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Research Paper

Effects of Hexane Addition in Waste Plastic Fuel-Biodiesel-Diesel Blends on the Performance and Emission Characteristics of DI Diesel Engine

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Abstract

The current study's sole objective is to evaluate the impact of hexane's addition to blends of diesel, waste plastic fuel, and jatropha biodiesel. Five fuel samples have been made in order to do this, including diesel-waste plastic fuel-jatropha biodiesel (D70WPF20JB10 and D70WPF10JB20), diesel-hexane-waste plastic fuel-jatropha biodiesel (D65HX5WPF20JB10 and D65HX5WPF10JB20), and plain diesel (D100) as a reference fuel. Following thorough characterization, studies using spectroscopic techniques such as FTIR, elemental analysis, and GC-MS are conducted. Finally, performance and emission tests on a direct-injection single-cylinder diesel engine were conducted. The density, flash point, and acid value of the diesel-waste plastic fuel-jatropha biodiesel blend are observed to decrease with the addition of hexane. With the addition of hexane, the calorific value and diesel index of the fuel both rise by 0.86% and 12.5%, respectively. In the case of the hexane mix fuel samples, it is discovered that the brake thermal efficiency and volumetric efficiency are higher and the brake-specific fuel consumption is lower. Hexane is added to the diesel-waste plastic fuel-jatropha biodiesel mixture, which results in a 34 percent rise in HC emissions and a 9 percent decrease in CO emissions. Additionally, it lowers by 8% and 15%, respectively, the temperature of the exhaust gas and the fuel's NOx emissions. The fuel sample with code D65HX5WPF10JB20 exhibits the best results among all the fuel samples in terms of performance and emission analyses.

Keywords: Engine performance; Alternate fuel; Emission; Diesel; Biodiesel; Waste plastic fuel

1. Introduction

The challenges to administer the global rising temperature and shortage of fossil fuel have led to desperate interest in alternative fuel. To restrict the global temperature and to maintain the set standard, it is necessary to decrease the usage of fossil fuel and at the same time providing the required energy needed for the human being [1]. Earlier researchers have worked on a variety of biodiesels, including the one obtained from orange peel [2]. Among the various possibilities, waste plastic fuel and biodiesel may be suitable alternatives.

Numerous plants produce oils that can be used in CI engines. For usage in internal combustion engines, non-consumable vegetable oils will be more cost-effective than consumable vegetable oils [3]. Biodiesel is the renewable source of energy similar to diesel. Because of the presence of inherent oxygen biodiesel possess some advantages like non-toxicity, better lubrication and lower exhaust emission [4], [5]. However, in recent past a few investigations have been carried out on studying the corrosive effects of various blends of biodiesel on few metal parts [6]. Much research on the biodiesel extracted from the

Nomenclature	
BSEC	Brake specific energy consumption
BSFC	Brake specific fuel consumption
BTE	Brake thermal efficiency
CFPP	Cold filter plugging point
CHNS	Carbon Hydrogen Nitrogen Sulphur
CO	Carbon monoxide
CO_2	Carbon dioxide
CN	Cetane number
EGT	Exhaust gas temperature
FTIR	Fourier transforms infrared spectroscopy
GC-MS	Gas chromatography mass spectrometer
HC	Hydrocarbon
NOx	Nitrogen oxide
PM	Particulate matter
PP	Pour point
PPM	Parts per million
D 100	100% Diesel
D70WPF10JB20	70% diesel, 10% waste plastic fuel and 20% Jatropha biodiesel
D65HX5WPF10JB20	65% diesel, 5% Hexane, 10% waste plastic fuel and 20% Jatropha biodiesel
D70WPF20JB10	70% diesel, 20% waste plastic fuel and 10% Jatropha biodiesel
D65HX5WPF20JB10	65% diesel, 5% Hexane, 20% waste plastic fuel and 10% Jatropha biodiesel

various vegetable oils and their blends along with the effect of additives on the performance and combustion in compression ignition engines has been performed by different researchers [7], [8]. Senatore et al. [9] looked into a mixture of rapeseed methyl ester and diesel fuel. They found that CO and smoke emissions went down a lot, but NOx emissions went up a lot.On a 6V921A diesel engine, Schumacher et al. [10] investigated the blending of 10, 20, 30, and 40% soyabean with diesel fuel. The heavy-duty engine test cycle was developed by the U.S. Environmental Protection Agency (EPA) and is used in this experiment. The drop in PM, HC, and CO was accompanied by a rise in NOx emissions, according to the study's findings. Mustafa et al. [11] investigated on soyabean oil biodiesel performance in a four-cylinder turbocharged diesel engine. They found that PM, CO, and HC emissions went down, but NOx emissions went up by 11.2%, and brake specific fuel consumption went up by 13.8% because the heating value went down. Chang et al. [12] discovered a 12 percent increase in NOx emissions but a 2.5 percent reduction in PM emissions in their study of the effects of isopropyl ester of soya bean oil-diesel on C.I. engines. Some of the research, however, found the opposite pattern. Researchers from Knothe et al. [13] and Rakopulos et al. [14] examined how ethanol and bioethanol blends affected diesel engines and discovered that NOx emissions were decreased.

A greater cetane number for diesel engines is associated with decreased NOx emissions [15]. Fatty acid alkyl esters were used in research by McCormic et al. [16] on diesel engines, and they discovered that NOx emissions increase as unsaturation and chain length decrease. There is a small increase in NOx emissions when a diesel engine is running on biodiesel, despite the fact that the cetane number of free fatty compounds is high [17].

