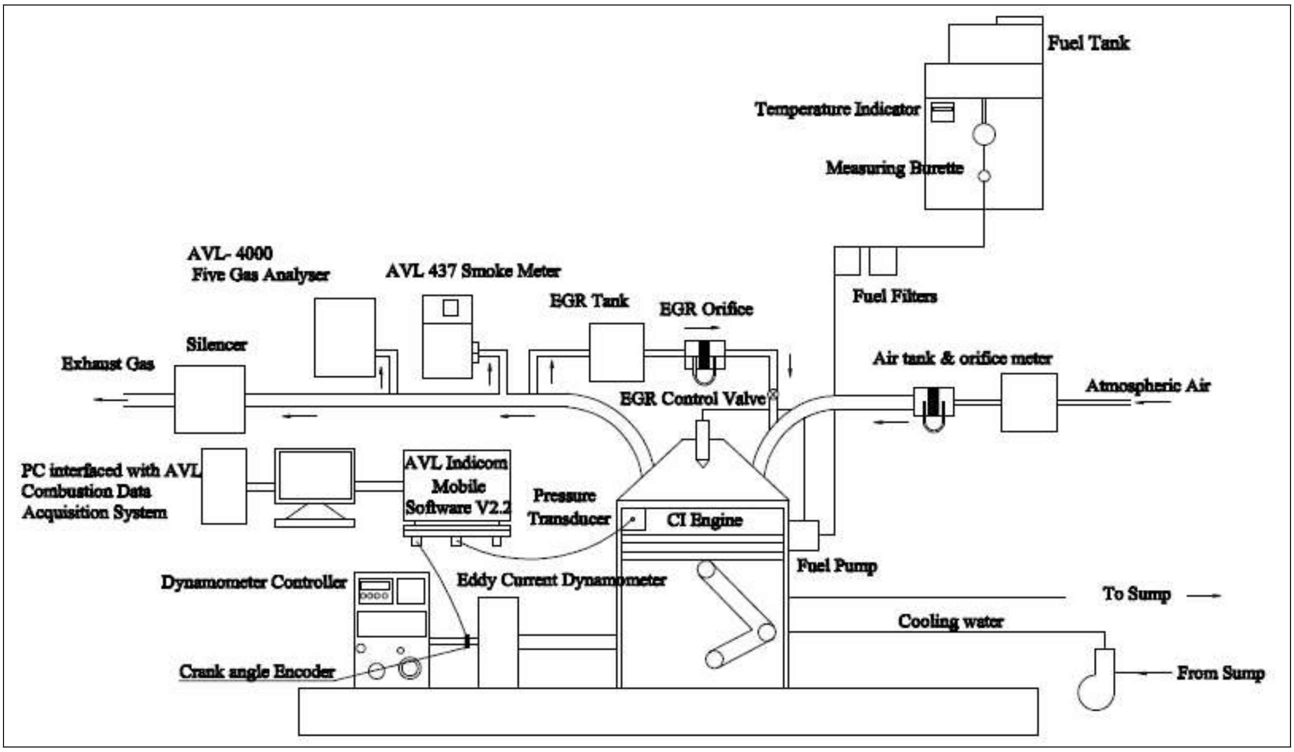

Fig 2: Diagram Design of Investigational Arrangement

The National Accreditation Board for Testing and Calibration Laboratories (NABL 141) methods and ISO/IEC 17025 specifications were utilized to perform the probability evaluation of diesel engine efficiency, the combustion process, and emission factors [15]. According to the "Evaluation of Measurement data-Guide to the Expression of Uncertainty in Measurement" (GUM) approach, the error and percentage uncertainty during the experimental trials resulting from the workplace conditions at work, tool selection, precision, and reliability of the results were calculated. The accuracy, precision, and resolution of the equipment were taken into consideration while calculating the percentage uncertainty of the engine findings. To further lessen the sense of risk that occurred during the process of experimentation, the accuracy of the result was also evaluated. A linear and standard distribution containing a confidence level of 95% range was chosen for precision and accuracy to identify the highest level of uncertainties. The total and expanded variance of the data from experiments are shown by equations (1) and (2), respectively. Specific data for engine efficiency and emission characteristics are shown in Table 3.

Table 3: Uncertainties in Engine Performance and Emission Constraints

S. No.	Engine Characteristics	Experimental Percentage Uncertainties
1.	Engine speed	± 0.47
2.	Load	± 2.31
3.	Brake power	±3.18
4.	Total fuel consumption	±1.02
5.	Brake-specific fuel consumption	±3.743
6.	In-cylinder pressure	±1.20
7.	Carbon monoxide	±3.9
8.	Hydrocarbon	±5.7
9.	Nitric oxide	±0.9
10.	Smoke emission	±1.8

$$U_{Combined} = \sqrt{(U_{\text{repeatability}})^2 + (U_{\text{accuracy}})^2 + (U_{\text{resolution}})^2 + (U_{\text{precision}})^2 + (U_{\text{calibration}})^2} \quad (1)$$

$$U_{expanded} = \frac{U_{Combined}}{2} \quad (2)$$

4. Results and Discussions

4.1 Performance Parameters

The efficiency parameters of the diesel engines based on each of the testing fuels were reviewed in this section. Diesel fuel is utilized as standard fuel for assessing emission and efficiency.

