# The Performance and Emission Traits of A Compression Ignition Direct Injection (CI DI) Engine Employing Mixtures of Biodiesel Derived From Waste Cooking Oil and Conventional Diesel Fuel

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*Abstract* — The study provides the experimental analysis of CI DI engine performances using blends of biodiesel (waste cooking oil) and diesel fuel. This experimental analysis has 6 permutations of blends of biodiesel with diesel in various quantity such as diesel, 100%WCO, 80% WCO diesel, 60% WCO diesel, 40% WCO diesel, 20% WCO diesel. Respective graphs depicting the correlation with multiple affecting parameters on engine performance is also presented in this paper. Based on the experimental findings, it is demonstrated that the highest mechanical efficiency achievable, at 83.54839%, is attained when utilizing 100% biofuel, surpassing all other combinations tested. Furthermore, the results indicate a proportional increase in mechanical efficiency with the rise in biofuel usage, while maintaining consistent environmental conditions. The future scope of biodiesel lies in its potential to serve as a sustainable alternative to conventional fossil fuels, offering reduced greenhouse gas emissions and greater energy security. Continued research and technological advancements are expected to enhance its production efficiency and widen its applications across various sectors.

***Keywords:*** Biodiesel (Waste Cooking Oil), Performance Analysis, Mechanical Efficiency

## I. Introduction

The significant surge in automobile numbers in recent times has led to a substantial demand for petroleum products. As crude oil reserves are projected to last only for a limited period, there is a pressing need to explore alternative fuel sources. The depletion of crude oil reserves could profoundly affect the transportation industry. Among the various alternative fuels being explored, biodiesel, sourced from vegetable oils, emerges as the most promising substitute for diesel due to the following factors:

1) Biodiesel integration into existing engines requires no modifications, offering seamless compatibility.
2) Derived solely from vegetable sources, biodiesel lacks sulphur, aromatic hydrocarbons, metals, or residues from crude oil.
3) As an oxygenated fuel, biodiesel tends to decrease emissions of carbon monoxide.
4) Biodiesel's environmental benefits extend to its carbon cycle; the CO2 it emits is reabsorbed by plants cultivated for its production, thus maintaining equilibrium.

Among these methods, transesterification stands out as the predominant commercial process for producing environmentally friendly methyl/ethyl esters fuel. Various vegetable oils such as sunflower, rice bran, palm, mahua, jatropha, Karanja, soybean, rapeseed, and rubber seed oils have undergone successful testing on compression-ignition engines, albeit with different performances. While sunflower, soybean, and palm oils are viable options, their costliness renders them unsuitable for large-scale biodiesel production. Non-edible oils like jatropha and Karanja, though economically attractive, demand significant land and time investment for cultivation, posing hurdles to widespread adoption. Used cooking oils emerge as a practical alternative due to their easy availability, although they require purification to remove impurities for efficient biodiesel production. Despite promising studies on engine performance and emissions using waste cooking oils, research in this area remains relatively limited. Various studies have explored the potential of waste oils as biodiesel feedstock, analysing properties such as free fatty acid and moisture content. Additionally, engine tests and road trials using waste cooking oil methyl esters have shown promising results. This paper contributes to the understanding of combustion behaviour and emissions of used cooking oil methyl ester (UCME) and its blends with diesel fuel, providing a thorough analysis of their performance characteristics.

## II. Objectives:

The literature review reveals extensive research utilizing a range of oil seeds, yet there is a notable scarcity of studies involving waste cooking oil methyl ester biodiesel as a fuel source. This project aims to investigate the significance of injection pressure on the performance and emission characteristics of compression-ignition engines. The objectives are outlined as follows:

1) Examination of the characteristics of biodiesel and biodiesel-diesel blends.
2) Conducting experimental assessments on the performance of a single-cylinder four-stroke diesel engine utilizing waste cooking oil methyl ester biodiesel and its blends.
3) Measurement of smoke and various emissions employing a smoke meter and gas analyzer.
4) Assessment of optimal performance parameters to achieve maximum efficiency and minimal pollution.

## III. Literature review:

Wail M. Adaileh, and Khaled S. AlQdah (2014) had investigated on Performance of Diesel Engine fuelled by a Biodiesel Extracted from a Waste Cocking Oil. In this study, the combustion characteristics and emissions of compression ignition diesel engine were measured using a biodiesel as an alternative fuel. The tests were performed. For a four-stroke single cylinder diesel engine loaded at variable engine speed between 1200-2600 rpm. The experimental results compared with standard diesel show that biodiesel provided significant reductions in CO, and unburned HC, but the NOx was increased. Biodiesel has a 5.95 % increasing in brake-specific fuel consumption due to its lower heating value. However, using B20 and B5 diesel fuel gave better emission results, NOx and brake specific fuel consumption. The experimental results show that the fuel consumption rate, brake thermal efficiency, and exhaust gas temperature increased while the bsfc, emission indices of CO2, CO decreased with an increase of engine speed.

G Lakshmi Narayana Rao, S Sampath, K Rajagopal's investigation focused on experimental studies examining the combustion and emission characteristics of both a diesel engine and its blends with diesel fuel. In this study, used cooking oil underwent dehydration followed by transesterification using an alkaline catalyst. The research analyzed the combustion, performance, and emission traits of Used Cooking Oil Methyl Ester (UCME) and its blends with diesel oil in a direct injection compression-ignition engine. The fuel properties and combustion behaviour of UCME were found to closely resemble those of diesel, with a minor decrease in thermal efficiency but significant improvements in reducing particulates, carbon monoxide, and unburnt hydrocarbons compared to diesel. Utilizing transesterified used cooking oil and its blends as diesel engine fuel offers the potential to decrease reliance on fossil fuels and substantially mitigate environmental pollution.

Tushar R Mohod, Rahul S Tadse, Ifthekar a Pathan et al, (2012) conducted study to assess the performance of a diesel engine powered by waste cooking oil methyl ester. Waste cooking oil methyl ester was produced through a transesterification process utilizing KOH (Potassium Hydroxide) as a catalyst, followed by experimentation on a single-cylinder diesel engine equipped with a variable compression ratio mechanism. The results revealed that lower blends of biodiesel enhanced Brake Thermal Efficiency (BTE) and decreased fuel consumption. However, NOx emissions rose with higher concentrations of biodiesel.

Jagannath Hirkude, Atul Padalkar, Deepa vedartham et al, (2012) had investigated the influence of waste fried oil methyl ester blends and load on the performance and smoke opacity of a diesel engine, utilizing response surface methodology. Particularly in the rural agricultural sector of developing countries like India, engines often utilize bio-origin alternative fuels. Variations in blend and load were examined, correlating with parameters such as Brake Thermal Efficiency (BTE), Brake Specific Fuel Consumption (BSFC), Exhaust Gas Temperature (EGT), and Smoke Opacity (SO). Employing Response Surface Methodology (RSM), the analysis modelled and evaluated engine characteristics, determining WC20 blend and a brake load of 2.5 kW as optimal input parameters for waste fried oil methyl ester blends.

Mohammed EL_Kassaby, Medhat A. Nemit_allah et al (2013) has investigated the impact of compression ratio on an engine fuelled with waste oil-derived biodiesel/diesel blend. Neat biodiesel was produced from restaurant waste oil via transesterification, then blended with diesel. The study examined how blending ratio and compression ratio affect engine performance, emissions, and combustion characteristics across various blends (B10, B20, B30, and B50) and diesel (B0) at compression ratios ranging from 14 to 18. Results indicated that increasing compression ratio enhanced engine torque and brake thermal efficiency across all blends. Additionally, the study found varying effects on emissions, with CO2 increasing, HC and CO decreasing, and NOx emissions showing variation. Overall, increasing compression ratio exhibited greater benefits with biodiesel blends compared to pure diesel.

R. Senthil Kumar1, M. Prabu et al (2014) experimented the use of tyre pyrolysis oil-diesel blends as biodiesel in a diesel engine. Pyrolysis oils from waste tire and waste plastic were studied for application in a single-cylinder multipurpose agricultural diesel engine. Performance tests were conducted using varying blends of tyre pyrolysis oil (TPO) and diesel fuel (5%, 15%, 25%, 50%, 75%, and 85%). The TPO, derived from waste automobile tires through vacuum pyrolysis, was blended with diesel to identify the most suitable ratio, with concentrations of 50% and 75% yielding optimal results.

Santosh Kumar Kurre, Shyam Pandey, Mukesh Saxena et al (2013) explored the impact of compression ratio on performance and emissions of a diesel engine using diesel-ethanol blends. Conducted on a 3.7kW, 4-stroke single cylinder, water-cooled engine with variable compression ratio, the study tested ethanol-diesel blends at compression ratios of 17, 17.5, and 18. Various blends of ethanol (5% as E5, 10% as E10, 15% as E15, and 20% as E20) were evaluated for engine performance and emissions. Results revealed that increasing compression ratio led to increased NOx emissions for neat diesel but decreased NOx for lower ethanol blends, while CO remained unchanged across all blends. Furthermore, brake specific fuel consumption decreased with higher compression ratio, while brake thermal efficiency increased. Exhaust gas temperature rose with compression ratio for all blends.

Swarup Kumar Nayaka, Bhabani Prasanna Pattanaika et al experimented the performance and emission characteristics of a diesel engine fuelled with Mahua biodiesel, enhanced with an additive. The study involved producing biodiesel from neat Mahua oil via base-catalysed transesterification and blending it with Dimethyl carbonate additive in varying proportions to create test fuels for engine application. Results indicated increased brake power and brake thermal efficiency with load across all test fuels. Furthermore, higher additive percentages in biodiesel led to significant improvements in all test results. This study offers a foundation for further investigation into biodiesel usage in diesel engines with different fuel additives and varying engine operating parameters.

P. L. Puthani et. al (2013) explored engine effects on performance in a CI engine using Paradise tree borne oil. This study investigates combustion, performance, and emissions of Simarouba oil methyl ester (SOME) and diesel blends in a single-cylinder, four-stroke, direct injection, water-cooled diesel engine. Findings revealed lower BTE, CO, HC, and smoke opacity with SOME-diesel blends, while BSEC and NOx were higher at 200 bar injection pressure and 23˚ bTDC injection timing. Although biodiesel blends had higher BSFC due to lower heating value, they exhibited superior emission properties compared to diesel, with reduced CO, HC, and smoke emissions at full load.