As a result, the primary constraints of biodiesel are its high viscosity and high NOx emission, and the structure of branching esters, chain length, and location all play a significant role in determining the physicochemical qualities and hence the performance and emission characteristics.

Now a day's plastics are frequently used in the household and industrial sectors due to their ease and low cost [18]. Due to the usage of plastic for packaging and consumer products in various sectors, there is a significant increase in the production of plastics, which subsequently causes a substantial increase in plastic waste. Researchers from all across the globe are interested in the fuels produced by depolymerizing plastic wastes [19], [20]. Waste plastic fuel (WPF) has qualities comparable to diesel fuel and might be used as a diesel substitute [21]. It was reported that WPF consist of 55% aromatic compounds and the soot formation was generally found to be higher when the engine is set off with neat waste plastic fuel [22]–[24]. Additionally, it has been asserted that when waste plastic fuel (WPF) is blended with heavy oil, the oil's viscosity decreases, hence improving engine performance [22]. Experiments carried out by Mohammadi et al. [25] show that mixing biodiesel with liquid made from expanded polystyrene (EPS) reduces CO, CO_2, and NOx emissions by a large amount.

Hexane is a significant constituent of gasoline. It is a colorless liquid, odorless when pure, and with boiling points approximately 69 °C (156 °F). It is widely used as a cheap, relatively safe, largely uncreative, and easily evaporated non-polar solvent [26].

The literature review suggests that and diesel, waste plastic fuel and biodiesel can be utilized as a fuel and used on a diesel engine without any modification with the different prone and cons. The innovative aspect of the current research is the use of oil that was obtained from plastic waste. This was accomplished by evaluating diesel-waste plastic fuel-biodiesel blends, diesel-waste plastic fuel-biodiesel blends, and the reference fuel diesel in terms of fuel quality, performance, and emission characteristics.

2. Materials and Method

2.1. *Waste Plastic fuel*

The Waste Plastic Oil (WPF) is produced by Sustainable Technologies & Environmental Projects Private Limited, Vasai, Mumbai. It is a value-added product obtained by the depolymerization of waste plastic with the help of a specially designed reactor. The reaction is carried out using a unique catalyst and a very restricted supply of oxygen, wherein the peak temperature is restricted to 350 °C.

The existing plant made use of a variety of garbage in batches ranging from 25 to 50 kg in size. It is necessary to circulate cooling water in order to keep the condenser at a cool temperature. Gases are produced during the processing of the material, and they are burned close to the vent pipe to get rid of them.

The organic waste is weighed and loaded into the plant. The gradual heating is then started with the help of the control panel. The developed gases flow past a catalyst and are permitted to crack when the temperature exceeds 150 °C. The gases are then routed via the condensing unit, which separates the water and condensed liquid fuel before allowing the gases to escape through the vent line. The vent pipe is then kindled to begin the gas combustion process. The liquid which is collected in the condenser is drained. The conversion of liquid fuel from waste plastic takes 4 hours and 30 minutes. The residue is separated and weighed after each cycle.

The HDPE, LDPE, and PP have the best conversion ratios, with yields of around one liter from 1 kg of waste, whereas for other plastics the conversion ratio is 800 ml per kg.

The energy requirement for the conversion in the plant is approximately eight times less than the output. The plant does not require any external power; instead, the unit is powered by the plant's exhaust gas.

2.2. *Jatropha Biodiesel*

The jatropha biodiesel is procured from Southern Online Bio Technologies Limited, Hyderabad (India).

2.3. *Hexane and Diesel*

The n-hexane and diesel is procured from local chemical supplier and local fuel station loacated in dhanbad (India).

2.4. *Fuel Sample Preparation*

Using a magnetic stirrer, different compositions of jatropha biodiesel, waste plastic fuel, and diesel were blended to examine fuel quality and performance as well as emission characteristics in engines. This mixing technique is done at 35 °C. Each sample was three liters and agitated for an hour. The first sample is made up of a mix of diesel, waste plastic fuel and jatropha biodiesel with a volumetric ratio of 70:20:10 (D70WPF20JB10). The second mixture is consists of diesel, hexane, waste plastic fuel and jatropha biodiesel with a volumetric ratio of 65:5:20:10 (D65HX5WPF20JB10). Similarly third and fourth samples are consist of diesel, waste plastic fuel and jatropha biodiesel and diesel, hexane, waste plastic fuel and jatropha biodiesel respectively with a volumetric ratio of 70:10:20 (D70WPF10JB20) and 65:5:10:20 (D65HX5WPF10JB20). Further a sample of plain diesel (D100) is prepared as a reference fuel for comparison. All of the fuel samples were subjected to a stability test after being stored at room temperature for four weeks.

3. Experimental Procedure

3.1. *Physico-Chemical Properties Determination*

The test technique and apparatus utilized are detailed in the **Table 1**. On M/s Elementar's Vario EL III employing helium like a carrier gas, the analytical data of CHNS examination of fuel samples were analysed, and combustion temperature was kept at 950 °C. On a Shimadzu Corporation infrared spectrometer, the infrared spectra of liquid fuel samples were obtained down in the 4000-400cm^{-1} range. For identification of the moieties present and their analysis in the fuel samples, by putting a drip amongst two kBr plates utilizing FTIR. The analytical technique "gas chromatography-mass spectrometry (GC-MS)" is used to identify the various chemicals contained in fuel samples. This technique combines the advantages of liquid and gas chromatography, as well as mass spectrometry. Fuel samples were chromatographed using "Jeol, AccuTOF CGV, and NIST software," which was then used to examine the chromatogram's peak. The engine used in the study and their setup are shown in **Table 2** and **Figure 1**.