4.2 Brake Thermal Efficiency

Figure 3 illustrates how, even at full loads, the Brake Thermal Efficiency (BTE) of fresh oil was lower than that of diesel. Under 5kW load conditions, PSO10, PSO20, PSO40, PSO60, and PSO100 had BTEs that were 4.11, 4.50, 6.09, 6.71, and 9.00% lower than pure diesel fuel.

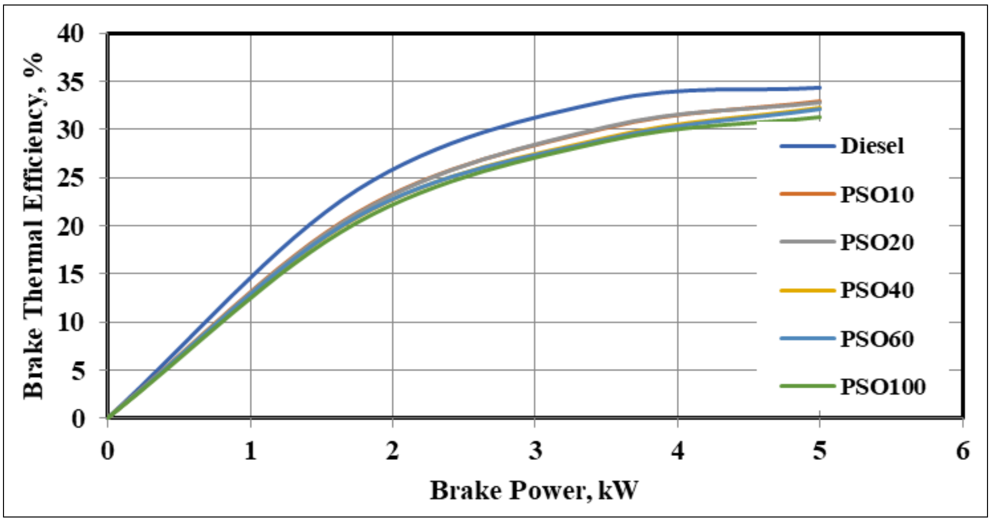

Fig 3: Brake Thermal Efficiency (BTE) of fresh oil

Similarly, raw oil blends at 1.75 and 3.5kW decreased BTE compared to diesel by about 11.08-18.05% and 8.46-12.72%, respectively. Because of its higher density and viscosity, distinct distillation properties, poor spray characteristics, air-fuel mixing, low volatility, and CV [16], it burns inadequately when compared to diesel [17] because the spray has a confined cone angle and the tip pierces more deeply. BTE was significantly reduced when the raw oil content was increased. The percentage reduction also dropped as the load grew. At higher loads, atomization was better than at lower loads because the heating chamber's heat was extremely high.

4.3 Brake-Specific Energy Consumption

A reliable statistic for evaluating fuels with significantly varying density and calorific values is brake specific energy consumption of or BSEC. As illustrated in Figure 4, the BSEC of PSO10, PSO20, PSO40, PSO60, and PSO100 at 5kW loaded conditions were 4.9, 4.7, 6.5, 7.2, and 9.4% higher than the diesel alone.

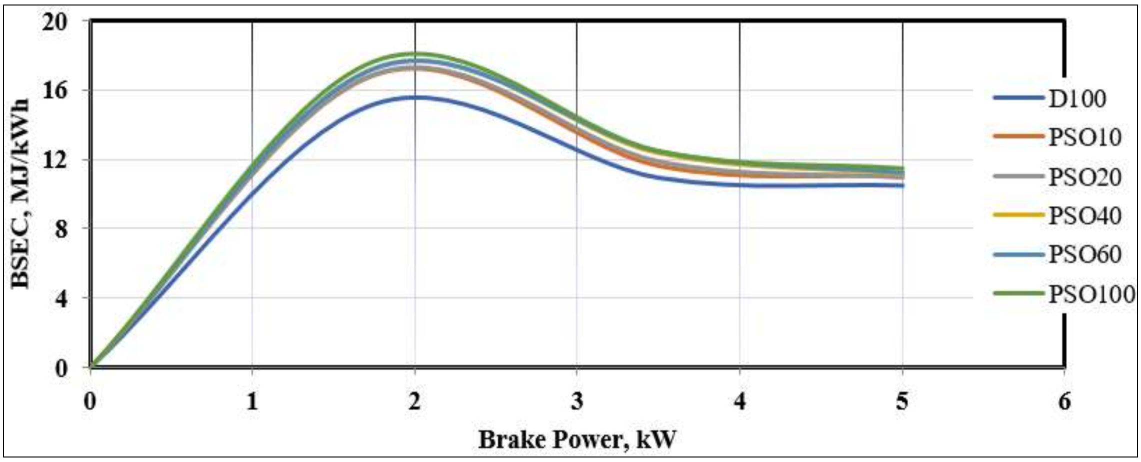

Fig 4: Brake Exact Energy Consumption (BEEC)

