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EVALUATING PERFORMANCE, COMBUSTION, AND EMISSION CHARACTERISTICS OF WASTE PLASTIC OIL BLENDS IN CRDI DIESEL ENGINES USING DATA ENVELOPMENT ANALYSIS

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Abstract

As fossil fuels run out quickly, researchers studying engines are increasingly interested in alternative fuels. This paper covers the use of plastic paralysis oil as biodiesel in diesel engines. This was done using a four-stroke, multi-cylinder CRDI diesel engine running between 2000 and 2500 rpm. From zero loads to fifty percent load, the performance, combustion, and emission characteristics were computed for a variety of load scenarios. The analysis revealed that the blend D80WPO20 at 2000 rpm reduced hydrocarbon emissions from 0.059 g/kW to 0.045 g/kW, which is lower than that of 25% diesel at 26 kW. At high speed, the blend D80WPO20 at 2000 rpm gave the maximum BTE of 34.53%. The nitric oxide (NOx) emissions from D50WPO50 and diesel at a 26 kW load are 6.48 g/kWh and 5.37 g/kWh, respectively, according to reports. Data envelopment analysis, a multi-response linear programming optimization tool, was used to evaluate the output and emissions of DI diesel engines using waste plastic oil mixtures.

Keywords: Combustion, Data Envelopment Analysis, Pyrolysis, Waste plastic oil.

I. Introduction

Plastics contribute significantly to industrial applications and our daily lives in today's environment because they have many advantages, such as less weight, a lengthy life, a cheap price, simple availability, rapid production of specific shapes and sizes, and so on. Although the use of plastics in living organisms is on the rise, they contain non-biodegradable elements that pollute the environment. Massive amounts of plastic require proper recycling and disposal due to the widespread use of plastic in all areas. Plastics are non-biodegradable, which has become a significant concern. Because the waste plastics are less active and haven't reacted with natural resources, they create serious environmental hazards. Dumping remains a significant barrier, persisting even after several years. Unlike metals, plastics cannot melt and recycle into new usable components. As a result, several researchers are working in the field, touching on use in conjunction with correct disposal while not inflicting significant environmental damage.

Operations research and economics use data envelopment analysis (DEA), also known as multi-response linear programming, as a non-parametric technique to estimate industrial frontiers. Empirical evaluations utilize it to gauge the effectiveness of executive procedures. While non-parametric methods do not provide a complete input-output connection, they do offer the benefit of not assuming anything about a given function. This study investigates the efficacy and efficiency of CRDI diesel engines using the DEA Frontier method.

To repurpose waste plastic into the needed form and lessen future fuel shortages, we collect waste plastics, recover pyrolysis oil, and blend it with diesel in this research. The blended oil fuels the diesel engines. We also examined the performance characteristics of the ideal blend ratio. Recycling or properly disposing of waste plastics has become a major problem for both local and foreign enterprises. Enhancing the WPO to diesel ratio increased smoke and NOx emissions, which in turn increased the cetane index and heat index. "[I] conducted an examination and found that combining WPO with diesel enhances performance by increasing heat output, cylinder pressure, and [II] demonstrated that WPO90 was the best SF for engine performance, and they also found that WPO mixed with POB was an efficient diesel alternative. At zero load, [III] found that diesel fuel exhibits higher thermal efficiency, whereas WPO exhibits higher thermal efficiency at full load. [IV] successfully tested WPO in diesel engines, examining diesel volume fractions ranging from 10% to 75% combined with WPO.

The diesel infusion increased the mix's cetane rating and encouraged auto-ignition. The majority of studies found higher soot emissions; however, others found decreased emissions. Investigations have not yielded a consistent pattern from which to infer their behavior. [V] measured that WPO emits a lot more NOx than the other test fuels. Premixed MEA and DEE change the neat diesel combustion's NOx characteristics while also revealing advantages. Reports indicate a 5.5% reduction in NOx emissions for 50D40W10DEE. The 50D40W10MEA has a negligible impact on NOx emissions. When compared to 50D40W10DEE, NOx increased by 7.2%. According to [VI] analysis, the mixture of waste plastic oil acts as a catalyst for combustion because of its excellent thermal properties. Elevated temperatures will trigger the production of plastic gas, a valuable resource for automobiles. [VII] measured the emissions and performance of B25, which are quite comparable to those of diesel at standard injection pressure. Consequently, they selected B25 as the optimal blend. According to [VIII], the best performance is thought to be a mix of WPO70P30 injected at 21° CA bTDC with 10% EGR. They found this by measuring their results and getting an optimum of 0.968.