Table 1. Test Method and apparatus utilized

Attributes	Test Methodology	Equipment Used
Specific Gravity	IP 59/82	Westpal Balance
Viscosity	ASTM D2270	Redwood Viscometer
Flash Point	ASTM D93-80	Pensky Martens Apparatus
Calorific Value	ASTM D808/240	Bomb Calorimeter
Acid Number	ASTM D664-09a	REMI Equipments
Cold Filter Plugging Point	ASTM D6371	Vibson Scientific
Pour Point	ASTM D97-09	Vibson Scientific

Table 2. CI Engine Details

Equipment	Details
Engine	Diesel Engine, Kirloskar
Type	AV1
Depiction	Vertical, natural temperature starting, totally enclosed, water cooled,
Timing, fuel injection	26° prior to "Top Dead Centre"
Acid Number	ASTM D664-09a
Capacity of Diesel tank	1 Gallon (4.6 Liters)
Injection nozzle	Bosch type DLL. 110 S 32
Fuel Pump	Bosch type H-PFR 1A 90/1
No. of strokes	4
No. of cylinder	Single
Bore diameter	80 mm
Stroke length	110 mm
Rated power	5 HP
Speed	1500 rpm
Cooling	Water
Loading Device	Electrical Swinging field type Dynamometer

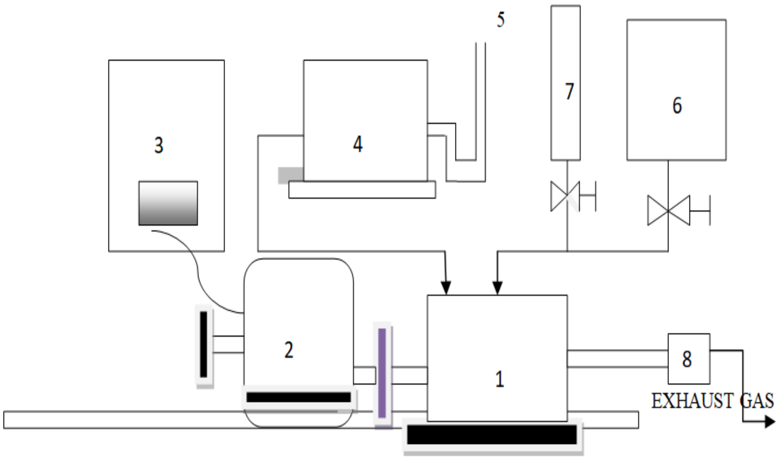

Figure 1. Setup for Experiments. 1. DI diesel engine; 2. Dynamometer (electrical); 3. Control of the dynamometer; 4. Air box; 5. U-bend manometer; 6. Fuel Storage tank; 7. Burette for fuel measurement; 8. Gas analysis set-up

3.2. *Setup of an Engine for Experimentation*

To measure the engine load, an electrical type dynamometer was connected to it. The air consumption was measured using an air-box fitted with a U-bend manometer at the engine inlet. A burette was attached to the side of the cylindrical tank, which was supported by a wooden stand. The valve connecting to it must be closed so that fuel mix may flow into the engine via a graded burette filter to calculate fuel consumption. A tachometer was used to gauge the engine's speed. This particular quantity of fuel usage was tracked by using a timer. The exhaust output was measured using an emission analyzer (model HG-540 mode). A probe was allowed to come into touch with exhaust gas. All of the tests were run at 1500 rpm, which is the maximum engine speed recommended by the manufacturer. All studies began with the engine operating on diesel before transitioning to waste plastic fuel-biodiesel-diesel and biodiesel-diesel combinations.

4. Result and Discussion

The results and related discussion are in following categories Oil Characterization, Oil sample GC-MS analysis and test engine's performance and emission parameters.

4.1. *Oil Characterization*

The five fuel samples, D70WPF20JB10, D65HX5WPF20JB10, D70WPF10JB20, and D100, are listed by their varied attributes in **Table 3**. The fuel's viscosity is an essential component and should have the highest attainable value. The size of the droplets will increase with viscosity, which will result in poor mixture formation, poor energy exploitation, poor performance, and increased soot production. The fuel injection system's sliding parts do not receive enough lubrication if the viscosity is below the set limit [27].

The viscosity of D70WPF10JB20 is found to be lowest, whereas the viscosity of D70WPF20JB10 is highest. Addition of hexane in the mixture of diesel-waste plastic fuel-jatropha biodiesel does not affect the viscosity significantly. However the viscosity of hexane added fuel samples are found to be lower than diesel.

The fuel injector system of a diesel engine operates on a volume metering system. The energy content per unit volume rises as the density rise. As a consequence, the fuel density rises, so does the mass flow rate of the fuel injected. The exhaust increases at full load due to a richer mixture with the increase of density [28]. The density of diesel is found to be lowest and the addition of hexane in the blend of diesel-waste plastic fuel–jatropha biodiesel decreases the density slightly.