Alemayehu Gashaw, Abile Teshita [2014] analysed the increasing concern for energy resources and the environment has spurred interest in exploring alternative energy sources. To address rising energy demands, there's a growing interest in biodiesel as a viable substitute for diesel oil in internal combustion engines. Biodiesel presents a promising alternative as it is renewable and shares similar properties with diesel oil. Its significance stems from the projected depletion of conventional fuels and environmental apprehensions. Utilizing liquid fuels like biodiesel derived from waste cooking oil via transesterification offers a promising avenue to mitigate reliance on conventional fossil fuels. However, concerns arise over biodiesel's competition with food supplies, prompting recent emphasis on utilizing waste cooking oil as a primary feedstock for biodiesel production.

M. Mittelbach, B. Pokits, and A. Silberholz in their paper "Diesel fuels derived from vegetable oils, IV: Production and fuel properties of fatty acid methyl esters from used frying oil, liquid fuels from renewable resources," in Proceedings of an Alternative Energy Conf., American Society of Agricultural Engineers, 1992; 74-78 revels waste cooking oils offer a feasible substitute for diesel due to their widespread availability. While containing traces of vegetable oil degradation products and foreign matter, these impurities can be eliminated through heating and filtration, thus not hindering their suitability as biodiesel feedstock.

## IV. Experimental Setup and Methodology:

### A. *Engine Setup:*

The experiments were conducted on a single-cylinder, four-stroke Kirloskar diesel engine with compression ignition direct injection, as depicted in Figure 1.1. The experimental setup and instrumentation layout are illustrated in Figure 1.2. This water-cooled engine has a rated power of 5.2 kW at 1500 rpm, with a bore of 87.5 mm and stroke of 110 mm, featuring a compression ratio of 17.5. The injection pressure remains constant at 200 bar, with injection occurring at 23˚bTDC. The setup includes a test bed, a diesel engine equipped with an eddy current dynamometer, and instrumentation such as the AVL444 5-gas analyzer and AVL437 smoke meter (as shown in Figure 3.3). Additionally, pressure sensors measure cylinder pressure, while a TDC sensor records pressure at every two degrees of crank rotation, enabling the plotting of P - θ curves.

Fig. 1.1: Single cylinder Kirloskar Engine.

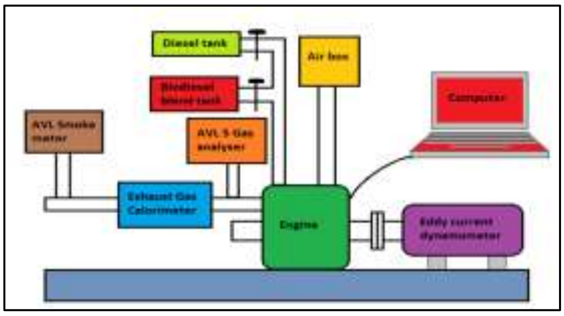


Fig. 1.2: Layout of the experimental setup

The engine is coupled to an eddy current dynamometer, mounted on a base frame and interconnected with the engine to apply varying loads. A rotameter is utilized for measuring the flow of engine cooling water, while a pipe-in-pipe type calorimeter is installed at the engine's exhaust gas outlet line, with its cooling water flow regulated by the rotameter. Temperature sensors are positioned at the calorimeter's inlet and outlet for temperature measurement. A pump supplies water to the eddy current dynamometer, engine cooling system, and calorimeter. Inside the control panel, a fuel tank and fuel measuring unit are installed. An air box is equipped to dampen airflow line pulsations, with an orifice meter and manometer at its inlet for flow measurement. A piezo-electric type sensor with a water-cooled adapter is fitted in the cylinder head for combustion pressure measurement, connected to an engine indicator in the control panel. This indicator scans pressure and crank-angle data interfaced with a computer through a COM port. Additionally, an encoder is incorporated to convert information between formats. The rotary encoder serves as an optical sensor employed for speed and crank angle measurement. Positioned on the dynamometer shaft, it interfaces with the engine indicator. Temperature sensors of the thermocouple type monitor cooling water inlet, outlet, and exhaust temperatures, with digital display available on the control panel indicator. The opacity meter and diesel smoke opacity meter employ a distributary sample type, incorporating gas temperature, pressure, and distributor control cells to ensure measurement stability and reproducibility. It continuously measures the total opacity and smoke degree at both idle and free speed conditions. The exhaust gas analyzer is utilized to gauge the proportions of gaseous components in the engine's exhaust emissions. The engine under study is a single-cylinder, four-stroke, direct injection, water-cooled diesel engine, coupled to an electrical generator to apply load. Throughout the experiments, injection pressures of 190, 205, and 220 bar and a compression ratio of 17.5 are maintained. Indicators on the test bed electrically measure engine speed, brake power, and various temperatures. The computer interfaces with the engine via the PCI 1050 IC card connected to the CPU's COM port. Engine Soft, a LabVIEW-based software, controls the engine readings. Tests are conducted at a constant rated speed of 1500 rpm across its power range using WC0, WC20, WC40, WC60, WC80, and WC100 blends.

Tests are performed on the engine under various loads ranging from 0kg to 18.3 kg, with load increments of 2.5kg (rated load). Blends WC0, WC20, WC40, WC60, WC80, and WC100 are evaluated at an injection timing of

23˚bTDC and injection pressures of 190, 205, and 220 bar (advanced, normal, and retarded timing) respectively.

| | |
|---|---|
| Make | Kirloskar Engine |
| Bore & stroke | 87.5mm x110mm |
| Type of cooling | Water cooled |
| Speed | 1500 rpm |
| Compression ratio | 17.5:1 |
| Number of cylinders | 1 |
| Rated power | 5.2 kW |
| Start of injection | 23˚ bTDC |
| Injection pressure | 205 bar |

Table 1: Engine specifications

In the diesel engine setup, diesel serves as the pilot fuel, followed by the utilization of SOME blends as the primary fuel source. Performance and emission characteristics are meticulously observed and analyzed for each blend. Prior to testing each blend, the fuel tank is emptied entirely, after which a new blend of SOME is added as fuel, and the engine's performance is assessed.

### *B. Data Reduction:*

To calculate density, kinematic viscosity, brake power, brake specific fuel consumption, brake specific energy consumption, thermal efficiency, mechanical efficiency and air fuel ratio following equations are used.

1) *For estimation of density the following formula is used,*

$$\rho = \frac{(Y - X)}{50} \ldots \ldots gms/cc$$

where, Y is weight of flask with 50ml oil in gms.
X is weight of empty measuring flask in gms.

2) *For estimation of kinematic viscosity, the following formula is used,*

$$\vartheta = At + \frac{B}{t} \ldots \ldots \ldots Stokes$$

where A= 0.0026, B= 1.71
t is time for 50 ml oil collection in seconds.

3) *For estimation of brake power, the following formula is used,*

$$BP = \frac{2\pi NT}{60000} \ldots \ldots KW$$

Where, N is speed of engine in rpm.
T is torque in Nm.

4) *For estimation of brake specific fuel consumption, the following formula is used,*

$$BSFC = \frac{TFC}{BP} \ldots \ldots Kg/KwHr$$

Where, TFC is Total Fuel Consumption in kg/hr. BP is Brake Power in kW.

5) *For estimation of brake specific energy consumption, the following formula is used,*

$$BSEC = \frac{CV * TFC}{BP} \ldots KJ/KwHr$$

Where, CV is calorific value in kJ/kg

6) *For estimation of thermal efficiency, the following formula is used,*

$$\eta th = \frac{BP}{mf \times CV} * 100 \ldots \%$$

Where mf is fuel consumption rate in kg/s.

7) *For estimation of mechanical efficiency, the following formula is used,*

$$\eta mech = \frac{BP}{IP} * 100 \ldots \%$$

Where, IP is indicated power in Kw

8) *For estimation of air-fuel ratio the following formula is used,*

$$\frac{A}{F} = \frac{Ma}{Mf}$$

Where, Mf is fuel consumption rate in kg/s.
Ma is mass flow rate of air in kg/s.

## V. RESULT AND DISCUSSION:

In this section of the study, results estimation and analysis of its inferences are carried out for analysing the various efficiencies with respect to the load using permutation of diesel and biofuel (waste cooking oil). The various permutations are

1) Diesel
2) For 100% WCO Diesel
3) For 80% WCO Diesel
4) For 60% WCO Diesel
5) For 40% WCO Diesel
6) For 20% WCO Diesel

In order to analyse the experiment results constructively the parameters like load, speed, time taken, manometric head, We, Wc, temp at various interval, smoke value, concentration value of CO, HC, $CO_2$, $O_2$, $NO_X$ are mentioned in the table for each combination and thus the output resulting values like BP, IP, Mf, TFC, ρa, Heq, Va, Ma, BSFC, $\eta th$ A/F, $\eta vol$, $\eta mech$, BMEP, Qs, Qp, Qc, Qexh, Qun for each combination are also calculated and mentioned in the respective table. The graphical representation of the result for each combination against various parameters are depicted so that one can get the clear understanding of the utilization of the biofuel. The utilization of different combinations of biofuel led to enhanced engine performance efficiency. Below is the summary of the performance experiment of using biofuel.

### *A. For Diesel:*

The initial experiment involved utilizing diesel as the fuel to facilitate subsequent comparisons with the performance achieved using biofuel.