In terms of performance and emissions, pentanol fared better than n-hexanol and n-octanol. According to [IX], the best conditions for making 25 grams of plastic waste oil with a catalyst were 10%, 650 °C, and 36 minutes of production time. [X] found that an 18:1 CR, a 100% load, and a D60W20E20 mix provided the greatest performance and highest quality of emissions. In their study [XI], they looked into how mixing 40% plastic oil with methanol and diethyl could improve combustion, performance, and emissions. In 2013, [XII] investigated how engine timing and fuel injection techniques affected combustion, emission characteristics, and performance. To increase the SOI, we drastically lowered the temperatures in the exhaust, BMEP, and BSFC. CO2 and HC emissions dropped with FIP; however, NOx emissions rose. [XIII] looked at the comparative effectiveness of several institutions in two different historical periods. Using this method, it is possible to identify the schools that, according to the total college efficiency ratings, are particularly inefficient. Adjustments to their outputs and inputs. [XIV] measured the general, technical, and scale productivity of the Taiwan Power Company service center in China using DEA. We considered the number of clients and the capacity of the distribution network transformer as output parameters, as well as the number of employees and general equipment as input parameters. [XV] looked into the effectiveness of the patient hospitals affiliated with Perking University in China.

An approach based on linear programming called data envelope analysis (DEA) assesses the efficiency of organizational units in situations where there are many inputs and outputs. Based on hospital source data, they identified and assessed the relative efficacy of numerous departments using hospital source data. [XVI] computed the rise in youth enrolling in higher education, indicating that DEA has options that it may choose from when allocating resources, like moving beds, hiring personnel, and improving the medication process. The need to run universities more efficiently has arisen as a result of the mounting financial pressures that governments around the world are experiencing. This study estimates the academic performance of specific Australian universities using non-parametric methods. His findings reveal that the Australian institution consistently demonstrates high-performance levels, regardless of the output-input combination. Using DEA, [XVII] assessed the technical effectiveness of 118 university libraries from English-speaking (the United States, Australia, and Canada) and German-speaking (Austria, Germany, and Switzerland) nations that were picked at random. The number of serial subscriptions, overall circulation, weekly opening hours, and the addition of book resources are the factors that libraries use to calculate their DEA efficiency ratings. Book inventory maintenance and library staff are examples of inputs, expressed as full-time equivalents. We examined 118 university libraries and found that ten of them are fully efficient. There are no appreciable variations between small and large university libraries when comparing group-specific efficiency scores. In addition to plastic oil, researchers have mixed other oils into diesel and gasoline that come from a variety of sources. Only a few of these oils aim to provide an alternative fuel while also recycling toxic waste. Gathering waste plastics, making pyrolysis oil, mixing different ideas, and assessing the efficiency of the blended diesel are all planned steps in this investigation.

II. Materials and Methods

The production procedure of waste plastic oil

The single-use, reusable low-density polyethylene (LDPE) saline bottles and bags were collected in our hometown, as well as a government hospital in Chidambaram, Tamil Nadu. We used an electric-powered cutter to chop the plastic from the saline bottles into small pieces. The cutter reduced the size of the bottles before sending them into the crushing chamber above the crusher. In [XVIII], investigation, worked with LDPE to generate WPO at 180 °C to 250 °C under atmospheric pressure. Fig. 1 displays schematic and photographic images of the apparatus used to manufacture the WPO, respectively.

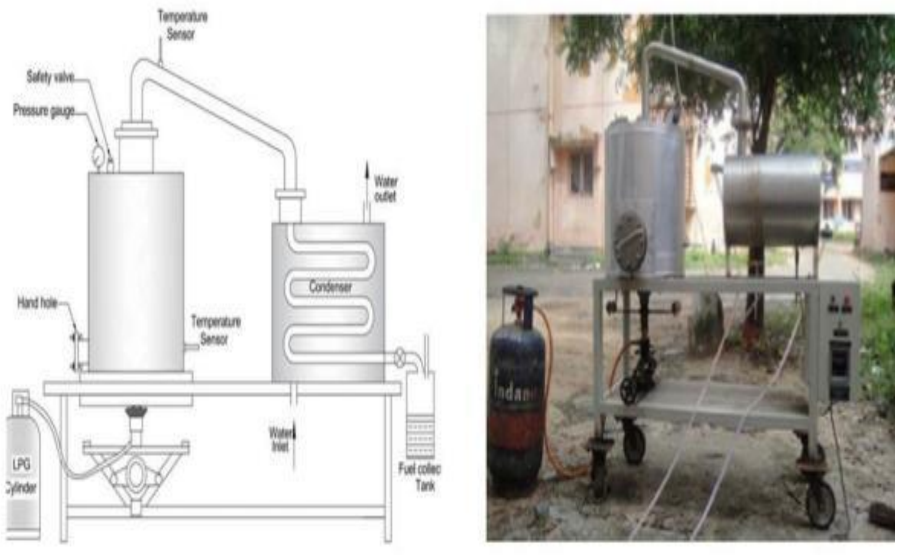

Fig. 1. Schematic and Photographic view of Cracking Reactor

The apparatus consists of an electrical panel, condenser, heating coil, thermocouple, safety valve, pressure gauge, and condenser. We utilized calibrated k-type thermocouples to measure the vapor temperature. First, we introduced five liters of neat WPO to the cracking reactor. An electric coil heated the reactor until the WPO reached temperatures ranging from 180 to 250 degrees Celsius. The electric heater's temperature controller kept the temperature stable. The condenser condenses the vapor produced while heating. We collect the condensate in a beaker. We refer to this organic component as LDPE. The condenser circulates coolant water at a steady flow rate. To detect and stop excessive pressure, we install a safety valve and pressure gauge in the reactor. Table 1 describes WPO properties.