Similarly, as compared with diesel, raw oil blends at 1.75 and 3.5kW enhanced its BSEC by approximately 11-16.3% and 6.3-14.1%, respectively. Beneficial combustion is shown by the finding that, for the same fuel combinations, as load rises, BSEC tumbles and BTE increases [18].

4.4 Ignition Features

Cylinder pressure, heat release, rise in pressure rate, combustion delay, ignition time, and the percentage of mass-consumed are among the characteristics of the PSO and diesel fuel that are investigated and analysed.

4.5 Variations in In-Cylinder Pressure

Figure 5 depicts the relationship between in-cylinder pressure and crank angle for the tested fuels at 5 kW. Diesel has the greatest pressure of all the fuels at 64.28 bar due to its enhanced autoignition properties and calorific value, while PSO mixes have the lowest value equivalent to diesel fuel. The maximum cylinder pressures measured for PSO10, PSO20, PSO40, PSO 60, and PSO 100 were 63.654, 62.511, 62.233, 61.931, and 61.15 bar, respectively, which was 0.97, 2.75, 3.18, 3.65, and 4.86% less than diesel.

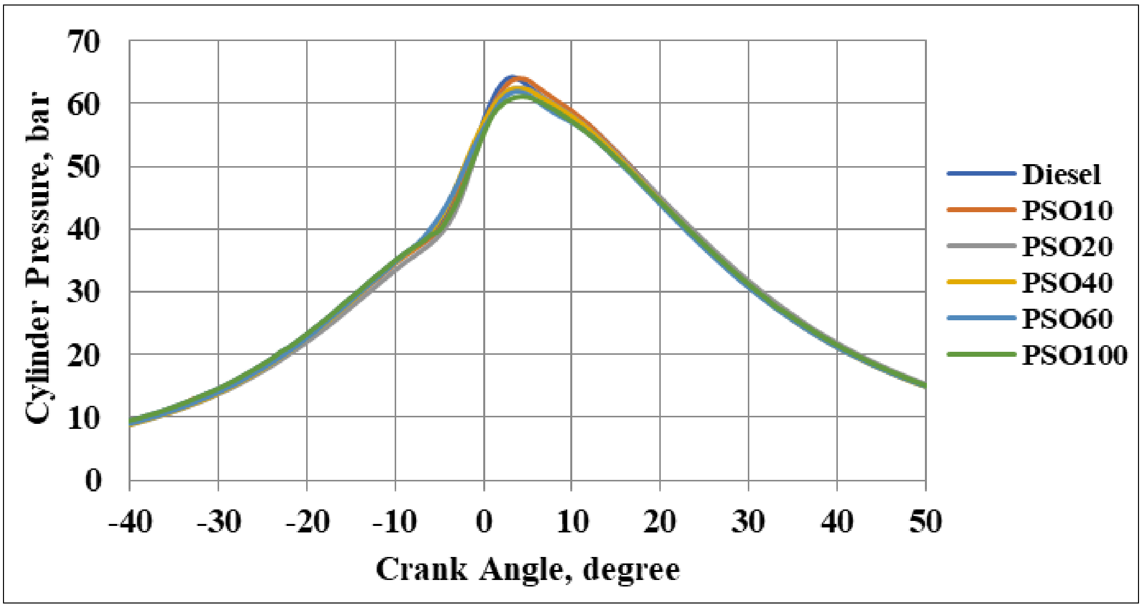

Fig 5: Variations in In-cylinder engine

This could be because to the higher viscosity and lower mobility of the PSO molecules, resulting in poor atomisation and reduced embarkation of Air-Fuel (A/F) mixing rates.