- The maximum load estimated in the experiment = 18.3 Kg
- The maximum BP estimated in the experiment = 5.071475 Kw
- Break Specific Fuel Consumption estimate at this BP & Load = 0.319434 Kg/Kw.hr
- Thermal Efficiency estimate at this BP & Load = 25.55543
- Mechanical Efficiency estimate at this BP & Load = 78.3666
- Air-Fuel ratio estimated at this BP & Load = 18.23867

### *B. For 100% WCO Diesel:*

- The maximum load estimated in the experiment = 18.3 Kg

 

- The maximum BP estimated in the experiment = 5.078432 Kw
- Break Specific Fuel Consumption estimate at this BP & Load = 0.371958 Kg/Kw.hr
- Thermal Efficiency estimate at this BP & Load = 24.31784
- Mechanical Efficiency estimate at this BP & Load = 83.54839
- Air-Fuel ratio estimated at this BP & Load = 15.2851

### C. *For 80% WCO Diesel:*

- The maximum load estimated in the experiment = 18.3 Kg
- The maximum BP estimated in the experiment = 5.071475 Kw
- Break Specific Fuel Consumption estimate at this BP & Load = 0.356736 Kg/Kw.hr
- Thermal Efficiency estimate at this BP & Load = 24.86885
- Mechanical Efficiency estimate at this BP & Load = 80.86574
- Air-Fuel ratio estimated at this BP & Load = 16.63498

### D. *For 60% WCO Diesel:*

- The maximum load estimated in the experiment = 18.3 Kg
- The maximum BP estimated in the experiment = 5.09234511 Kw
- Break Specific Fuel Consumption estimate at this BP & Load = 0.34508 Kg/Kw.hr
- Thermal Efficiency estimate at this BP & Load = 25.17704
- Mechanical Efficiency estimate at this BP & Load = 79.66318
- Air-Fuel ratio estimated at this BP & Load = 17.37574

### E. *For 40% WCO Diesel:*

- The maximum load estimated in the experiment = 18.3 Kg
- The maximum BP estimated in the experiment = 5.071475 Kw
- Break Specific Fuel Consumption estimate at this BP & Load = 0.326168 Kg/Kw.hr
- Thermal Efficiency estimate at this BP & Load = 26.11443
- Mechanical Efficiency estimate at this BP & Load = 80.9081
- Air-Fuel ratio estimated at this BP & Load = 18.26679

### F. *For 20% WCO Diesel:*

- The maximum load estimated in the experiment = 18.3 Kg
- The maximum BP estimated in the experiment = 5.085388 Kw
- Break Specific Fuel Consumption estimate at this BP & Load = 0.313412 Kg/Kw.hr
- Thermal Efficiency estimate at this BP & Load = 26.62985
- Mechanical Efficiency estimate at this BP & Load = 80.9081
- Air-Fuel ratio estimated at this BP & Load = 16.63498

| Sr. No | load (kg) | speed (rpm) | time(sec) | mano (mm) | We(lph) | Wc(lph) | T1 | T2 | T3 | T4 | T5 | T6 | Ta | smoke | CO | HC | $CO_2$ | O2 | NOX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1575 | 76 | 116 | 180 | 70 | 28 | 37 | 28 | 31 | 157 | 138 | 31 | 3.9 | 0.05 | 13 | 2.8 | 17.22 | 171 |
| 2 | 2.5 | 1571 | 55 | 110 | 180 | 70 | 28 | 40 | 28 | 31 | 203 | 175 | 32 | 8.5 | 0.07 | 16 | 4 | 15.59 | 373 |
| 3 | 5 | 1545 | 43 | 110 | 180 | 70 | 28 | 40 | 28 | 32 | 246 | 212 | 32 | 10.2 | 0.04 | 17 | 5.1 | 14.34 | 676 |
| 4 | 7.5 | 1524 | 36 | 106 | 180 | 70 | 28 | 41 | 28 | 32 | 298 | 256 | 32 | 14.3 | 0.04 | 12 | 6.5 | 12.79 | 971 |
| 5 | 10 | 1510 | 30 | 102 | 180 | 70 | 28 | 43 | 28 | 32 | 350 | 305 | 22 | 28.3 | 0.04 | 16 | 7.8 | 11.29 | 1159 |
| 6 | 12.5 | 1495 | 26 | 96 | 180 | 70 | 28 | 44 | 28 | 33 | 412 | 357 | 33 | 47.1 | 0.06 | 18 | 9.5 | 9.31 | 1361 |
| 7 | 15 | 1480 | 22 | 94 | 180 | 70 | 28 | 47 | 28 | 33 | 474 | 405 | 33 | 65.2 | 0.18 | 20 | 11.4 | 7.12 | 1466 |
| 8 | 17.5 | 1465 | 19 | 88 | 180 | 70 | 28 | 49 | 28 | 33 | 546 | 455 | 33 | 88.6 | 0.61 | 21 | 13.3 | 4.53 | 1510 |
| 9 | 18.3 | 1458 | 18 | 84 | 180 | 70 | 28 | 51 | 28 | 34 | 590 | 489 | 33 | 85 | 1.38 | 14 | 13.9 | 3.29 | 1335 |

| S.no | BP kW | IP kW | $M_f$ kg/sec | TFC kg/hr | $\rho_a$ kg/m3 | Heq m | Va m3/s | Ma kg/sec | BSFC kg/kWhr | $\eta_{th}$ % | A/F | $\eta_{vol}$ % | $\eta_{mech}$ % | BMEP bar | Qs KJ/S | Qp KW | Qc KJ/S | Qexh KJ/S | Qun KJ/S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1.4 | 0.000107 | 0.38368421 | 1.15761966 | 100.2056 | 0.00835897 | 0.009677 | | 0 | 90.79197 | 96.27171 | 0 | 0 | 4.700132 | 0 | 1.8837 | 1.355937 | |
| 2 | 0.746521 | 2.1465207 | 0.000147 | 0.53018182 | 1.15382418 | 95.33515 | 0.0081533 | 0.009407 | 0.710204 | 11.49426 | 63.87792 | 94.14203 | 34.77817 | 0.86197 | 6.494727 | 0.746521 | 2.5116 | 1.797248 | 1.439358 |
| 3 | 1.468332 | 2.86833162 | 0.000188 | 0.67813953 | 1.15382418 | 95.33515 | 0.0081533 | 0.009407 | 0.461844 | 17.67539 | 49.94092 | 95.72629 | 51.19114 | 1.723939 | 8.307209 | 1.468332 | 2.5116 | 2.258863 | 2.068415 |
| 4 | 2.172561 | 3.57256056 | 0.000225 | 0.81 | 1.15382418 | 91.86842 | 0.00800369 | 0.009235 | 0.372832 | 21.89529 | 41.04376 | 95.26456 | 60.81242 | 2.585909 | 9.9225 | 2.172561 | 2.7209 | 2.767951 | 2.261088 |
| 5 | 2.870137 | 4.27013688 | 0.00027 | 0.972 | 1.19293687 | 85.50327 | 0.00772144 | 0.009211 | 0.33866 | 24.10462 | 34.11552 | 92.75719 | 67.21417 | 3.447878 | 11.907 | 2.870137 | 3.1395 | 3.420813 | 2.47655 |
| 6 | 3.552032 | 4.95203198 | 0.000312 | 1.12153846 | 1.15005352 | 83.47438 | 0.00762928 | 0.008774 | 0.315746 | 25.85393 | 28.16371 | 92.56964 | 71.72878 | 4.309848 | 13.73885 | 3.552032 | 3.3488 | 3.787794 | 3.05022 |
| 7 | 4.219671 | 5.61967144 | 0.000368 | 1.32545455 | 1.15005352 | 81.73533 | 0.00754939 | 0.008682 | 0.314113 | 25.98829 | 23.58129 | 92.52868 | 75.08751 | 5.171817 | 16.23682 | 4.219671 | 3.9767 | 4.390341 | 3.650106 |
| 8 | 4.873055 | 6.27305525 | 0.000426 | 1.53473684 | 1.15005352 | 76.51818 | 0.00730448 | 0.008401 | 0.314943 | 25.91978 | 19.70497 | 90.44361 | 77.68233 | 6.033787 | 18.80053 | 4.873055 | 4.3953 | 4.980996 | 4.551175 |
| 9 | 5.071475 | 6.47147484 | 0.00045 | 1.62 | 1.15005352 | 73.04008 | 0.00713654 | 0.008207 | 0.319434 | 25.55543 | 18.23867 | 88.78841 | 78.3666 | 6.309617 | 19.845 | 5.071475 | 4.8139 | 5.304389 | 4.655236 |

Table 2: Performance Analysis and Graphs: Diesel

 