Table 1: lists the fuel properties that were investigated

Properties	Measurement standards	Diesel	WPO
Density at 25°C (g/cc)	ASTM D1298	0.8/0.84	0.793
Flashpoint (°C)	ASTM D 93	80	<48
Calculated cetane index	ASTM D 976	51	48
Boiling point (°C)	ASTM D1160	180- 340	180-380
Kinematic viscosity at 30 °C (cP)	ASTM D 445	2.0 to 4.5	3
Calorific value (kJ/kg)	ASTM D 240	43000	41900
Pour point (ºC)	ASTM D6751-02	-7	-8
Cloud point (ºC)	ASTM D6751-02	-3	-5
Carbon residue (mol/mol)	ASTM D4530	0.050 max	0.06
Copper strip Corrosion (3h, 50ºC)	ASTM D130	1	1
Carbon (%)	ASTM D6751-02	86.40	85.47
Hydrogen (%)	ASTM D6751-02	1.45	1.7014
Oxygen (%)	ASTM D6751-02	1.60	2.54
Nitrogen (%)	ASTM D6751-02	0.2806	0.094
Sulfur Content (%)	ASTM D6751-02	0.046	0.032
Refractive Index	ASTM D6751-02	1.45	1.33

Researchers looked at how well a common rail direct injection diesel engine worked, how much pollution it put out, and how well it burned by testing different mixes of DP90WPO10, DP80WPO20, DP70WPO30, DP60WPO40, and DP50WPO50 blended WPO and pure diesel fuel. The emissions measured were BSFC, BTE, EGT, Pmax, HRR, HC, CO, and NOx. The engine maintained an injection pressure of 900 bar while operating at different speeds between 2500 and 2000 rpm. The experiment used a four-stroke, multi-cylinder CRDI diesel engine producing 70.09 kW of power and operating at 4000 rpm. In Fig. 2, a Maruti Ertiga car engine serves as the test bed for the investigation. We use a variety of measurement tools, including an orifice meter and a U-tube manometer, to quantify air consumption, monitor fuel use with a 1-liter burette, and fit an independent fuel tank to the test engine. The test rig had National Instruments software installed to collect various curves and outcomes while it was in use. A five-gas analyzer measured the characteristics of the exhaust gas emission, including CO_2, CO, HC, NOx, and O_2 levels. We conducted the combustion, emission, and performance tests at a 17.5 compression ratio, varying the speeds to 2000 rpm and 2500 rpm while maintaining a 26.5 kW rated power.

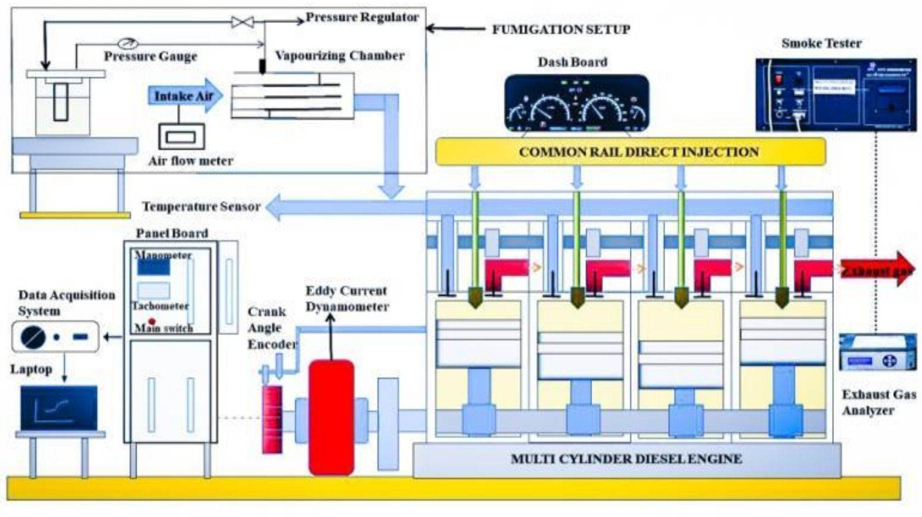

Fig. 2. Schematic view of Experimental Setup

We ran the experiment at various ratios, which included DP90WPO10, DP80WPO20, DP70WPO30, DP60WPO40, and DP50WPO50 WPO blended with 100% diesel fuel (D100). We measured the Pmax, HRR, ignition delay time, combustion duration, rate of pressure increase, BSFC, BTE, and emissions of CO, CO2, HC, O2, and NOx in order to evaluate the engine's performance at different rated powers. Table 2 displays the parameters of the test engine.