One of the crucial factors in determining safety measures, such as fire risks, storage, and fuel transportation, is the flash point. It is based on the threshold at which fuel vapour can ignite using an external ignition source. It has been noted that the flash point of mixes of diesel, waste plastic fuel, and jatropha biodiesel is greater and that the addition of hexane greatly lowers the flash point of the blend of diesel, waste plastic fuel, and jatropha biodiesel.

A calorific value is a measurement of the amount of heat released per unit mass of any particular fuel. All of the fuel samples analyzed revealed that the calorific value of the tested blends was lower than diesel. With the addition of hexane, the calorific value of all fuel samples—diesel, waste plastic fuel, and jatropha biodiesel—increases.

Table 3. Characteristics of samples

Characteristics	D70WPF20 JB10	D65HX5WPF20 JB10	D70WPF10 JB20	D65HX5WPF10 JB20	D100
Viscosity(Poise)	0.0656	0.0567	0.0496	0.0541	0.061
Density (g/ml)	0.818	0.817	0.824	0.821	0.80
Flash Point (°C)	64	46	72	48	61
Calorific value(MJ/kg)	44.14	44.52	43.65	43.82	45.35
Pour point	3	-	0	-	6
CFPP	-3	-	-2	-	1
Acid number(mgKOH/g)	1.85	1.77	0.94	0.88	0.03
Aniline point	39.7	51.5	48.5	55.6	68.1
Diesel index	41	42	48	54	49

The acid number of a fuel reflects the amount of acidic constituents present. Some additions or breakdown products in the form of acidic components can be found in petroleum and biodiesel mixes. A higher Acid Number causes rubber components to corrode and deposits to form in the engine. The acid value of diesel is the lowest of all the fuels, while it is the highest for D70WPF20JB10. It's also worth noting that the addition of hexane in the blend of diesel-waste plastic fuel-jatropha biodiesel decreases the acid value.

Because determining an engine's Cetane Number (CN) is costly and time-consuming, a new correlation known as the "Diesel Index" was devised, which is connected to the hydrocarbon content and density of the fuel. The ignition quality of n-paraffin is higher, whereas aromatic has a lower ignition quality. Aniline Point's function is Diesel Index. The minimum temperature at which an equal quantity of fuel and aniline become miscible, indicating the aromaticity of the fuel, is known as the aniline point. The greater the aromatic content of fuel, lower will be aniline point. Diesel oil with a higher cetane level is simpler to ignite and heats up more quickly. The fuel cetane number determines the ignition delay, which affects peak combustion pressure and temperature for a specific engine.

It is found that the addition of hexane in the blend of diesel-waste plastic fuel-jatropha biodiesel increases the aniline point and thus reduces the aromaticity of the fuel. This also increases the diesel index, which is one of the very important parameter as this significantly affects the combustion characteristics of the fuel.

This is also confirmed by the CHNS analysis shown in **Table 4**. As usually the fuel having high carbon content has higher value of diesel index. It can be seen that the addition of hexane in the blend increases the carbon content and thus diesel index.