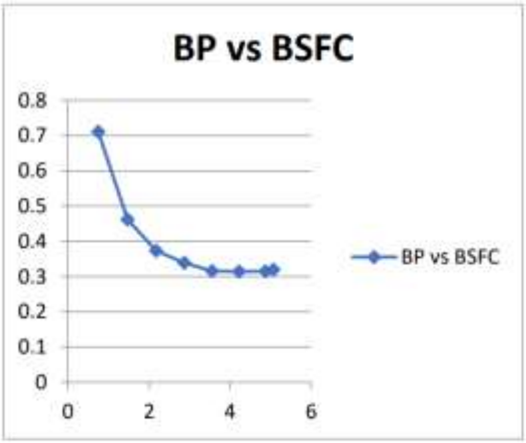


Fig. 1.2: BP vs BSFC for Diesel

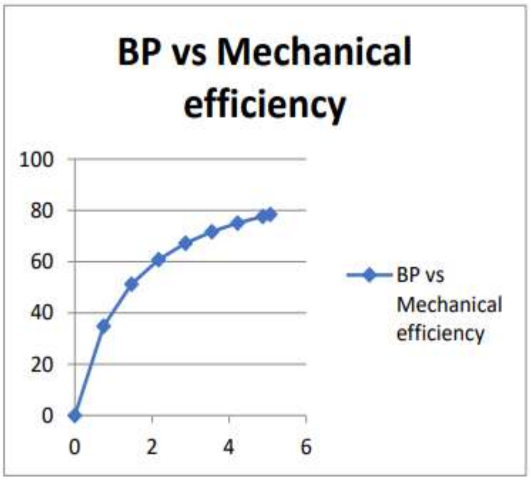


Fig. 1.4: BP vs Mech. Efficiency for Diesel

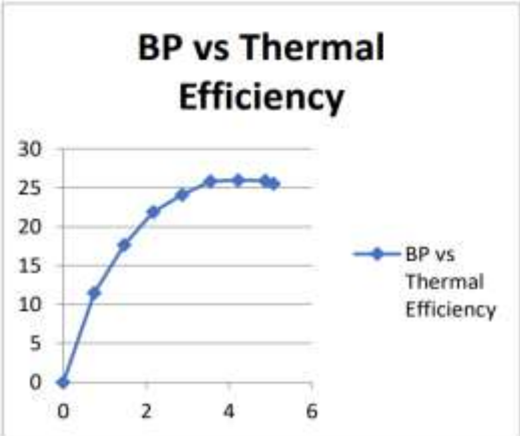


Fig. 1.3: BP vs Thermal Efficiency for Diesel

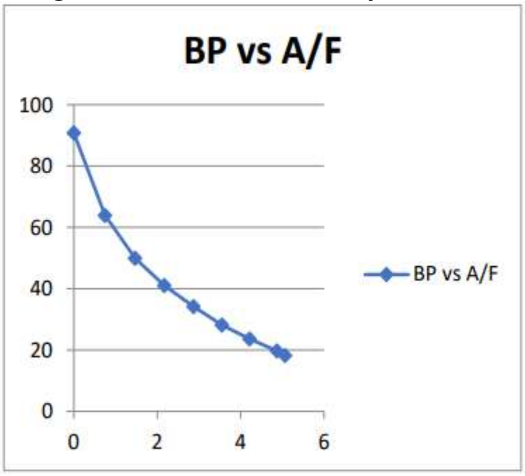


Fig. 1.4: BP vs A/F for Diesel

| Sr. No | load (kg) | speed (rpm) | time(sec) | mano (mm) | We(lph) | Wc(lph) | T1 | T2 | T3 | T4 | T5 | T6 | Ta | smoke | CO | HC | $CO_2$ | O2 | NOX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1608 | 80.69 | 114 | 180 | 70 | 28 | 37 | 28 | 34 | 155 | 135 | 34 | 2.1 | 0.05 | 15 | 2.7 | 17.3 | 183 |
| 2 | 2.5 | 1572 | 57.75 | 112 | 180 | 70 | 28 | 38 | 28 | 34 | 201 | 169 | 35 | 7.1 | 0.06 | 17 | 3.8 | 15.65 | 362 |
| 3 | 5 | 1554 | 45.2 | 109 | 180 | 70 | 28 | 40 | 28 | 34 | 240 | 204 | 35 | 9.3 | 0.05 | 18 | 4.9 | 14.42 | 663 |
| 4 | 7.5 | 1532 | 36.8 | 104 | 180 | 70 | 28 | 41 | 28 | 35 | 282 | 246 | 35 | 10.1 | 0.04 | 13 | 6.3 | 12.79 | 1001 |
| 5 | 10 | 1522 | 30.69 | 99 | 180 | 70 | 28 | 43 | 28 | 35 | 339 | 294 | 35 | 23.1 | 0.03 | 13 | 7.7 | 11.19 | 1292 |
| 6 | 12.5 | 1497 | 26.1 | 95 | 180 | 70 | 28 | 46 | 28 | 35 | 410 | 351 | 36 | 29.9 | 0.04 | 15 | 9.5 | 9.22 | 1469 |
| 7 | 15 | 1480 | 22 | 89 | 180 | 70 | 28 | 47 | 28 | 35 | 470 | 401 | 36 | 59 | 0.18 | 17 | 11.5 | 6.91 | 1554 |
| 8 | 17.5 | 1464 | 18.2 | 86 | 180 | 70 | 29 | 51 | 29 | 36 | 563 | 478 | 36 | 94.2 | 0.63 | 8 | 13.5 | 4.07 | 1521 |
| 9 | 18.3 | 1460 | 17.4 | 81 | 180 | 70 | 29 | 52 | 29 | 36 | 594 | 500 | 36 | 92.5 | 0.86 | 7 | 14.1 | 3.36 | 1553 |

| S.no | BP kW | IP kW | $M_f$ kg/sec | TFC kg/hr | $\rho_a$ kg/m3 | Heq m | Va m3/s | Ma kg/sec | BSFC kg/kWhr | $\eta_{th}$ % | A/F | $\eta_{vol}$ % | $\eta_{mech}$ % | BMEP bar | Qs KJ/S | Qp KW | Qc KJ/S | Qexh KJ/S | Qun KJ/S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 0.000113 | 0.40733672 | 1.14630741 | 99.44976 | 0.00832739 | 0.009546 | | 0 | 84.36433 | 93.93967 | 0 | 0 | 4.503334 | 0 | 1.8837 | 1.285599 | 1.334035 |
| 2 | 0.746996 | 1.74699589 | 0.000158 | 0.56914286 | 1.14258564 | 98.02329 | 0.00826745 | 0.009446 | 0.761909 | 11.87179 | 59.7505 | 95.39932 | 42.75888 | 0.86197 | 6.29219 | 0.746996 | 2.093 | 1.753757 | 1.698438 |
| 3 | 1.476885 | 2.476885 | 0.000202 | 0.72716814 | 1.14258564 | 95.39766 | 0.00815597 | 0.009319 | 0.492366 | 18.37094 | 46.13518 | 95.20309 | 59.62671 | 1.723939 | 8.039248 | 1.476885 | 2.5116 | 2.146961 | 1.903802 |
| 4 | 2.183965 | 3.18396508 | 0.000248 | 0.89315217 | 1.14258564 | 91.02162 | 0.00796671 | 0.009103 | 0.408959 | 22.11768 | 36.68977 | 94.32932 | 68.59262 | 2.585909 | 9.874293 | 2.183965 | 2.7209 | 2.540599 | 2.428829 |
| 5 | 2.892946 | 3.89294591 | 0.000297 | 1.07096774 | 1.14258564 | 86.64558 | 0.00777285 | 0.008881 | 0.3702 | 24.43337 | 29.85348 | 92.63855 | 74.31251 | 3.447878 | 11.84014 | 2.892946 | 3.1395 | 3.069336 | 2.738362 |
| 6 | 3.556784 | 4.55678386 | 0.00035 | 1.25931034 | 1.13888795 | 83.4147 | 0.00762655 | 0.008686 | 0.354059 | 25.54725 | 24.83013 | 92.41292 | 78.0547 | 4.309848 | 13.92238 | 3.556784 | 3.7674 | 3.717244 | 2.880947 |
| 7 | 4.219671 | 5.21967144 | 0.000415 | 1.494 | 1.13888795 | 78.14641 | 0.00738179 | 0.008407 | 0.354056 | 25.54744 | 20.2579 | 90.47446 | 80.84171 | 5.171817 | 16.517 | 4.219671 | 3.9767 | 4.211636 | 4.108993 |
| 8 | 4.869729 | 5.86972893 | 0.000502 | 1.80593407 | 1.13888795 | 75.51226 | 0.00725631 | 0.008264 | 0.370849 | 24.39059 | 16.47393 | 89.90852 | 82.96344 | 6.033787 | 19.9656 | 4.869729 | 4.6046 | 5.081516 | 5.409759 |
| 9 | 5.078432 | 6.0784316 | 0.000525 | 1.88896552 | 1.13888795 | 71.12201 | 0.00704221 | 0.00802 | 0.371958 | 24.31784 | 15.2851 | 87.49482 | 83.54839 | 6.309617 | 20.88356 | 5.078432 | 4.8139 | 5.244921 | 5.74631 |

Table 3: Performance Analysis and Graphs: For 100% WCO Diesel

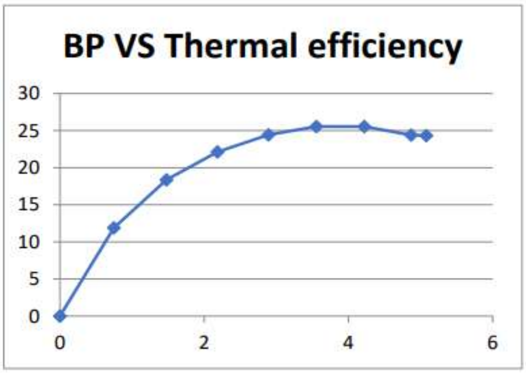


Fig. 1.5: BP vs Thermal Efficiency for 100% WCO Diesel

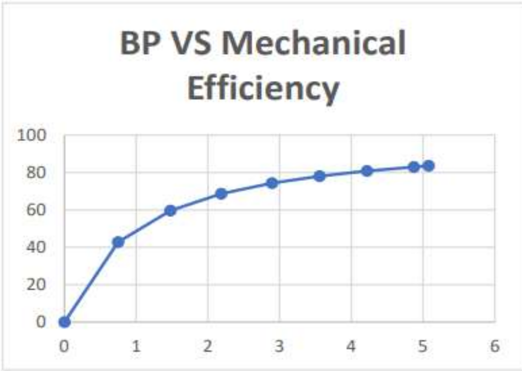


Fig. 1.7: BP vs Mech. Efficiency for 100% WCO Diesel

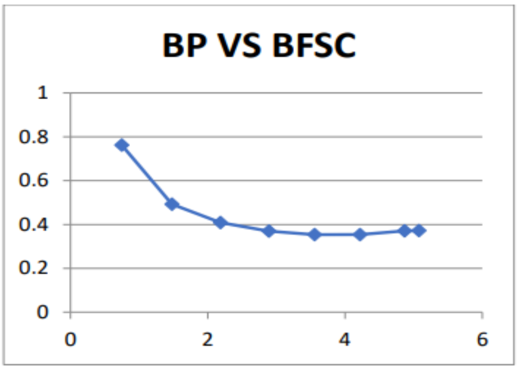


Fig. 1.6: BP vs BSFC for 100% WCO Diesel


Fig. 1.8: BP vs A/F for 100% WCO Diesel

| Sr. No | load (kg) | speed (rpm) | time(sec) | mano (mm) | We(lph) | Wc(lph) | T1 | T2 | T3 | T4 | T5 | T6 | Ta | smoke | CO | HC | $CO_2$ | O2 | NOX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1597 | 77.32 | 115 | 180 | 70 | 28 | 38 | 28 | 35 | 152 | 134 | 36 | 2.8 | 0.05 | 10 | 2.5 | 17.41 | 180 |
| 2 | 2.5 | 1564 | 56.86 | 110 | 180 | 70 | 28 | 38 | 28 | 35 | 195 | 163 | 36 | 8.5 | 0.05 | 13 | 3.8 | 15.99 | 311 |
| 3 | 5 | 1557 | 44 | 108 | 180 | 70 | 28 | 40 | 28 | 35 | 238 | 199 | 36 | 11.1 | 0.05 | 13 | 4.8 | 14.48 | 587 |
| 4 | 7.5 | 1539 | 36.05 | 106 | 180 | 70 | 28 | 42 | 28 | 35 | 285 | 242 | 36 | 12.8 | 0.03 | 11 | 6.2 | 13.04 | 938 |
| 5 | 10 | 1525 | 30 | 100 | 180 | 70 | 28 | 44 | 28 | 35 | 343 | 293 | 36 | 14.7 | 0.03 | 13 | 7.7 | 11.43 | 1171 |
| 6 | 12.5 | 1494 | 25.56 | 96 | 180 | 70 | 28 | 45 | 28 | 35 | 400 | 342 | 36 | 28.26 | 0.04 | 13 | 9.3 | 9.56 | 1439 |
| 7 | 15 | 1482 | 21.98 | 94 | 180 | 70 | 28 | 47 | 28 | 36 | 466 | 394 | 36 | 45.1 | 0.15 | 15 | 11.1 | 7.37 | 1611 |
| 8 | 17.5 | 1464 | 18.74 | 90 | 180 | 70 | 29 | 49 | 29 | 36 | 538 | 450 | 36 | 96.1 | 0.45 | 13 | 13.1 | 4.95 | 1701 |
| 9 | 18.3 | 1458 | 17.75 | 88 | 180 | 70 | 29 | 52 | 29 | 36 | 578 | 481 | 36 | 94.1 | 0.84 | 10 | 13.8 | 3.91 | 1587 |