Table 2: Test Engine Specification

Parameter	Specification
Make	MarutiErtiga
Engine Type	4 Stroke cycle, Water-cooled
Cylinder Type	Vertical
No. of Cylinder	4
Displacement	1248 cc
Bore	69.6 mm
Stroke	82 mm
Fuel Supply Type	CRDI
Compression Ratio	17.5:1
Power	88.5 BHP @ 4000 RPM
Loading System	Eddy Current Dynamometer

III. Gas Chromatography Analysis

The gas chromatograph used was an Agilent 6890 model, which had a straight deactivated 2 mm direct injector liner and a 15 m Alltech EC-5 column with a 250µ I.D. and a 0.25µ film thickness. To introduce the sample, we used the split injection method with a split ratio of 10:1. We set the oven temperature program to initiate at 35 °C, maintain that temperature for 2 minutes, and then increase at a rate of 20 °C per minute until reaching 300 °C, a temperature we would maintain for 5 minutes. In constant flow mode, we set the helium carrier gas flow rate to 2 ml/minute. We measured the fuel dilution of the WPO using gas chromatography-mass spectrometry (GC-MS) on samples collected during different tests. Fig. 3 displays the condensed findings. GC-MS analysis revealed that the cracking process's primary outcomes are a blend of hydrocarbons with linear chains, both saturated and unsaturated, as well as oxygenated compounds including linear aldehydes, carboxylic acids, water, and ketones, along with carbon dioxide and carbon monoxide. The chemical characteristics of WPO by GC-MS presented in Table 3.

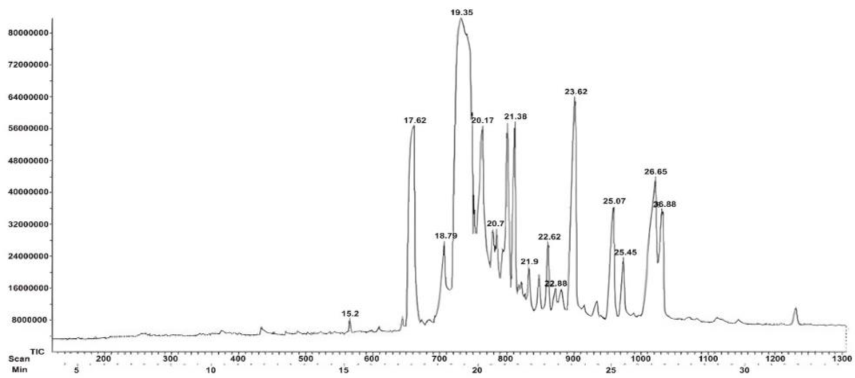

Fig. 3. GC - MS of WPO

Table 3: Chemical characteristics of WPO by GC-MS

SI.no	Time	Component
1	21.38	Eicosanoic Acid, Methyl ester
2	21.1	11- Eicosenoic Acid, Methyl ester
3	20.17	Oleic Acid
4	17.37	Pentadecanoic Acid, 14-methyl-Methyl ester

IV. Results and Discussions

Brake Specific Fuel Consumption (BSFC)

Fig. 4 shows how brake-specific fuel consumption (BSFC) changes at different speeds, such as 2000 rpm and 2500 rpm, when D90WPO10, D80WPO20, D70WPO30, D60WPO40, and D50WPO50 are used in different amounts. At no load, the blend of diesel and D90WPO10 gave a better result of 600 g/kW-hr at 2000 rpm when compared to other blends and diesel fuel. At 2500 rpm with no load, the diesel gave a better result of 570 g/kW-hr. We can assert that burning diesel fuel at no load requires a significant amount of thermal energy, leading to an increase in fuel consumption at high injection pressure and speed. As a result, the exhaust temperature rises, leading to a significant amount of nitrogen oxide deposition in the exhaust valve outlet pipe and increased emissions. At 2000 rpm and 2500 rpm, with a power output of 26.5 kW, the diesel engine produced superior results, achieving 210 and 220 g/kW-hr, respectively.

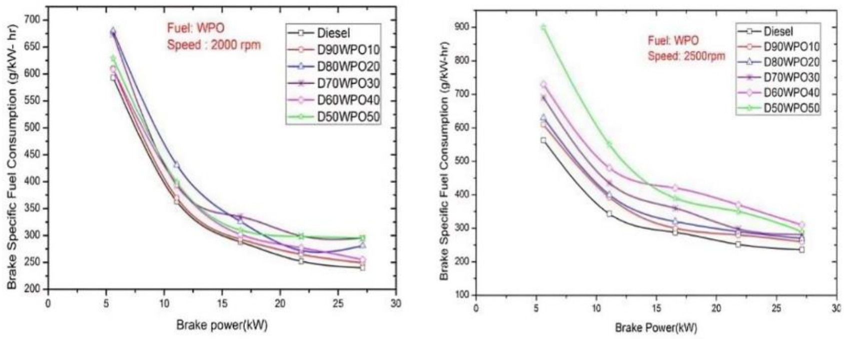

Fig. 4: Comparison of BSFC at Different Speeds

At full load and high injection pressures of 900 bar to 1200 bar, the fuel vaporizes easily and quickly inside the combustion chamber due to the maximum gas cylinder pressure, allowing for complete combustion and the production of a large amount of heat energy. Injecting fuel into a combustion chamber at high injection pressure increases the maximum gas cylinder pressure, vaporizing the fuel more efficiently and producing more thermal energy.