4.6 Net Heat Release Rate

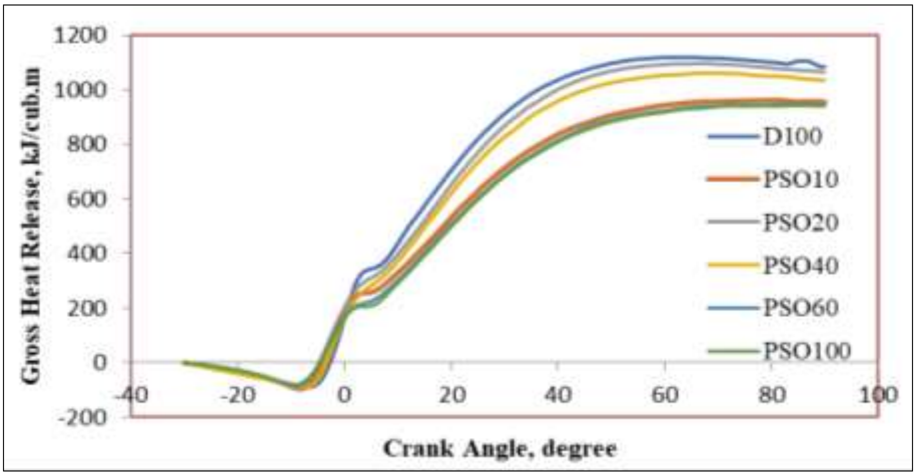

Fig 6: Net heat release rate

Figure 6 depicts the premixed and diffusion phases of the combustion of tested fuels. PSO10, PSO20, PSO 40, PSO 60, and PSO 100 had NHRRs that were 15, 30.1, 30.4, 42.5, and 48.1% lower than diesel at 5kW.

However, the diffusion combustion phase was significantly larger, resulting in a decrease in the NHRR as the proportion of raw oil in the fuel blends increased. Because of the longer ID of diesel, more air-fuel preparation is possible, resulting in a higher premixed HRR [19]. This is because compounds with higher O2 content are sufficient to confirm the absolute burning of remaining fuel from the first stage and continue to burn in the late stage.

4.7 Cumulative Rate of Heat Release: Figure 7 illustrates the effects of the fuel blends under consideration on the Combined Heat Release Rate (CHRR). The inability to transform fuel into energy is the main importance of CHRR. As demonstrated by the CHRR values of PSO 10, PSO 20, PSO 40, PSO 60, and PSO 100 were 1.8, 4.9, 13.8, 15.1, and 15.8% lower than if diesel had been employed, PSO conversion features are incapable to change heat energy. When compared with diesel at 5 kW, larger PSO blend results in greater CHRR values. Higher oxygen levels in the raw oil combinations produced rapid ignition rates as well as faster flame transmission, which produced better outcomes.

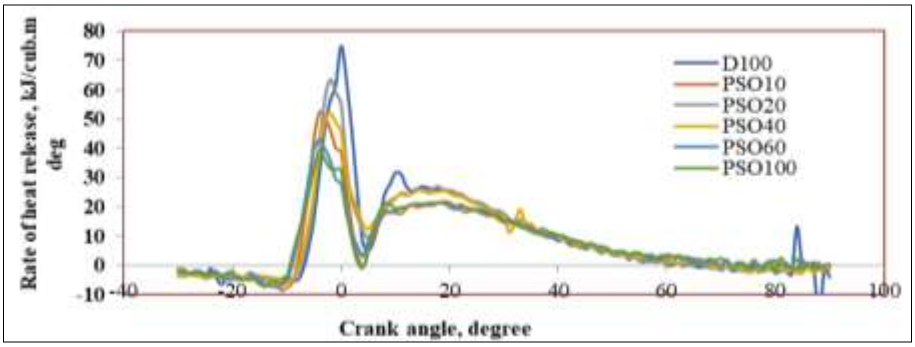

Fig 7: Cumulative Rate of heat release

When canola oil and kerosene were evaluated in a diesel-powered engine, the researchers found the same results [20].

4.8 Delay Period

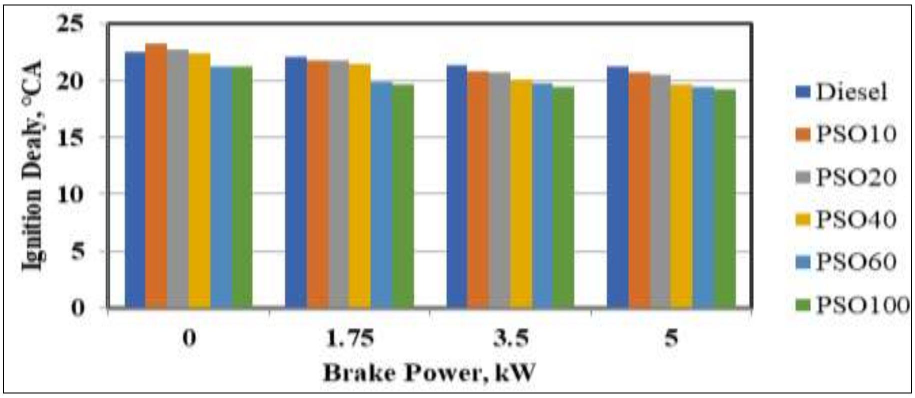

Fig 8: Delay period of ignition

In the combustion process, ignition delay (ID) is extremely important. The measurement of the ignition delay (ID) period takes place between the fuel supply point and the 5% fraction of mass burnt angles and shown in Figure 8. Additionally, ID reduces exponentially with the oil content since the variables behind the loss are greater CN, higher fuel accumulation during the primary combustion phase, greater viscosity, and decreased mobility of biodiesel fuel [21]. 10% organic oil (PSO10) has a little better ID than diesel at lesser loads. In contrast to diesel, other PSO compositions have a decrease in ID. Viscosity improvements and reduces the period of delay.