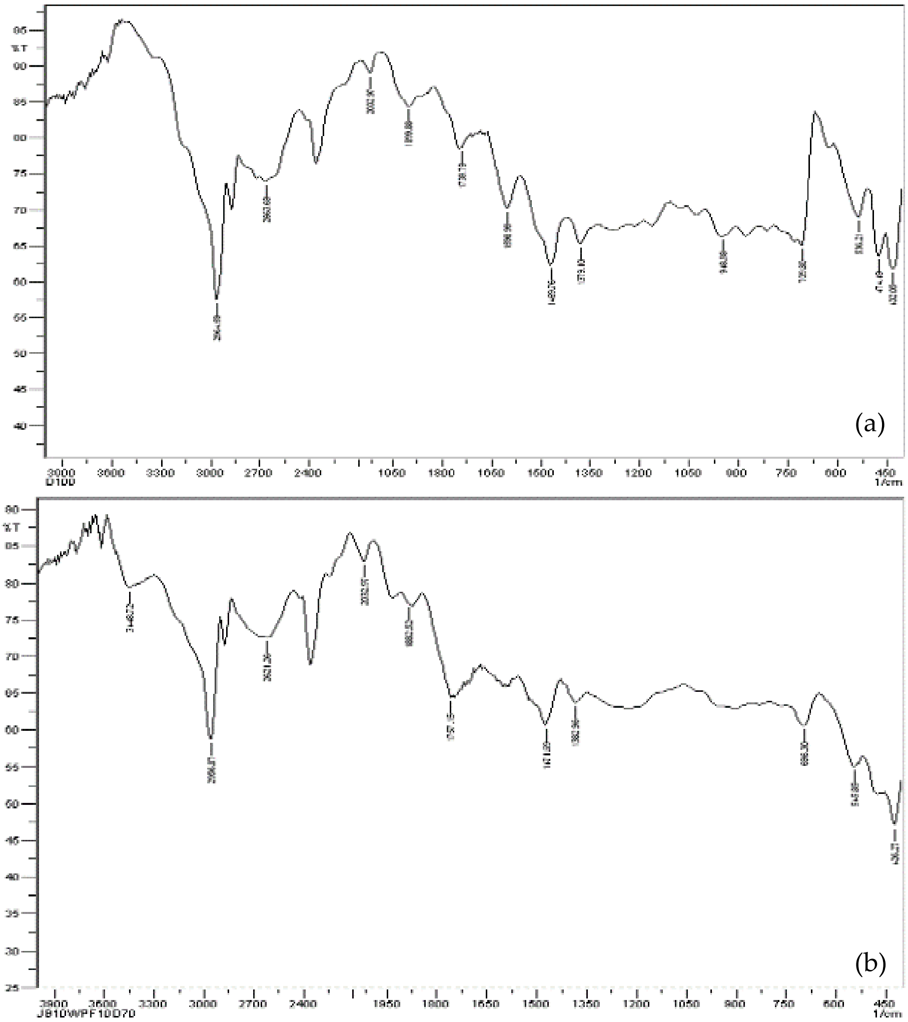

Figure 2. (a) D100 - FTIR Spectrum; (b) D70WPF20JB10 - FTIR Spectrum

Figure 2 shows the FTIR spectrum of D100 and D70WPF20JB10. FTIR (Fourier transform infrared spectrophotometry) studies of fuel samples: The FTIR spectrum of different blends of oil is shown in **Figure 3**, whereas FTIR analysis of different blends of oil, and diesel following the distinct types of moieties are shown in **Table 5**. From the analysis, it is found that different blends of waste plastic fuel- diesel, waste plastic fuel- diesel-jatropha biodiesel and diesel have some similar characteristics, which consist of some bulky C-CH_3 groups and some compact like CH_2, CH_3 group and C=CH_2 and thus can be utilized as a fuel.

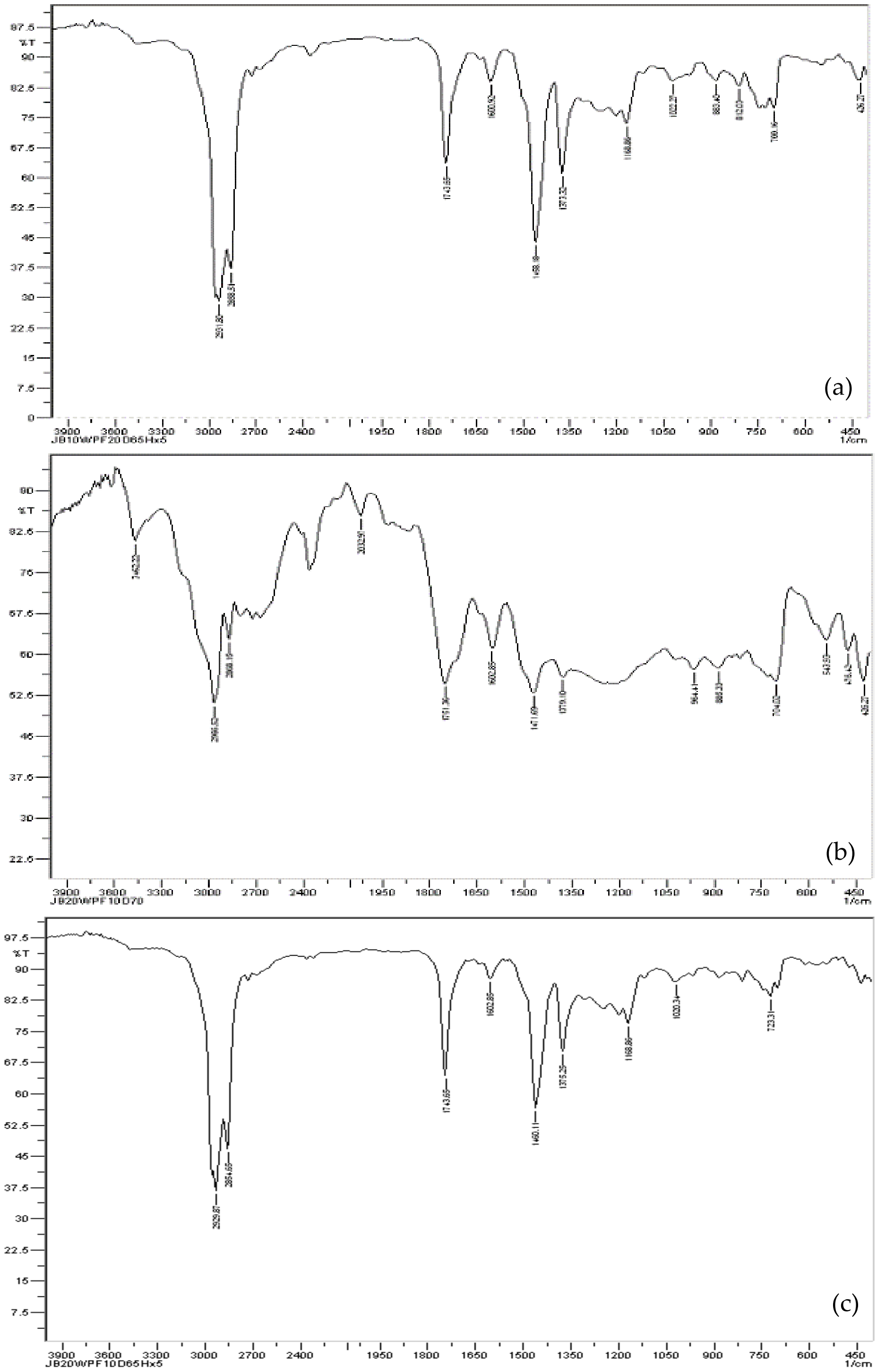

Figure 3. (a) D65HX5WPF20JB10 - FTIR Spectrum; (b) D70WPF10JB20- FTIR Spectrum; (c) D65HX5WPF10JB20 - FTIR Spectrum