V. Brake Thermal Efficiency

Thermal efficiency is defined as the ratio of the fuel's energy supply to the brake power, or indicated power, during the same time period. Fig. 5 illustrates the BTE for different blends at varying speeds. When running a CRDI diesel engine with biodiesel at different speeds, the thermal efficiency of the waste plastic oil gradually improves, reaching a maximum of 35.50% for the blend D90WPO10 at 2000 rpm. However, when compared to diesel, the D50WPO50 offered lower performance, coming in at 29.03% at 2000 rpm. When operating at moderate speed, both diesel and biodiesel's thermal efficiency increases from 0% to 50% load. Despite a decrease in the density and viscosity of biodiesel, the waste plastic oil fuel is unable to outperform diesel at varying loads and speeds. The diesel fuel consistently exhibits a higher thermal efficiency compared to D90WPO10 biodiesel.

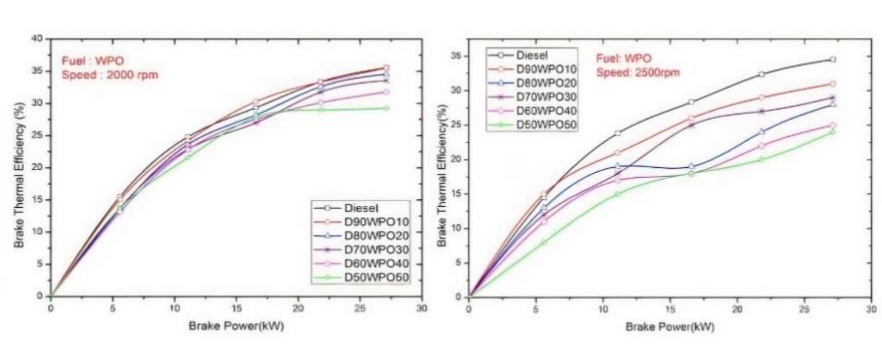

Fig. 5. Comparison of BTE at different Speed

VI. Exhaust Gas Temperature

Fig. 6 shows how EGT varies. The EGT of diesel, D90WPO10, D80WPO20, D70WPO30, D60WPO40, and D50WPO50 is 345 °C, 342 °C, 341 °C, 340 °C, 339 °C, and 338 °C, respectively, at 26 kW between 2000 and 2500 rpm. For both diesel and WPO mixes, the exhaust gas temperature varies with load. The exhaust gas temperature of both fuels rises with increasing load; at all loads, the WPO mix exhibits greater temperatures than the diesel. [XIX] looked into this because the oxygen present in the biofuel improves combustion and raises exhaust temperature. Higher mixes of WPO oil have lower EGTs than diesel because of better combustion. However, because of the decreased viscosity, the EGT rises in lower WPO mixtures.

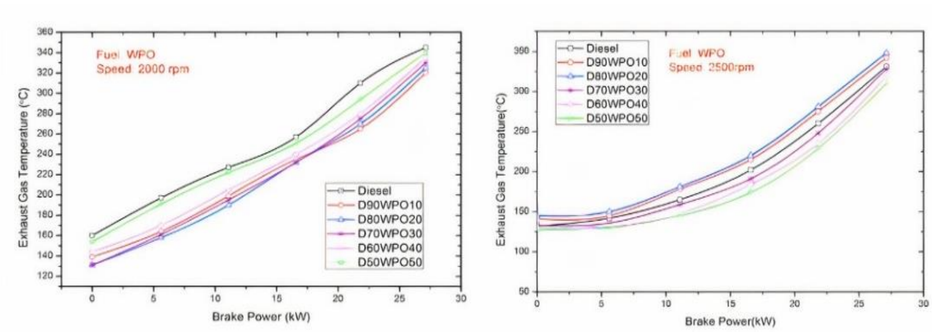

Fig. 6: Comparison of EGT at different Speed

VII. Hydro Carbon

Unburned hydrocarbon emissions are fuels that are either completely unburned or only partially burned. Problems with fuel and air mixing primarily cause these emissions, and the air-fuel equivalency ratio has no impact on them. Fig. 7 below shows the variation of UHC emissions in g/kW-hr with respect to loads ranging from 0–50% at speeds of 2000 and 2500 rpm.