| S.no | BP kW | IP kW | $M_f$ kg/sec | TFC kg/hr | $\rho_a$ kg/m3 | Heq m | Va m3/s | Ma kg/sec | BSFC kg/kWhr | $\eta_{th}$ % | A/F | $\eta_{vol}$ % | $\eta_{mech}$ % | BMEP bar | Qs KJ/S | Qp KW | Qc KJ/S | Qexh KJ/S | Qun KJ/S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1.2 | 0.000115 | 0.41531298 | 1.13888795 | 100.9757 | 0.00839103 | 0.009556 | | 0 | 82.83681 | 95.30961 | 0 | 0 | 4.6815 | 0 | 2.093 | 1.234123 | 1.354377 |
| 2 | 0.743194 | 1.94319438 | 0.000157 | 0.56475554 | 1.13888795 | 96.58545 | 0.00820659 | 0.009346 | 0.759903 | 11.67434 | 59.57798 | 95.18144 | 38.24601 | 0.86197 | 6.36605 | 0.743194 | 2.093 | 1.662121 | 1.867735 |
| 3 | 1.479736 | 2.67973613 | 0.000203 | 0.72981818 | 1.13888795 | 94.82935 | 0.00813164 | 0.009261 | 0.493208 | 17.98705 | 45.68221 | 94.7362 | 55.21947 | 1.723939 | 8.226673 | 1.479736 | 2.5116 | 2.102847 | 2.13249 |
| 4 | 2.193944 | 3.39394403 | 0.000247 | 0.89076283 | 1.13888795 | 93.07325 | 0.008056 | 0.009175 | 0.40601 | 21.85012 | 37.08009 | 94.95263 | 64.64291 | 2.585909 | 10.04088 | 2.193944 | 2.9302 | 2.580772 | 2.335961 |
| 5 | 2.898648 | 4.09864817 | 0.000297 | 1.0704 | 1.13888795 | 87.80495 | 0.00782468 | 0.008911 | 0.369276 | 24.0237 | 29.97118 | 93.07282 | 70.72205 | 3.447878 | 12.06579 | 2.898648 | 3.3488 | 3.1098 | 2.708539 |
| 6 | 3.549656 | 4.74965604 | 0.000349 | 1.25633803 | 1.13888795 | 84.29275 | 0.00766659 | 0.008731 | 0.353932 | 25.06515 | 25.01952 | 93.08457 | 74.73501 | 4.309848 | 14.16172 | 3.549656 | 3.5581 | 3.635779 | 3.418187 |
| 7 | 4.225374 | 5.4253737 | 0.000406 | 1.46096451 | 1.13888795 | 82.53665 | 0.00758631 | 0.00864 | 0.34576 | 25.65759 | 21.28993 | 92.85567 | 77.88171 | 5.171817 | 16.46832 | 4.225374 | 3.9767 | 4.278652 | 3.987591 |
| 8 | 4.869729 | 6.06972893 | 0.000476 | 1.7135539 | 1.13888795 | 79.02446 | 0.00742314 | 0.008454 | 0.351879 | 25.21143 | 17.76125 | 91.97565 | 80.22976 | 6.033787 | 19.31556 | 4.869729 | 4.186 | 4.931208 | 5.328623 |
| 9 | 5.071475 | 6.27147484 | 0.000503 | 1.80912676 | 1.13888795 | 77.26836 | 0.0073402 | 0.00836 | 0.356726 | 24.86885 | 16.63498 | 91.32223 | 80.86574 | 6.309617 | 20.39288 | 5.071475 | 4.8139 | 5.283643 | 5.223861 |

Table 4: Performance Analysis and Graphs: For 80% WCO Diesel

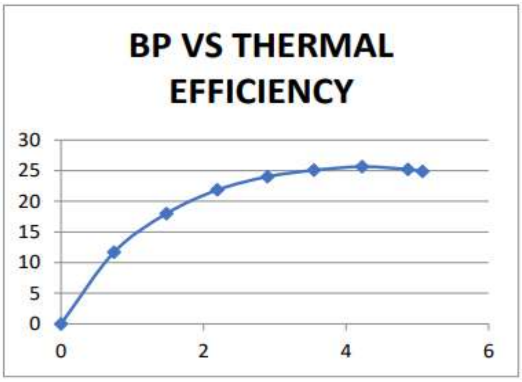


Fig. 1.9: BP vs Thermal. Efficiency for 80% WCO Diesel

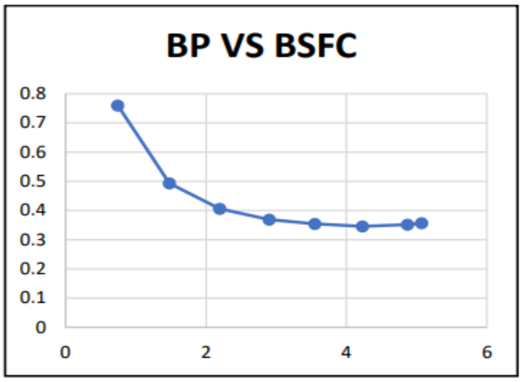


Fig. 1.10: BP vs A/F for 80% WCO Diesel

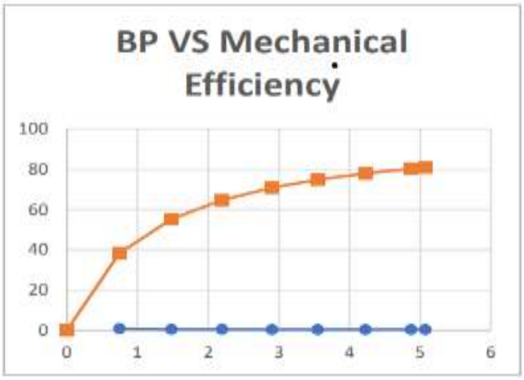


Fig. 1.11: BP vs Mech. Efficiency for 80% WCO Diesel

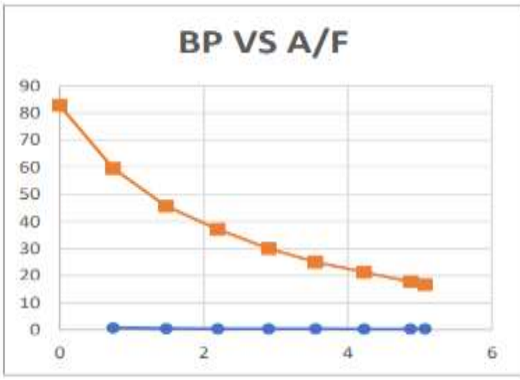


Fig. 1.12: BP vs A/F for 80% WCO Diesel

| Sr. No | load (kg) | speed (rpm) | time(sec) | mano (mm) | We(lph) | Wc(lph) | T1 | T2 | T3 | T4 | T5 | T6 | Ta | smoke | CO | HC | $CO_2$ | O2 | NOX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1588 | 76.095 | 116 | 180 | 70 | 28 | 37 | 28 | 30 | 154 | 133 | 31 | 3.5 | 0.05 | 11 | 2.7 | 17.36 | 190 |
| 2 | 2.5 | 1574 | 55.82 | 112 | 180 | 70 | 28 | 38 | 28 | 31 | 197 | 167 | 31 | 7.6 | 0.06 | 13 | 3.8 | 15.98 | 321 |
| 3 | 5 | 1559 | 44.25 | 108 | 180 | 70 | 28 | 40 | 28 | 31 | 242 | 206 | 32 | 9.5 | 0.04 | 11 | 5 | 14.64 | 608 |
| 4 | 7.5 | 1527 | 36.55 | 106 | 180 | 70 | 28 | 41 | 28 | 31 | 286 | 246 | 32 | 11.1 | 0.03 | 8 | 6.3 | 13.25 | 962 |
| 5 | 10 | 1514 | 30.2 | 102 | 180 | 70 | 28 | 43 | 28 | 31 | 341 | 294 | 32 | 13.6 | 0.03 | 9 | 7.8 | 11.51 | 1261 |
| 6 | 12.5 | 1503 | 25.68 | 98 | 180 | 70 | 28 | 46 | 28 | 32 | 397 | 344 | 32 | 27.4 | 0.06 | 10 | 9.3 | 9.82 | 1449 |
| 7 | 15 | 1487 | 21.89 | 94 | 180 | 70 | 28 | 49 | 28 | 32 | 470 | 402 | 33 | 37.8 | 0.17 | 15 | 11.1 | 7.57 | 1576 |
| 8 | 17.5 | 1469 | 18.6 | 92 | 180 | 70 | 28 | 51 | 28 | 33 | 545 | 459 | 33 | 84.5 | 0.52 | 8 | 13.2 | 4.86 | 1535 |
| 9 | 18.3 | 1464 | 17.86 | 90 | 180 | 70 | 28 | 51 | 28 | 33 | 579 | 489 | 34 | 92.2 | 0.86 | 7 | 13.6 | 4.14 | 1598 |