4.9 Emission Parameters

This section compares and examines engine emission factors for all investigated fuels, including unburned hydrocarbons, oxide of nitrogen into the air, carbon monoxide and carbon dioxide, smoking transparency, and exhaust gas temperatures.

4.9.1 Hydrocarbon emission

Unburned Hydrocarbon (UBHC) emissions were higher for all PSO blends than mineral diesel, as shown in Figure 9. At 5 kW loading, the UBHC of PSO 10, PSO 20, PSO 40, PSO 60, and PSO 100 were 18.75, 28.23, 12.5, 15.63, and 28.13% higher than pure diesel, respectively, while the increase in UBHC emission was around 12.5 -37.5% and 7.4 - 29.6% for raw oil blends at 1.75 and 3.5kW, respectively, when compared to diesel. Because PSO is highly viscous, it results in poor fuel breakdown [22, 23]. Because of the low volatility of vegetable oil, spray production in the burning space may have been compromised, resulting in sluggish burning and HC emission.

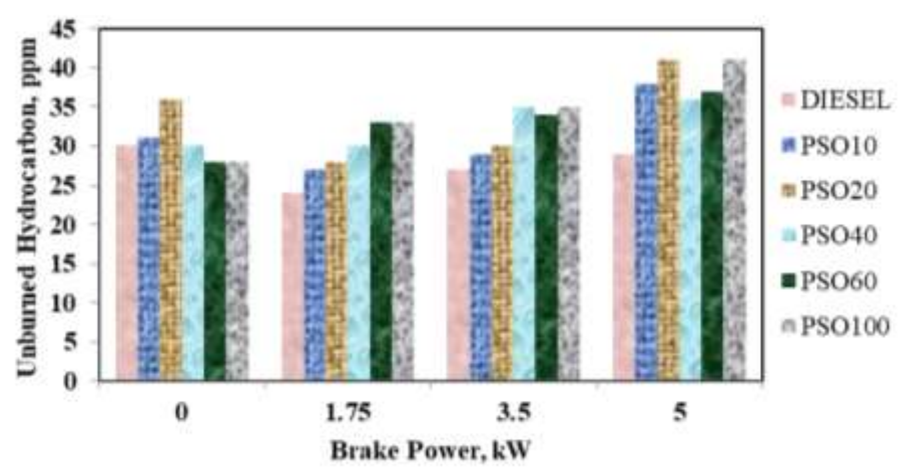

Fig 9: Hydrocarbon emission

Also, when using higher loads and higher concentrations of PSO blends, the percentage rise in emissions skyrockets. Even when additional fuel is supplied at a high load, a lack of oxygen for reaction has a disastrous effect on the burning [24].

4.9.2 Nitrogen Oxide Emissions

The emissions of NOx from PSO blends are significantly lower than those from pure diesel, as shown in Figure 10. At 5kW load, the nitrogen oxides (NOx) of PSO 10, PSO 20, PSO 40, PSO 60, and PSO 100 were 9.22, 10.86, 11.38, 16.64, and 20% less than those of diesel fuel. For the vegetable oil blends at 1.75 and 3.5kW, each, the decrease in nitrogen oxides (NOx) was approximately 12.39-31.19% and 7.53-18.75% when compared with diesel. Greater combustion temperatures led it to rise with loads, influencing the combination's local stoichiometry, persuasion, and reaction resting time [25].

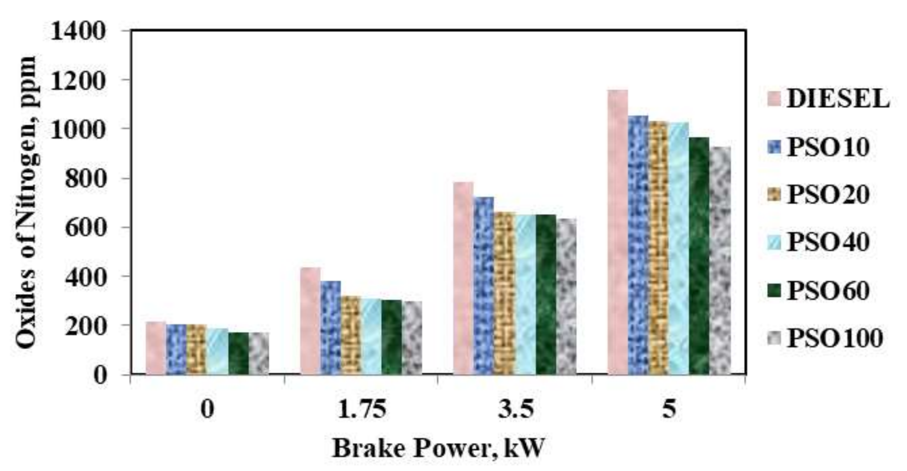

Fig 10: Nitrogen oxide emissions

Furthermore, lower emissions of NOx can result from greater paradise oil mixes burning less well given their greater viscosity. Diesel engines show possibilities as a fuel alternative for petroleum diesel, as indicated by a decreasing pattern of PSO NOx emissions. The research results clearly show that using PSO and its mixtures in diesel engines reduced emissions of NOx.