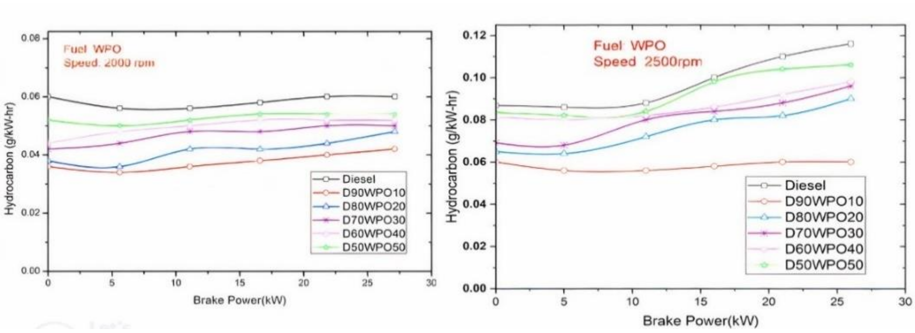

Fig. 7. Comparison of HC at different Speed

The hydrocarbon emission decreases as the load increases in biofuel and pure diesel at 2000 rpm. The blend D90WPO10 gave a better result of 0.037 and 0.0580 g/kW-hr when compared to diesel, which produced 0.06 and 0.85 g/kW-hr at 2000 and 2500 rpm in no load. At full load, the D50WPO10 blend produces hydrocarbon emissions of 0.050 g/kW-hr, while pure diesel fuel contributes 0.057 g/kW-hr. Waste plastic oil, due to its self-oxygenation, contributes less hydrocarbon emissions than pure diesel fuel at all loads and two different speeds. The decrease in UHC led to an increase in the biofuel's oxygen content, which in turn led to a rise in complete combustion. The biofuel's higher cetane number also led to a decrease in the combustion delay by increasing the injection pressure.

VIII. Carbon Monoxide

Fig. 8 illustrates the CO emissions of the engine under test with two speeds of five different blends, such as D90WPO10, D80WPO20, D70WPO30, D60WPO40, and D50WPO50 with pure diesel. We measured the carbon monoxide using an exhaust gas analyzer at different speeds, specifically 2000 rpm and 2500 rpm. When using biodiesel, a diesel engine's CO emissions rise from zero to 50%. In a 26 kW load, only D50WPO50 gave a better result of 0.07 g/kW-hr at 2000 rpm. The CO emissions rates for both diesel and biodiesel fuel range from a minimum of 0.02% to a maximum of 0.08%. This is a point of stagnation; in other words, the 2000 and 2500 rpm fuel injection pressures at 900 bar have an effect on CO emissions for WPO biodiesel blends and pure diesel fuel.

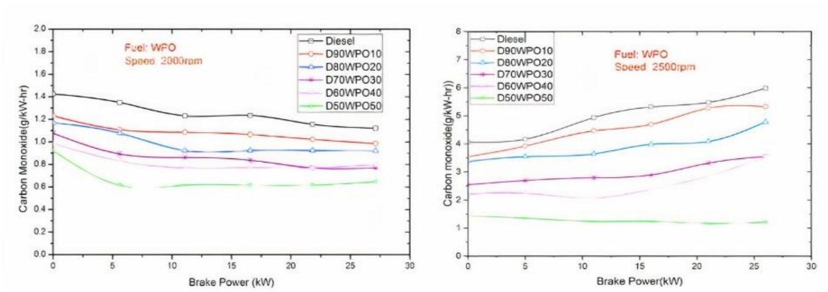

Fig. 8. Comparison of CO at different Speed

IX. Cylinder Pressure

In a compression ignition (CI) engine, the rate at which fuel burns during the premixed burning phase determines the cylinder pressure. Fig. 9 illustrates how, at full load, cylinder pressure varies along the crank angle. It shows that D50WPO50 fuel peaks at 70 bars at 2000 rpm, while diesel and D90WPO10 fuels attain a peak pressure of 73 bars. It also depends on how the temperature and response rate relate to one another. However, D50WPO50 fuel peaks at 62 bar, while diesel fuels at 2500 rpm attain a peak pressure of 70 bar. This is due to the insufficient pre-mixing of D50WPO50 blends. Thus, better combustion will occur at 2000 rpm, as opposed to 2500 rpm and 2000 rpm. According to [XIX], higher blend quantities result in more fuel participating in the mixture's uncontrolled combustion stage, which raises the pressure.

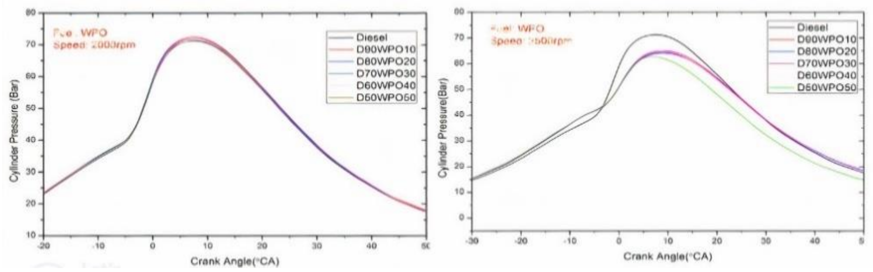

Fig. 9. Comparison of Pmaxat different Speed

X. Maximum Heat Release Rate

Fig. 10 shows that diesel, D90WPO10, D80WPO20, D70WPO30, D60WPO40, and D50WPO50 fuels have the highest HRR at 50% load. As per the controlled heat release described by Velmurugan et al. [XIX], the premixed fuel burns rapidly and generates a substantial quantity of heat.