| S.no | BP kW | IP kW | $M_f$ kg/sec | TFC kg/hr | $\rho_a$ kg/m3 | Heq m | Va m3/s | Ma kg/sec | BSFC kg/kWhr | $\eta_{th}$ % | A/F | $\eta_{vol}$ % | $\eta_{mech}$ % | BMEP bar | Qs KJ/S | Qp KW | Qc KJ/S | Qexh KJ/S | Qun KJ/S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1.3 | 0.000115 | 0.41244234 | 1.15762 | 100.2056 | 0.008359 | 0.009677 | | 0 | 84.46137 | 95.48359 | 0 | 0 | 4.747211 | 0 | 1.8837 | 1.324733 | 1.538778 |
| 2 | 0.74794627 | 2.04794627 | 0.000156 | 0.56225009 | 1.15762 | 96.75026 | 0.008214 | 0.009508 | 0.751725 | 11.55754 | 60.87961 | 94.65739 | 36.52177 | 0.871906 | 6.471499 | 0.747946 | 2.093 | 1.764718 | 1.865834 |
| 3 | 1.48163689 | 2.78163689 | 0.000197 | 0.70926102 | 1.153824 | 93.60178 | 0.008079 | 0.009322 | 0.478701 | 18.14932 | 47.3135 | 94.00028 | 53.26493 | 1.743811 | 8.163594 | 1.481637 | 2.5116 | 2.198791 | 1.971566 |
| 4 | 2.17683726 | 3.47683726 | 0.000239 | 0.85868126 | 1.153824 | 91.86842 | 0.008004 | 0.009235 | 0.394463 | 22.02514 | 38.71687 | 95.0774 | 62.6097 | 2.615717 | 9.883421 | 2.176837 | 2.7209 | 2.646859 | 2.338825 |
| 5 | 2.87773989 | 4.17773989 | 0.000289 | 1.03923179 | 1.153824 | 88.40168 | 0.007851 | 0.009059 | 0.361128 | 24.05824 | 31.38101 | 94.06706 | 68.8827 | 3.487623 | 11.96156 | 2.87774 | 3.1395 | 3.177251 | 2.767067 |
| 6 | 3.57103951 | 4.87103951 | 0.000339 | 1.22214953 | 1.153824 | 84.93495 | 0.007696 | 0.00888 | 0.342239 | 25.38604 | 26.1558 | 92.87898 | 73.31165 | 4.359529 | 14.06694 | 3.57104 | 3.7674 | 3.701433 | 3.027068 |
| 7 | 4.23962934 | 5.53962934 | 0.000398 | 1.43375057 | 1.150054 | 81.73533 | 0.007549 | 0.008682 | 0.338178 | 25.69088 | 21.80011 | 92.09311 | 76.53273 | 5.231434 | 16.50247 | 4.239629 | 4.3953 | 4.36498 | 3.50256 |
| 8 | 4.88636052 | 6.18636052 | 0.000469 | 1.68735484 | 1.150054 | 79.99628 | 0.007469 | 0.008589 | 0.345319 | 25.1596 | 18.3255 | 92.2245 | 78.98603 | 6.10334 | 19.42145 | 4.886361 | 4.8139 | 5.101494 | 4.619699 |
| 9 | 5.09234511 | 6.39234511 | 0.000488 | 1.75726764 | 1.146307 | 78.51297 | 0.007399 | 0.008482 | 0.34508 | 25.17704 | 17.37574 | 91.67751 | 79.66318 | 6.38235 | 20.22615 | 5.092345 | 4.8139 | 5.377364 | 4.942541 |

Table 5: Performance Analysis and Graphs: For 60% WCO Diesel

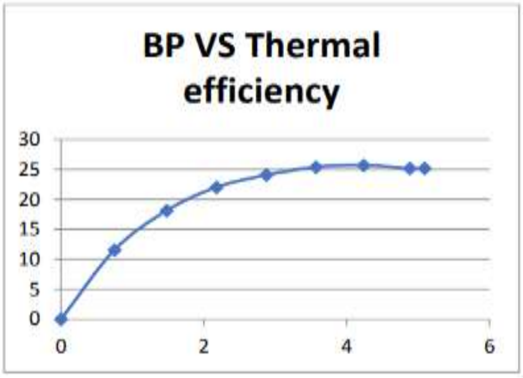


Fig. 1.13: BP vs Thermal. Efficiency for 60% WCO Diesel

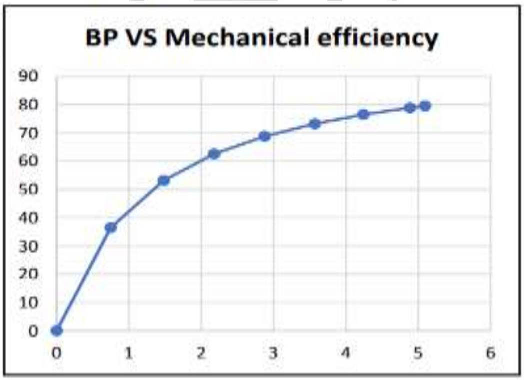


Fig. 1.15: BP vs Mech. Efficiency for 60% WCO Diesel

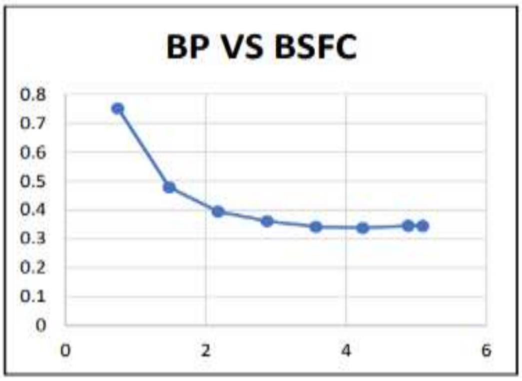


Fig. 1.14: BP vs BSFC for 60% WCO Diesel

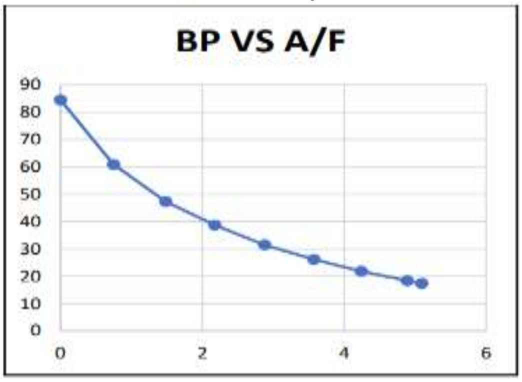


Fig. 1.16: BP vs A/F for 60% WCO Diesel

| Sr. No | load (kg) | speed (rpm) | time(sec) | mano (mm) | We(lph) | Wc(lph) | T1 | T2 | T3 | T4 | T5 | T6 | Ta | smoke | CO | HC | $CO_2$ | O2 | NOX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1566 | 79.87 | 114 | 180 | 70 | 28 | 38 | 28 | 32 | 150 | 131 | 33 | 2.4 | 0.04 | 12 | 2.6 | 17.58 | 182 |
| 2 | 2.5 | 1556 | 58.015 | 110 | 180 | 70 | 28 | 39 | 28 | 32 | 196 | 165 | 34 | 6 | 0.05 | 14 | 3.7 | 16.19 | 330 |
| 3 | 5 | 1548 | 45.2 | 106 | 180 | 70 | 28 | 40 | 28 | 33 | 239 | 201 | 34 | 9 | 0.05 | 14 | 4.9 | 14.67 | 593 |
| 4 | 7.5 | 1536 | 37.51 | 103 | 180 | 70 | 28 | 42 | 28 | 33 | 285 | 242 | 34 | 10.3 | 0.04 | 14 | 6.2 | 13.08 | 967 |
| 5 | 10 | 1522 | 30.93 | 100 | 180 | 70 | 28 | 44 | 28 | 33 | 339 | 290 | 34 | 8.8 | 0.03 | 11 | 7.6 | 11.45 | 1259 |
| 6 | 12.5 | 1499 | 26.41 | 98 | 180 | 70 | 28 | 46 | 28 | 34 | 396 | 341 | 34 | 22.6 | 0.03 | 14 | 9.2 | 9.82 | 1552 |
| 7 | 15 | 1486 | 22.42 | 95 | 180 | 70 | 28 | 48 | 28 | 34 | 465 | 397 | 35 | 48.1 | 0.09 | 16 | 11.1 | 7.52 | 1673 |
| 8 | 17.5 | 1472 | 19.145 | 91 | 180 | 70 | 28 | 52 | 28 | 35 | 543 | 455 | 35 | 78 | 0.34 | 13 | 13 | 5.1 | 1704 |
| 9 | 18.3 | 1462 | 18.47 | 89 | 180 | 70 | 28 | 53 | 28 | 35 | 581 | 489 | 35 | 88.7 | 0.62 | 10 | 13.8 | 4.06 | 1620 |

| S.no | BP kW | IP kW | $M_f$ kg/sec | TFC kg/hr | $\rho_a$ kg/m3 | Heq m | Va m3/s | Ma kg/sec | BSFC kg/kWhr | $\eta_{th}$ % | A/F | $\eta_{vol}$ % | $\eta_{mech}$ % | BMEP bar | Qs KJ/S | Qp KW | Qc KJ/S | Qexh KJ/S | Qun KJ/S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1.2 | 0.000107 | 0.38357331 | 1.15005352 | 99.12582 | 0.00830958 | 0.009556 | | 0 | 89.69145 | 96.2528 | 0 | 0 | 4.503257 | 0 | 2.093 | 1.243629 | 1.166628 |
| 2 | 0.739393 | 1.93939288 | 0.000147 | 0.52807033 | 1.14630741 | 95.9603 | 0.00817582 | 0.009372 | 0.714194 | 11.92628 | 63.8915 | 95.31208 | 38.12497 | 8.619696 | 6.199692 | 0.739393 | 2.3023 | 1.69623 | 1.461769 |
| 3 | 1.471183 | 2.67118274 | 0.000188 | 0.67778761 | 1.14630741 | 92.47083 | 0.00802579 | 0.0092 | 0.460709 | 18.4882 | 48.86499 | 94.04661 | 55.07608 | 17.23939 | 7.957415 | 1.471183 | 2.5116 | 2.117061 | 1.857571 |
| 4 | 2.189667 | 3.38966734 | 0.000227 | 0.8167422 | 1.14630741 | 89.85373 | 0.0079114 | 0.009069 | 0.372998 | 22.83572 | 39.9735 | 93.43048 | 64.5983 | 25.85909 | 9.58878 | 2.189667 | 2.9302 | 2.566563 | 1.90235 |
| 5 | 2.892946 | 4.09294591 | 0.000275 | 0.99049467 | 1.14630741 | 87.23663 | 0.00779534 | 0.008936 | 0.342383 | 24.87768 | 32.47778 | 92.90659 | 70.68126 | 34.47878 | 11.62868 | 2.892946 | 3.3488 | 3.090287 | 2.296649 |
| 6 | 3.561536 | 4.76153575 | 0.000322 | 1.16001515 | 1.14630741 | 85.4919 | 0.00771699 | 0.008846 | 0.325706 | 26.15142 | 27.45288 | 93.38402 | 74.79805 | 43.09848 | 13.6189 | 3.561536 | 3.7674 | 3.650805 | 2.639159 |
| 7 | 4.236778 | 5.43677821 | 0.00038 | 1.36645852 | 1.14258564 | 83.14475 | 0.00761032 | 0.008695 | 0.322523 | 26.40954 | 22.90856 | 92.89885 | 77.9281 | 51.71817 | 16.0426 | 4.236778 | 4.186 | 4.292481 | 3.327343 |
| 8 | 4.896339 | 6.09633947 | 0.000445 | 1.60020893 | 1.14258564 | 79.64392 | 0.00744838 | 0.00851 | 0.326817 | 26.06252 | 19.14593 | 91.7868 | 80.31606 | 60.33787 | 18.7869 | 4.896339 | 5.0232 | 5.004006 | 3.863352 |
| 9 | 5.085388 | 6.28538835 | 0.000461 | 1.65868977 | 1.14258564 | 77.8935 | 0.00736607 | 0.008416 | 0.326168 | 26.11443 | 18.26679 | 91.39343 | 80.9081 | 63.09617 | 19.47348 | 5.085388 | 5.2325 | 5.331597 | 3.823993 |