4.9.3 Carbon monoxide Emissions: As illustrated in Figure 11, the amount of carbon dioxide produced by the PSO blends was better than diesel fuel and varied with the percentage of crude oil. PSO 10 reduced CO emissions by 20% at 5kW being loaded, however PSO 100 enhanced CO emissions by 20%. similarly, when testing crude oil blends at 1.75 and 3.5 kW, as well as diesel, the CO emission rise varied between 25-75% and 25-50%, etc. As a result of inadequate atomization and the resulting production of better fuel blends, the increased viscosity of crude oil blends is mostly the reason for an increase in carbon dioxide levels [26].

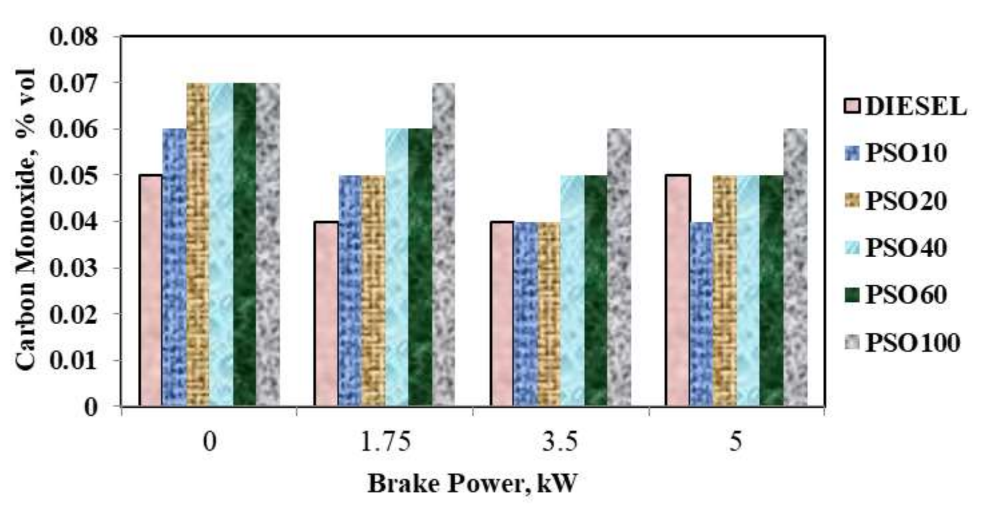

Fig 11: Carbon monoxide Emissions

Reduced optimum temperature and a reduced air-fuel mixture (A/F) at smaller loads lead to more CO emissions. A higher A/F ratio and greater ignition heat reduce CO results at medium loads. Those fuel-bound nanoparticles in the region of combustion that are not involved in ignition may cause CO emissions to rise higher at a 5kW load [27]. This is the case because oxygen with molecules enhances to accelerate combustion also in the relatively strong mixture regions, and the ignition mixture is succeeded in these mixtures in a similar way as diesel. Certain compounds have a fuel filler that causes the fuel to heat up too fast and consume an excess of oxygen, which prevents the fuel that remains from combustion normally [28].

4.9.4 Carbon Dioxide Emissions

For lower and middle loads, Figure 12 illustrates those emissions of carbon dioxide by mixtures of crude oils are significantly below that of pure diesel. The crude oil mixtures have been reduced to 9.98-14.80% and 3.98-8.26% at 1.75 and 3.5kW, respectively, in comparison with diesel. Due to inadequate burning caused by a high viscosity and inadequate atomization of PSO mixes, CO2 emissions decreased [29]. At 5kW loads, PSO blends emitted 1.2-3.6% more carbon dioxide than basic diesel fuel.