Table 4. CHNS analytical data of samples

Composition (%)	D70WPF20 JB10	D65HX5WPF20 JB10	D70WPF10 JB20	D65HX5WPF10 JB20	D100
C	84.10	84.38	76.62	81.59	84.7
H	12.71	12.46	10.44	12.42	13.6
N	1.013	1.854	1.337	1.196	1.14
S	0.655	0.366	0.576	0.368	0.44
O	1.522	0.940	10.987	4.426	0.03

Table 5. FTIR Spectroscopy of fuel

Characteristics	D70WPF20 JB10	D65HX5WPF20 JB10	D70WPF10 JB20	D65HX5WPF10 JB20	D100
C-CH_3	2996.87	2958.51	2996.87	2929.87	2964
Non-conjugated	1882.52 1754.15	1743.65	1751.36	1743.65 1902.85	2663 1850 1739
Conjugated	----	1600.92	1602.85	----	-----
CH_2	1471.69	1458.16	1471.69	1460.11	1469
CH_3	1382.96	1373.32	1379.10	1375.25	1379
C-O	-----	1168.96	----	1168.85	-----
Acetate	-----	----	----	1020.84	-----
-CH=CH-(trans)	-----	1022.27	964.41	----	948
C=CH_2	-----	883.40	885.33	----	-----
-CH=CH-(cis)	696.30	700.16	704.02	723.31	709

Elemental composition of oil samples: Table 4 shows the results of the CHNS analysis of various fuel.According to the results of the investigation, it can be observed that the addition of hexane in the blend of diesel-waste plastic fuel-jatropha biodiesel raises the C-content. The higher the cetane number, the more carbon atoms there are in the chain of hydrocarbon molecules [29]. The oxygen concentration of all the blended fuel samples are higher than that of diesel. At greater loads, fuel with a higher oxygen concentration will produce less dry soot [30].

4.2. *Oil Sample "GC-MS" Analysis*

Figure 4 to Figure 7 depicts the "GC-MS" Chromatogram of oil samples, while Table 6 to Table 9 depicts the data of oil samples.

The gas chromatography-mass spectrometry (GC-MS) approach is one of the most precise and accurate analytical techniques for identifying the likely chemicals present in various forms of organic fluid. The NIST programme is used to examine the GC-MS chromatogram peaks. The compounds present are shown in the Table 6 to Table 9, as well as their percentage area compared to the overall area of the chromatogram, which offers an indication of their relative concentration in various samples.

It can be seen that the blends are made up of a very complex combination, comparable to diesel that contains both aliphatic and aromatic chemicals, as well as fatty acid methyl ester components, diglycerides, and triglycerides [31], [32].

Table 6. GC-MS information of D70WPF20JB10

Peak	Holding time (minutes)	Extent (%)	Name of compound (Species)	Chemical combination
1	14.5	0.99	Heptadecane	$C_{17}H_{36}$
2	21.1	3.64	9-octadecenoic acid, methyl ester	$C_{19}H_{36}O_2$
3	21.1	3.64	11-octadecenoic acid, methyl ester	$C_{19}H_{36}O_2$
4	21.5	2.79	Octadecanoic acid, methyl ester	$C_{17}H_{38}O_2$

Table 7. GC-MS information of D70WPF10JB20

Peak	Holding time (minutes)	Extent (%)	Name of compound (Species)	Chemical combination
1	3.7	1.53	Decane	$C_{10}H_{22}$
2	8.5	2.59	Bicyclo[4,4,1] undeca -1,3,5,7,9-pentaene	$C_{11}H_{10}$
3	8.5	2.59	Naphthalene-2-methyl	$C_{11}H_{10}$
4	17.9	4.27	Hexadecanoic acid, methyl ester	$C_{17}H_{34}O_2$
5	22.7	-	Docosane	$C_{22}H_{46}$
6	24.1	-	Tetracosane	$C_{24}H_{50}$

Table 8. GC-MS information of D65HX5WPF10JB20

Peak	Holding time (minutes)	Extent (%)	Name of compound (Species)	Chemical combination
1	8.4	1.58	Tridecane	$C_{13}H_{28}$
2	10.1	1.33	Tetadecane	$C_{14}H_{30}$
3	14.6	1.40	Pentadecane-2,6,10,14-tetramethyl	$C_{19}H_{40}$
4	17.9	4.99	Hexadecanoic acid, methyl ester	$C_{17}H_{34}O_2$
5	21.2	8.54	9-octadecenoic acid, methyl ester	$C_{19}H_{36}O_2$
6	21.6	5.45	Octadecanoic acid, methyl ester	$C_{19}H_{38}O_2$

Table 9. GC-MS information of D100

Peak	Holding time (minutes)	Extent (%)	Name of compound (Species)	Chemical combination
1	3.1	0.75	Cyclohexane-1,1,2,3-tetramethyl-	$C_{10}H_{20}$
2	3.1	0.75	Cyclooctane-1,4-dimethyl-trans-	$C_{10}H_{20}$
3	3.3	1.22	Benzene acetic acid-6-ethyl-3-octyl ester	$C_{18}H_{28}O_2$
4	3.3	2.16	Benzene acetic acid-2-tetradecyl ester	$C_{22}H_{36}O_2$
5	3.4	0.94	Benzene -1,2,3-trimethyl	C_9H_{12}
6	5.8	2.36	Naphthalene decahydro-2-methyl-	$C_{11}H_2O$
7	21.2	3.31	7-octadecanoic acid methyl ester	$C_{19}H_{36}O_2$
8	25.4	2.72	Tetra cosine	$C_{24}H_{50}$