Table 6: Performance Analysis and Graphs: For 40% WCO Diesel

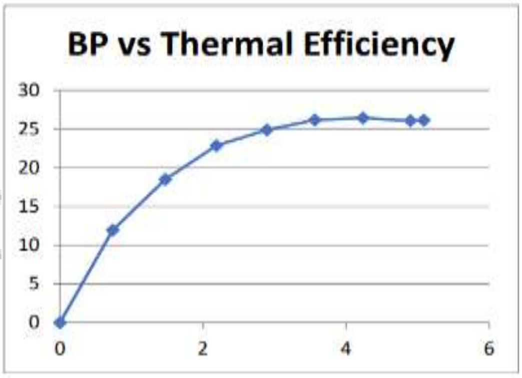


Fig. 1.17: BP vs Thermal. Efficiency for 40% WCO Diesel

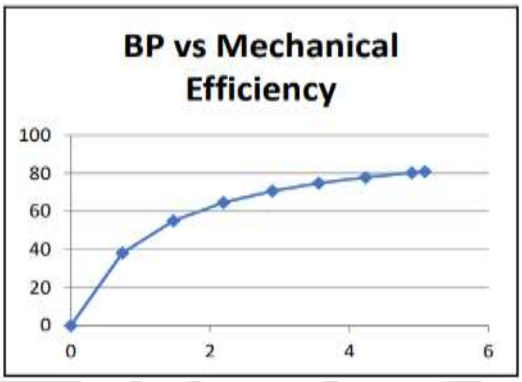


Fig. 1.19: BP vs Mech Efficiency for 40% WCO Diesel

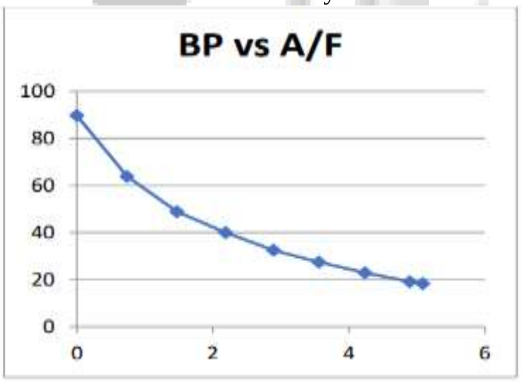


Fig. 1.18: BP vs A/F for 40% WCO Diesel

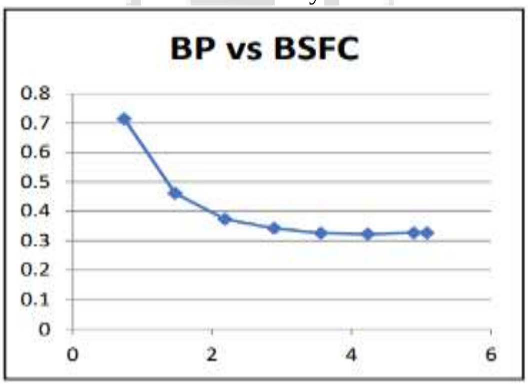


Fig. 1.20: BP vs BSFC for 40% WCO Diesel

| Sr. No | load (kg) | speed (rpm) | time(sec) | mano (mm) | We(lph) | Wc(lph) | T1 | T2 | T3 | T4 | T5 | T6 | Ta | smoke | CO | HC | $CO_2$ | O2 | NOX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1568 | 82.74 | 115 | 180 | 70 | 28 | 38 | 28 | 34 | 151 | 133 | 35 | 2.4 | 0.04 | 13 | 2.5 | 17.51 | 189 |
| 2 | 2.5 | 1555 | 58.56 | 111 | 180 | 70 | 28 | 39 | 28 | 34 | 192 | 162 | 35 | 6.4 | 0.05 | 13 | 3.6 | 16.24 | 324 |
| 3 | 5 | 1550 | 45.75 | 108 | 180 | 70 | 28 | 40 | 28 | 34 | 239 | 201 | 35 | 8.6 | 0.05 | 16 | 4.9 | 14.58 | 615 |
| 4 | 7.5 | 1522 | 37.57 | 105 | 180 | 70 | 28 | 42 | 28 | 34 | 284 | 240 | 35 | 9.5 | 0.03 | 11 | 6.2 | 13.33 | 977 |
| 5 | 10 | 1517 | 31.48 | 101 | 180 | 70 | 28 | 44 | 28 | 34 | 338 | 287 | 35 | 11.2 | 0.03 | 13 | 7.5 | 11.5 | 1348 |
| 6 | 12.5 | 1496 | 26.94 | 97 | 180 | 70 | 28 | 45 | 28 | 35 | 396 | 340 | 35 | 15.8 | 0.03 | 15 | 9.2 | 9.77 | 1560 |
| 7 | 15 | 1488 | 22.94 | 94 | 180 | 70 | 28 | 48 | 28 | 35 | 472 | 401 | 36 | 57.6 | 0.11 | 20 | 11.1 | 7.4 | 1670 |
| 8 | 17.5 | 1469 | 19.38 | 91 | 180 | 70 | 28 | 51 | 28 | 36 | 549 | 465 | 36 | 78 | 0.6 | 12 | 13.2 | 4.84 | 1582 |
| 9 | 18.3 | 1462 | 18.77 | 88 | 180 | 70 | 29 | 53 | 29 | 36 | 580 | 488 | 36 | 84.2 | 0.6 | 8 | 13.8 | 4.03 | 1629 |

 

| S.no | BP kW | IP kW | $M_f$ kg/sec | TFC kg/hr | $\rho_a$ kg/m3 | Heq m | Va m3/s | Ma kg/sec | BSFC kg/kWhr | $\eta_{th}$ % | A/F | $\eta_{vol}$ % | $\eta_{mech}$ % | BMEP bar | Qs KJ/S | Qp KW | Qc KJ/S | Qexh KJ/S | Qun KJ/S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1.2 | 0.0001 | 0.36156635 | 1.14258564 | 100.6489 | 0.00837744 | 0.009572 | | 0 | 95.30479 | 96.91515 | 0 | 0 | 4.332157 | 0 | 2.093 | 1.234196 | 1.004962 |
| 2 | 0.738918 | 1.93891769 | 0.000142 | 0.51086066 | 1.14258564 | 97.14808 | 0.00823046 | 0.009404 | 0.691363 | 12.07195 | 66.26937 | 96.01076 | 38.1098 | 0.86197 | 6.120948 | 0.738918 | 2.3023 | 1.648579 | 1.431152 |
| 3 | 1.473083 | 2.6730835 | 0.000182 | 0.65390164 | 1.14258564 | 94.52246 | 0.00811847 | 0.009276 | 0.4439 | 18.80177 | 51.06852 | 95.00993 | 55.10802 | 1.723939 | 7.834813 | 1.473083 | 2.5116 | 2.122306 | 1.727824 |
| 4 | 2.169709 | 3.36970944 | 0.000221 | 0.79627362 | 1.14258564 | 91.89683 | 0.00800492 | 0.009146 | 0.366996 | 22.74171 | 41.35101 | 95.40449 | 64.38862 | 2.585909 | 9.540663 | 2.169709 | 2.9302 | 2.565758 | 1.874996 |
| 5 | 2.883442 | 4.08344215 | 0.000264 | 0.95031766 | 1.14258564 | 88.396 | 0.00785097 | 0.00897 | 0.329578 | 25.32364 | 33.98175 | 93.87802 | 70.61303 | 3.447878 | 11.38636 | 2.883442 | 3.3488 | 3.077819 | 2.076302 |
| 6 | 3.554408 | 4.75440792 | 0.000308 | 1.11046771 | 1.14258564 | 84.89517 | 0.00769393 | 0.008791 | 0.31242 | 26.71438 | 28.49927 | 93.29172 | 74.76026 | 4.309848 | 13.30522 | 3.554408 | 3.5581 | 3.613388 | 2.579327 |
| 7 | 4.24248 | 5.44248047 | 0.000362 | 1.30409765 | 1.13888795 | 82.53665 | 0.00758631 | 0.00864 | 0.30739 | 27.15148 | 23.85084 | 92.48125 | 77.95123 | 5.171817 | 15.62523 | 4.24248 | 4.186 | 4.317456 | 2.879291 |
| 8 | 4.886361 | 6.08636052 | 0.000429 | 1.54365325 | 1.13888795 | 79.9025 | 0.00746427 | 0.008501 | 0.315911 | 26.41919 | 19.82535 | 92.17043 | 80.28378 | 6.033787 | 18.4955 | 4.886361 | 4.8139 | 5.039061 | 3.756174 |
| 9 | 5.085388 | 6.28538835 | 0.000443 | 1.59381993 | 1.13888795 | 77.26836 | 0.0073402 | 0.00836 | 0.313412 | 26.62985 | 18.88217 | 91.07238 | 80.9081 | 6.309617 | 19.09657 | 5.085388 | 5.0232 | 5.267351 | 3.720636 |