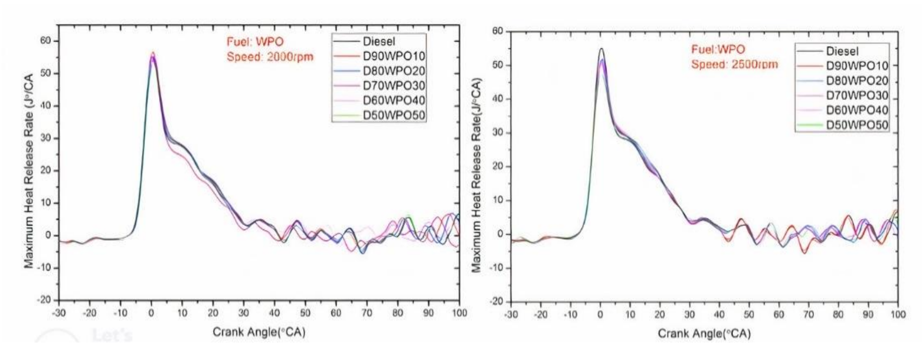

Fig. 10. Comparison of HRR at different Speed

In comparison to diesel and lower blends, higher blends of D50WPO50 have a lower heat release rate (HRR). This explains why, with lower mixes, combustion improves since the fuel combination has greater quality and less viscosity. At 2000 rpm, the highest HRR for diesel, D90WPO10, D80WPO20, D70WPO30, D60WPO40, and D50WPO50 is 55.82 J/ºCA, 54.23 J/ºCA, 54.46 J/ºCA, 53.84 J/ºCA, 53.46 J/ºCA, and 53.15 J/ºCA, respectively. However, at 2500 rpm, the fuel blends for maximum rate are 54.82 J/ºCA, 50.23 J/ºCA, 51.46 J/ºCA, 50.84 J/ºCA, 50.46 J/ºCA, and 47.15 J/ºCA, respectively.

XI. Data Envelopment Analysis approach to Diesel Engine Performance Suppliers Inputs Process Diagram (SIPOC)Outputs Customer

It falls within the Data Envelopment Analysis Model's boundary situation category. Before work begins, a team will use a SIPOC diagram to enumerate all relevant project elements for process improvement. The implementation of the SIPOC analysis was required to understand the process's fundamental elements and define its boundaries. The following table 4 shows the SIPOC diagram for a diesel engine. Currently, engine researchers are encountering numerous challenges related to fuels, components, and experimental trials. To find which process is efficient and inefficient and to reduce the number of tasks, the engine performance evaluation is needed. This study aims to validate the viability and benefit of utilizing DEA to assess the efficiency of CRDI diesel engines. Selecting practical and relevant key variables for input and output, often hindered by data collection issues, is a prerequisite for measuring engine performance using DEA. Researchers gather the data from their experimental work.

Table 4: Suppliers Inputs Process Outputs Customer Diagram for Diesel Engine

Suppliers	Inputs	Process	Output	Customer
Bio-Fuel Oil Agencies & Laboratory	Injection Pressure Injection Timing Mass Flow Rate	Running the Engine with Bio-Diesel at Different speeds and Various Loads	Engine Performance, Combustion & Engine Emission Characteristics	Universities, Industries and Other Agencies

XII. Input and Output Factors

Abbott and C. Doucouliagos (2003) [XVI] looked at how well Australian schools worked using DEA and variables like admission rates, student-to-faculty ratios, faculty resource rankings, and financial resource rankings. Academic standing, alumni donations, alumni graduation, and average freshmen retention rates are examples of output factors, along with student selectivity rank. We solely consider the diesel engine system for measurable input characteristics such as speed, IT, and MFR, drawing from the previously mentioned two publications. Table 5 shows a condensed DEA model based on DMU's input and output components. The numbers shown in the table represent the total of all the values that were noted throughout the experimental work under each stress condition.

Table 5: DMU's Input and Output Factors

DMU	Speed (rpm)	IP (°TDC)	MFR (CC)	BSFC (g/kW-hr)	BTE (%)	UHC (g/kW-hr)	CO g/kW-h	p-θ (bar)	HRR (J/°CA)	NOx (g/kW-hr)
DMU1 (D90WPO10)	2000	900	10	249	34.5	0.04204	0.985	72	55.82	6.03876
DMU2 (D80WPO20)	2000	900	10	281	33.55	0.04805	0.92	71.92	54.82	6.17148
DMU3 (D70WPO30)	2000	900	10	295	32.55	0.05005	0.769	71.05	54.86	6.37056
DMU4 (D60WPO40)	2000	900	10	255	31.75	0.05205	0.8	70.04	53.85	6.55637
DMU5 (D50WPO50)	2000	900	10	295	29.23	0.05405	0.646	70.01	53.55	6.58955
DMU6 (D90WPO10)	2500	900	10	260	31	0.09009	1.54	66.55	50.17	5.25571
DMU7 (D80WPO20)	2500	900	10	270	28	0.0961	1.55	65.55	48.25	4.66511
DMU8 (D70WPO30)	2500	900	10	281	29	0.0981	1.78	64.2	47.2	4.44612
DMU9 (D60WPO40)	2500	900	10	310	25	0.10611	1.82	64.2	46.25	4.6452
DMU10 (D50WPO50)	2500	900	10	290	24	0.11612	1.98	63.5	45.44	4.5478