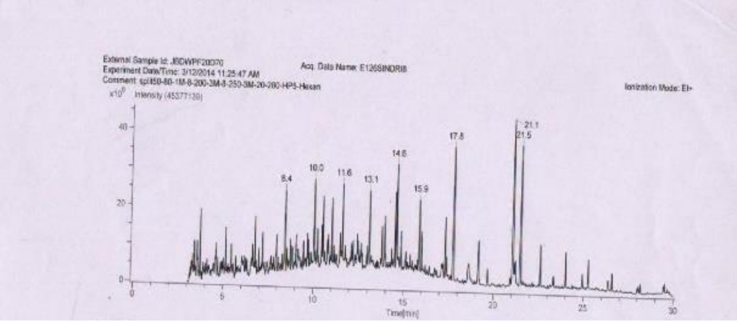

Figure 4. GC-MS. D70WPF20JB10

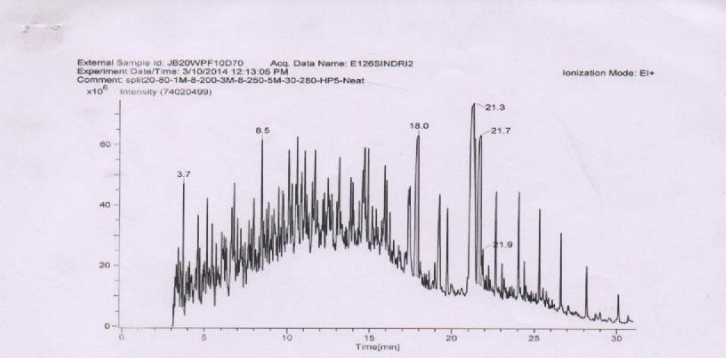

Figure 5. GC-MS. D70WPF10JB20

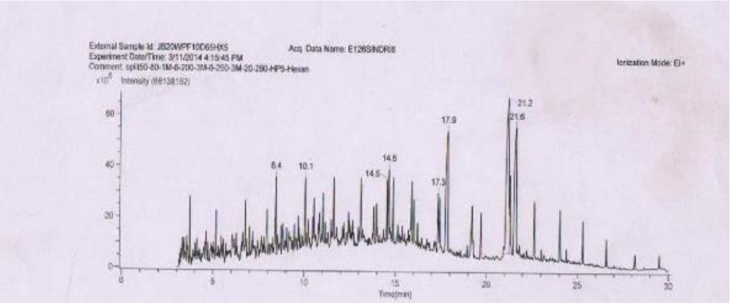

Figure 6. GC-MS.D65HX5WPF10JB20

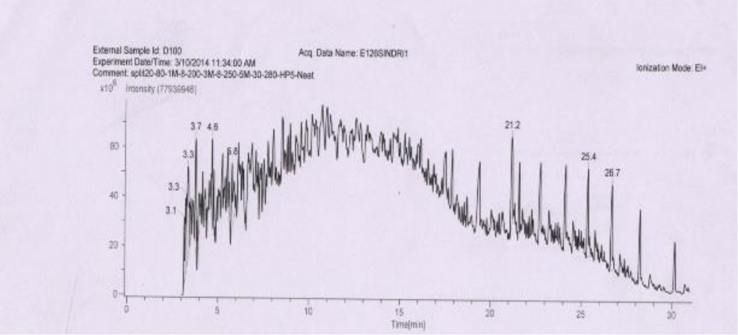

Figure 7. GC-MS. D100

4.3. A Test Engine's Performance and Emission Parameters

The variation in brake thermal efficiency (BTE) of the various test fuels is shown in **Figure 8**. It has been established that the BTE of all fuels increases with increasing load. The efficiency of the hexane-blend fuel sample is greater than that of neat diesel during peak loading. Among all the fuel samples, D65HX5WPF10JB20 had the highest BTE at increasing loads. The increased thermal efficiency of hexane added to diesel-waste plastic fuel-jatropha biodiesel blends may be explained by the reduced viscosity and density of the hexane mix fuel sample [33].

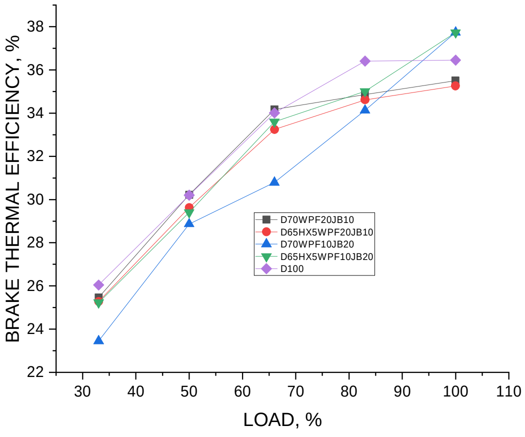

Figure 8. BTE Vs Load

Figure 9 shows the impact of various fuel samples on brake specific fuel consumption (bsfc) relative to the load. The term "BSFC" refers for the amount of gasoline used for every unit of braking power and is proportional to brake thermal efficiency for a certain fuel [22]. Diesel is found to have the lowest BSFC up to 66 percent load, while D70WPF10JB20 has the highest BSFC.