Table 7: Performance Analysis and Graphs: For 20% WCO Diesel

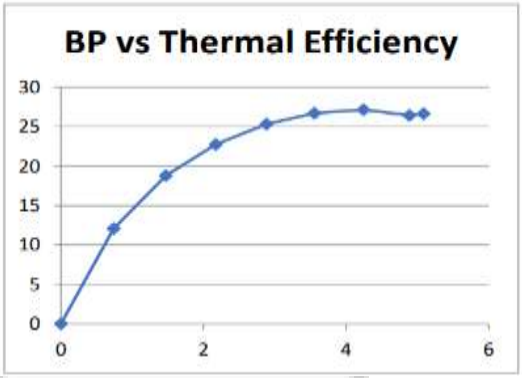

Fig. 1.21: BP vs Thermal. Efficiency for 20% WCO Diesel

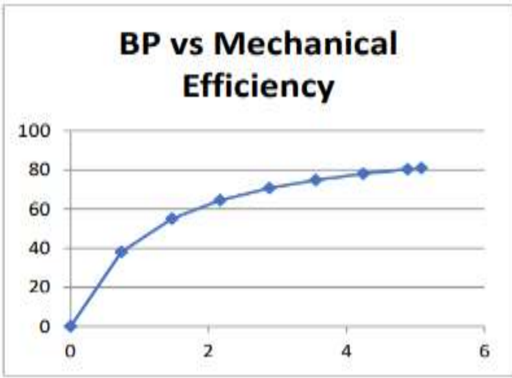

Fig. 1.23: BP vs Mech. Efficiency for 20% WCO Diesel

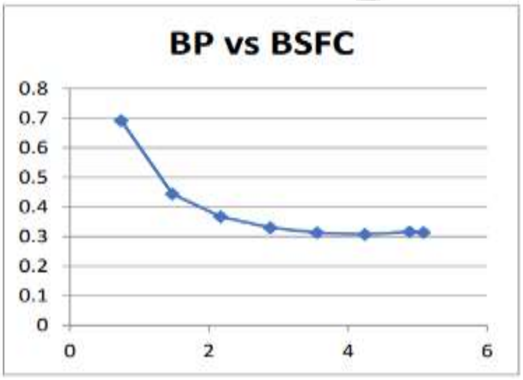

Fig. 1.22: BP vs BSFC for 20% WCO Diesel

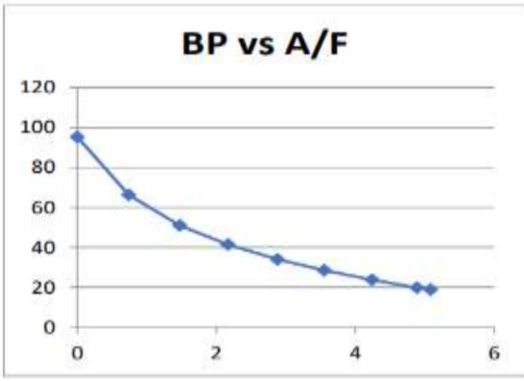

Fig. 1.24: BP vs A/F for 20% WCO Diesel

*G. BP vs Thermal Efficiency:*

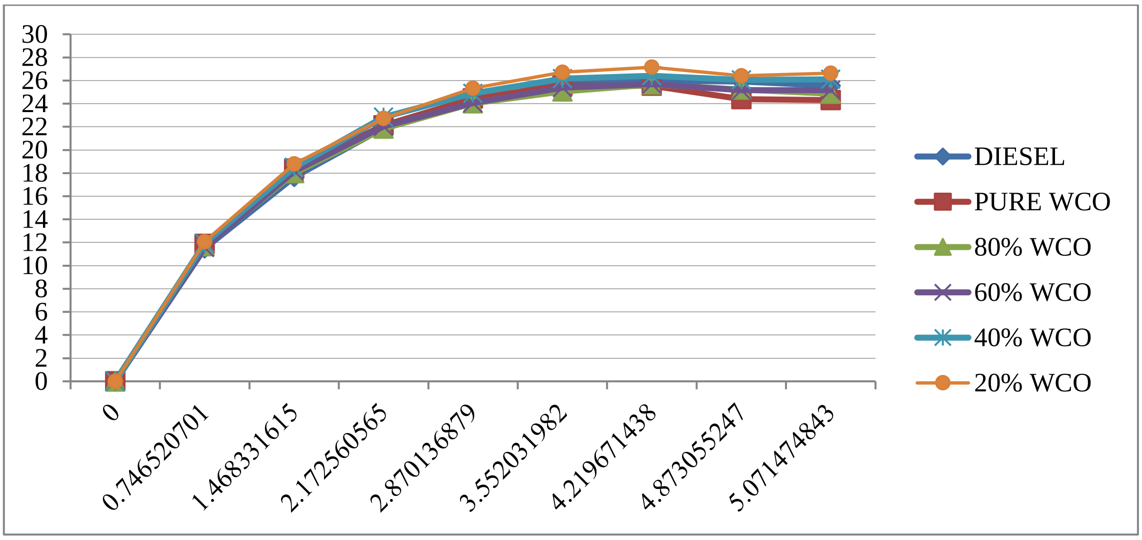

Fig. 1.25: Consolidated BP vs Thermal Efficiency chart for all permutations of Biofuel

 

### H. BP vs BSFC:

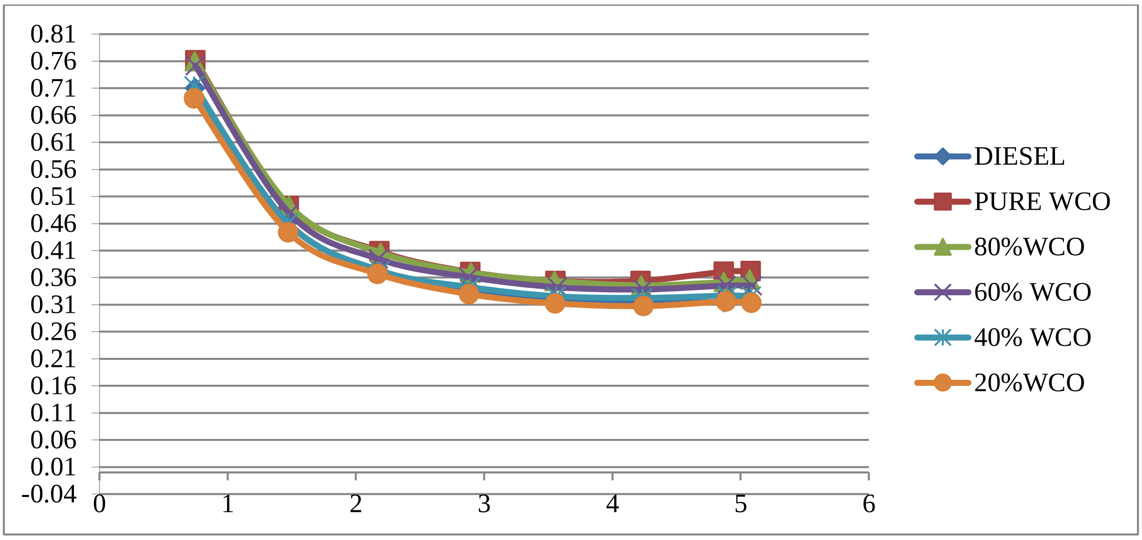


Fig. 1.26: Consolidated BP vs BSFC chart for all permutations of Biofuel

| Sr.no | Oil Content | Flash Point | Fire Point |
|---|---|---|---|
| 1 | Diesel | 52 | 69 |
| 2 | 20wco+80D | 69 | 82 |
| 3 | 40wco+60D | 87 | 101 |
| 4 | 60wco+40D | 102 | 115 |
| 5 | 80wco+20D | 125 | 140 |
| 6 | WCO | 157 | 175 |

Table 1.8: Flash pt. & Fire pt. of mixtures used

## VI. Conclusion

When assessing alternative fuels for internal combustion engines, both engine performance and environmental impacts are crucial considerations. This section examines and analyzes the performance and emission parameters of diesel engines, evaluated through experimental and numerical methods. Blends WC0, WC20, WC40, WC60, WC80, and WC100 undergo testing at an injection timing of 23˚bTDC and injection pressures of 190, 205, and 220 bar (advanced, standard, and retarded), respectively, for performance analysis. A test is conducted on a single cylinder four stroke diesel engine. In this test the engine is loaded from 0 kg to 18.3kg (Rated load) and the readings are noted and again unloaded from 18.3 kg to 0 kg. Tests are carried out on the engine across a range of loads from 0 kg to 18.3 kg (rated load) while maintaining constant speed, with load adjustments made up to the rated load while keeping cooling water flow and calorimeter water flow constant. Observations are recorded at injection pressures of 190, 205, and 220 bar to assess various performance parameters and emissions.

The use of biofuel in various combinations resulted in improved efficiency of the engine performance. Based on our experimental findings, it is evident that the maximum mechanical efficiency achieved, at 83.54839%, is attained when using 100% biofuel. Additionally, the results indicate that as the proportion of biofuel increases, mechanical efficiency also increases under constant conditions. Furthermore, the biofuel exhibits higher flash and fire points at 157 and 175 respectively, compared to pure diesel (52 and 69 respectively). Moreover, these values increase proportionally with the higher percentage of biofuel blended with diesel, as illustrated in the tabular data.

## VII. Future Scope

The future of CI DI engines using blends of biodiesel from waste cooking oil and traditional diesel fuels appears promising. As research and technology progress, these blends are expected to demonstrate improved combustion properties, resulting in enhanced engine efficiency and reduced emissions of particulate matter and greenhouse gases. Advances in fuel additives and engine design may further enhance compatibility and performance, potentially reducing engine wear and maintenance costs.

The sustainable nature of biodiesel derived from waste cooking oil also offers potential benefits, including reduced dependence on fossil fuels, mitigation of waste management issues, and support for calibration to optimize performance with biodiesel-diesel blends. This includes considerations for cold-start performance and compatibility with existing fuel infrastructure. These advancements could enhance commercial viability and widespread adoption, positioning biodiesel-diesel blends as a pivotal element in the transition towards sustainable transportation.

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## Conflict of Interests

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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