Table 6 shows that the target inputs for the DMU3, DMU8, and DMU9 are quite low compared to the existing input data, indicating that the input parameters will be reduced by the engine's fuel blends. For example, DMU3's injection pressure (IP) is 900 bar, but the target IP is 880 bar. Table 7 shows that the target outputs of the DMU3, DMU8, and DMU9 are lower than their current values, indicating that the engine has possibilities for enhancing the output parameter.

Table 6: DMU's Target Inputs

DMU No.	DMU Name	Speed(rpm)	IP(bar)	MFR (CC)
1	DMU1	2000	900	10.00000
2	DMU2	2000	900	10.00000
3	**DMU3**	**2370**	**880**	**9.77590**
4	DMU4	2000	900	10.00000
5	DMU5	2000	900	10.00000
6	DMU6	2500	900	10.00000
7	DMU7	2500	900	10.00000
8	**DMU8**	**2370**	**850**	**9.59912**
9	**DMU9**	**2480**	**880**	**9.92124**
10	DMU10	2500	900	10.00000

Table 7: DMU's Target Outputs

S No.	DMU Name	BSFC (g/kW-hr)	BTE (%)	UHC (g/kW-hr)	CO (g/kW-hr)	p-θ (bar)	HRR (J/°CA)	NOx (g/kW-hr)
1	DMU1	249	34.5	0.0420	0.985	72	55.82	6.038
2	DMU2	281	33.55	0.0480	0.92	71.92	54.82	6.1714
3	**DMU3**	**292**	**32.55**	**0.0500**	**0.769**	**70.8**	**53.86**	**6.298**
4	DMU4	294	31.75	0.0520	0.8	70.04	53.65	6.5563
5	DMU5	295	29.23	0.0540	0.646	70.01	53.55	6.5895
6	DMU6	260	31	0.0909	1.54	66.55	50.17	5.2557
7	DMU7	270	28	0.0961	1.55	65.55	48.25	4.6651
8	**DMU8**	**278**	**28.5**	**0.0971**	**1.68**	**64.2**	**46.98**	**4.4461**
9	**DMU9**	**305**	**25**	**0.1051**	**1.70**	**64.1**	**45.25**	**4.5432**
10	DMU10	298	24	0.1161	1.98	63.5	45.44	4.4375

Table 7 shows that the target outputs of the DMU3, DMU8, and DMU9 are lower than their current values, indicating that the engine has possibilities for enhancing the output parameter

XIII. Conclusion

This study found that employing waste plastic oil facilitated the engine's proper functioning. This experimental investigation tested different speeds while maintaining a constant mass flow rate and injection pressure. The results of the experimental analysis and the linear programming multi-response optimization tool lead to the following conclusions:

I. When comparing the WPO mixes to diesel fuel, the BSFC went up. At full load, D50WPO50's BSFC is 25% higher than that of diesel fuel.

II. When the diesel engine runs with WPO, the BTE gradually increases to a maximum of 36.65% for the blend D90WPO10 at 2000 rpm, but when compared to diesel, it achieves a better result of 34.05% at 2500 rpm.

III. The blend of D90WPO10, D80WPO20, D70WPO30, D60WPO40, and D50WPO50 at 2000, 2500 rpm produces hydrocarbon emissions that are 30% and 10% lower than those of diesel at 26kW.

IV. A diesel engine emits 26 kW of CO when it operates on biodiesel instead of 0 kW. However, when employed at 2000 and 2500 rpm, the blends of D90WPO10, D80WPO20, D70WPO30, D60WPO40, and D50WPO50 produced superior outcomes in terms of CO emissions.

V. The fuel injection pressure for the biodiesel fuel mixes affects the CO emissions. Diesel fuel has higher exhaust gas temperatures (EGT) than WPO mixes. At 26 kW, the EGT for diesel and D50WPO50 are 340ºC and 333 oC, respectively. All loads and speeds combined, biodiesel produces greater NOx emissions than diesel. Diesel has a maximum NOx emission of 5.5 g/kW-hr, whereas biodiesel has a maximum emission of 6.5 g/kW-hr.

VI. Diesel engine performance and emission characteristics have been measured using DEA Frontier. It was found that the DMU 3, 8, and 9 were inefficient technically in terms of their input and output parameters. To design technically sound DMUs, the expected input and output have been specified.

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Conflicts of interest

All authors declare that they have no conflicts of interest.

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