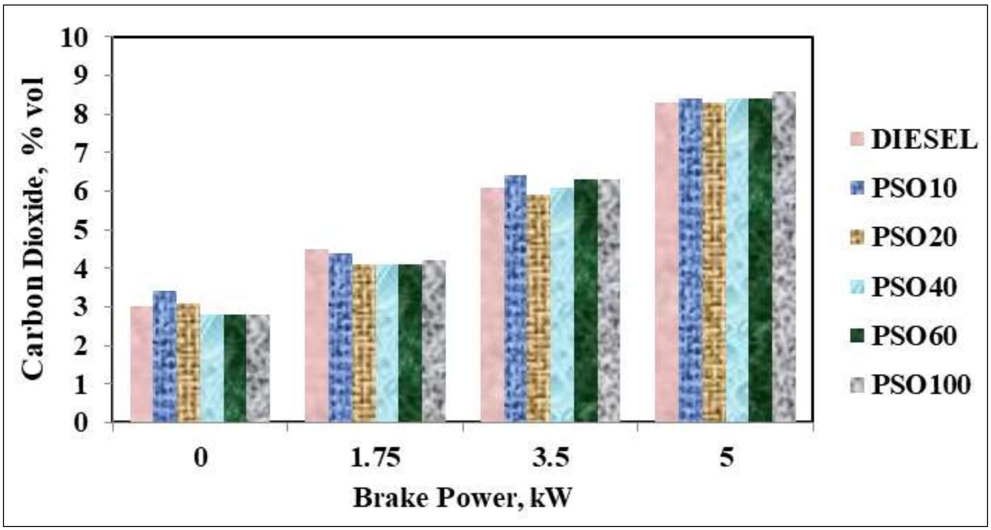

Fig 12: Carbon Dioxide Emissions

Better CO2 conversion, resulting in the total combustion of fuel, maybe the reason for this [30].

4.9.5 Smoke Opacity: As Figure 13 illustrates, the blend's PSO ratio improved carbon emissions. At 5kW operating conditions of use, the amount of smoke emissions from PSO 10, PSO 20, PSO 40, PSO 60, and PSO 100 are 0.13, 2.69, 3.49, 3.49, and 10.75% more compared to that from diesel. A lack of basic oxygen molecules in the lower-concentration PSO blends could be a result of this.

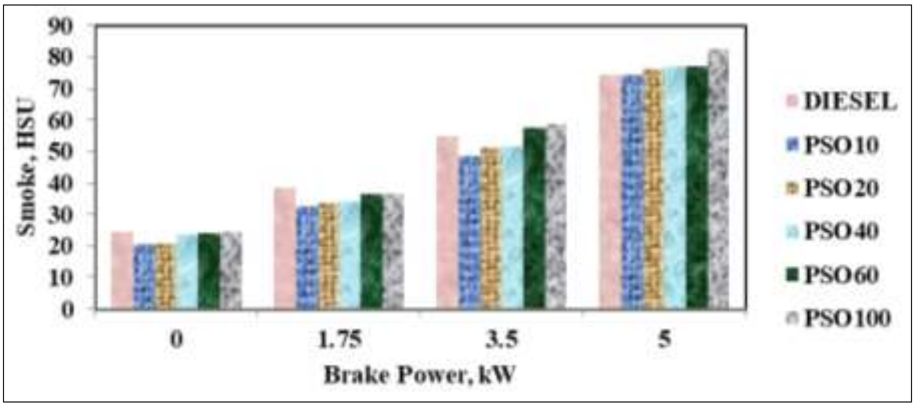

Fig 13: Smoke capacity

The two variables that are most significant in smoke formation are the combustion chamber heat and an absolute A/F ratio. When the actual A/F ratio in certain parts of the ignition zone in a cylinder was less than the theoretically appropriate mixture, smoky output increased considerably for both normal and maximum loads [31].

5. Conclusion

As a result, natural paradise fuel may be utilized to power an engine smoothly and without any issues or modifications. However, the investigation's application of PSO shows that the diesel engine's burning efficiency is slightly less efficient than the conventional diesel. Its reduced ID, extended CD, reduced chamber pressure, HRR values, and various other features also represent this. PSO methyl ester meets ASTM standards and offers properties that are comparable to diesel fuel. PSO 10 created 4.5% less BTE than diesel. In other mixtures, the BTE levels are low. Diesel consumes 4.8% less energy than PSO 10. For every load, PSO produced more hydrocarbon emissions; however, blends of biodiesel emitted less hydrocarbons than diesel. PSO 100 produced approximately 28% more hydrocarbon emissions at a 5kW power than conventional diesel. The NOx emissions of PSO were 7% higher and 20% lower, respectively, at a 5kW power. Diesel generated lower CO emissions than any other raw oil mixtures, except the exception of PSO 10. Eventually, additives like alcoholic beverages, oxidizers, metallic enhancements, and other substances could be used to remove ever-increasing percentages of raw paradise oil in composite engines. The long-term impacts of raw PSO on the system for fuel injection and engine parts require a great deal of investigation. In addition, a detailed investigation is needed into the reliability of basic oil reserves and the feasibility of large-scale production economically.

In the future, it might be possible to use enhancers such as alcohols, oxidizers, metallic alterations, and others to reduce the requirement for a larger percentage of raw oil in CI engines. For a complete understanding of the long-term impact of raw PSO on fuel infusion systems and material in parts of engines, additional research is required. Additional research is necessary on the financial feasibility of mass production along with the preservation reliability of raw Paradise oil and biofuels.

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7. References

1. Ibrahim IA, International Energy Agency. Ö.T.G.A.R.E.G.C.W.M. c2021.
2. Hoang AT, *et al.* Progress on the lignocellulosic biomass pyrolysis for biofuel production toward environmental sustainability. Fuel Processing Technology. c2021.
3. Hoang AT, *et al.* Rice bran oil-based biodiesel as a promising renewable fuel alternative to Petro diesel: A review. c2021.
4. Pradeep S. Effect of piston and cylinder head swirl generation techniques on the performance of ceiba pentandra and nigella sativa B20 biodiesel blended diesel engine operation. c2021.
5. Altimetric Articles. A study of emission characteristic, deposits, and lubrication oil degradation of a diesel engine running on preheated vegetable oil and diesel oil. c2018.
6. Sharzali Che Mat ZA, *et al.* Performance and emissions of straight vegetable oils and its blends as a fuel in diesel engine: A review. Renewable and Sustainable Energy Reviews. c2018.
7. Joshi HS, Simarouba-A potential oilseed tree. Current Science. c2000.
8. Mishra S, *et al.* Impact of Simarouba glauca biodiesel blends as a fuel on the performance and emission analysis in an unmodified DICI engine. Renew Energy. c2018.
9. Devan MN, *et al.* Utilization of unattended methyl ester of paradise oil as fuel in diesel engine. Fuel. c2000.

10. Devan MN, *et al*. A study of the performance, emission and combustion characteristics of a compression ignition engine using methyl ester of paradise oil-eucalyptus oil blends. Appl Energy. c2000.
11. Mishra S, Mohanty M, Panigrahi N, Pattanaik A. Impact of Simarouba glauca biodiesel blends as a fuel on the performance and emission analysis in an unmodified DICI engine. Renewable Energy Focus; c2018.
12. Hattori H. Synthesis of phenolic components of Grains of Paradise. Tetrahedron Letters; c2019.
13. Raj VM, *et al*. Effects of minor addition of aliphatic (1-pentanol) and aromatic (benzyl alcohol) alcohols in Simarouba Glauca-diesel blend fuelled CI engine. Fuel; c2018.
14. Jeyalakshmi P, *et al*. Biodiesel production from two stage esterification of simarouba glauca seed oil and its characterization. Energy Sources - Part A; c2016.
15. Santhoshkumar A, *et al*. Recycling of waste engine oil through pyrolysis process for the production of diesel like fuel and its uses in diesel engine; c2020.
16. Venkanna B, V.R.C. Direct injection diesel engine performance, emission, and combustion characteristics using diesel fuel, nonedible honne oil methyl ester, and blends with diesel fuel; c2012.
17. Sivakumar M, S.N.R.R.S.T.M. Effects of pongamia methyl esters and its blends on a diesel engine performance, combustion, and emission characteristics; c2017.
18. Tamilvanan A, B.K.V.M. Calorimetry. Effects of nano-copper additive on performance, combustion and emission characteristics of Calophyllum inophyllum biodiesel in CI engine; c2019.
19. Amini Niaki SR, M.S.M.J. Experimental and simulation investigation of effect of biodiesel-diesel blend on performance, combustion, and emission characteristics of a diesel engine; c2018.
20. Corsini A, A.M.F.R.F.S. Vegetable oils as fuels in diesel engine. Engine performance and emissions; c2015.
21. SC Mat MI, M.I.M.H.Z.Z. Performance and emissions of straight vegetable oils and its blends as a fuel in diesel engine: A review; c2018.
22. Bayındır H, I.M.A.H. Evaluation of combustion, performance and emission indicators of canola oil-kerosene blends in a power generator diesel engine. Applied Thermal Engineering; c2017.
23. Rakopoulos C, R.D.G.E.D.A. Investigation of the combustion of neat cottonseed oil or its neat bio-diesel in a HSDI diesel engine by experimental heat release and statistical analyses. Fuel; c2010.
24. Dabi M, S.UK. Application potential of vegetable oils as alternative to diesel fuels in compression ignition engines: A review; c2019.
25. Ramakrishnan C, D.P.K.R. Experimental study on the performance and emission characteristics of jojoba oil fueled DICI engine; c2017.
26. Dey P, R.S. Comparative analysis of waste vegetable oil versus transesterified waste vegetable oil in diesel blend as alternative fuels for compression ignition engine; c2020.
27. Gorkal A, R.C.R.MU. Experimental Investigations on LHR Single Cylinder Air Cooled Diesel Engine using Simarouba Biodiesel and its Blends as Alternate to Diesel Fuel; c2018.
28. Atmanlı E, E.I.B.Y.-A. Experimental investigation of engine performance and exhaust emissions of a diesel engine fueled with diesel-n-butanol-vegetable oil blends; c2014.
29. Asokan MA, R.V.S.P. A review on performance, emission and combustion characteristics of a diesel engine fuelled with various vegetable oil; c2018.
30. Attia A, A.H.AMA. Influence of diesel fuel blended with biodiesel produced from waste cooking oil on diesel engine performance. Fuel; c2016.
31. Application of straight vegetable oil from triglyceride-based biomass to IC engines-A review. Renewable and Sustainable Energy Reviews; c2017.