When the load was at its peak, the BSFC of D65HX5WPF10JB20 was found to be the lowest, while that of D70WPF20JB10 was found to be the highest. Because of the proper composition of the mixture, less fuel is required to create the same amount of power as before, which results in a lower BSFC of D65HX5WPF10JB20 under a heavier load.

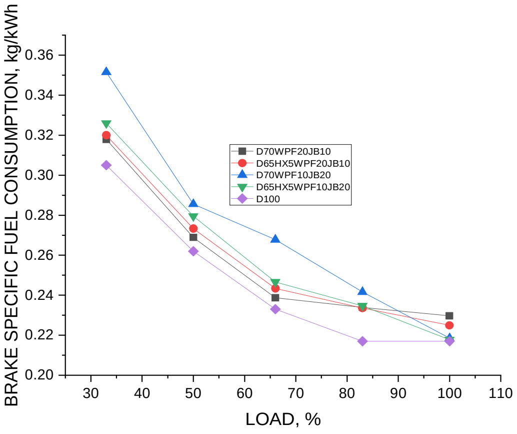

Figure 9. BSFC Vs Load

Figure 10 displays the change in brake specific energy consumption (BSEC) to loading for numerous fuel samples. A useful, objective tool for comparing the amount of energy needed to produce one unit of power from each test fuel is the BSEC meter. This makes logical given that BSEC declines with increasing load for all of the fuels taken into account.

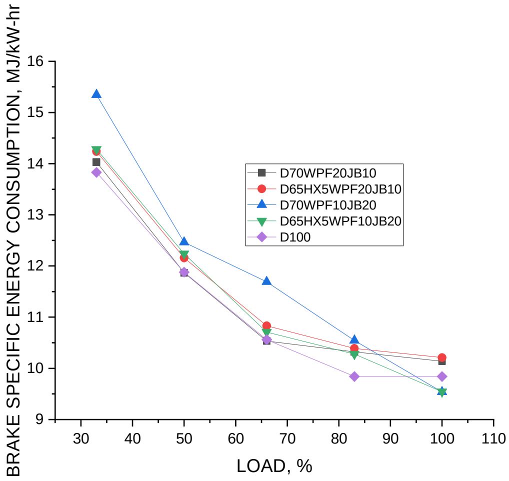

Figure 10. BSEC Vs Load

When two unique fuels with varied combustion characteristics are mixed together, the fuel usage may be erroneous due to the fact that the heating value and specific gravity of the two fuels are different from one another. In such cases, the BSEC is more reliable [34].

The BSEC of neat diesel is found to be lowest among all the fuel samples at all loading conditions. The BSEC of D65HX5WPF10JB20 is found to be slightly higher than diesel at partial loading conditions but it is found similar to that of diesel at higher loads.

The volumetric efficiency change with load is depicted in **Figure 11**. As the load is raised, the volumetric efficiency of the sample fuels decreases. The highest volumetric efficiency of blends with hexane added, particularly D65HX5WPF10JB20, is obtained at part load and full load.

The variation in heat release rate as a function of load is shown in **Figure 12**. The heat release rate of the hexane-blend fuel samples was discovered to be marginally lower than that of the blends of diesel and waste plastic fuel made from jatropha. This might be because diesel-waste plastic fuel-jatropha biodiesel blends had a lower diesel index and hence a lower cetane number than hexane-blend fuel samples.

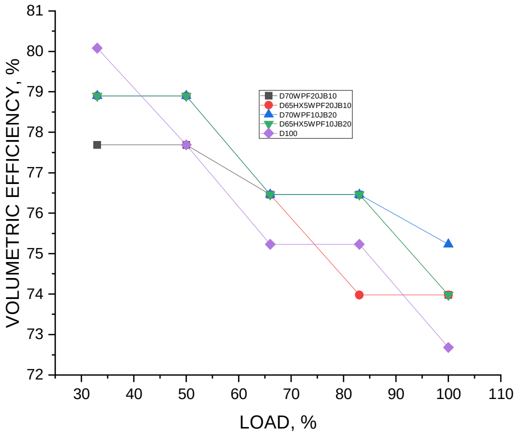

Figure 11. Alterations of volumetric efficiency with load

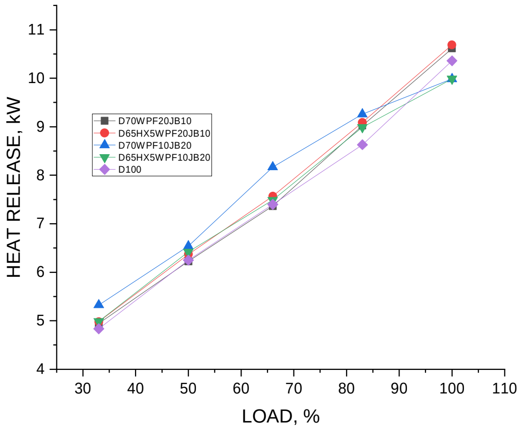

Figure 12. Comparison of Heat Release rate with load

Figure 13 depicts the variation of exhaust gas temperature (EGT) with load. In both part load and full load conditions, the exhaust temperature of hexane mixed fuels is found to be lower than that of diesel and diesel-waste plastic fuel-jatropha biodiesel blends. Higher exhaust temperatures are undesirable because they produce a substantial quantity of heat loss starting with the combustion zone and progressing to the surrounds which impairs an engine's thermal efficiency [35]. The increased EGT of diesel-waste plastic fuel-jatropha biodiesel blends when compared to hexane mixed fuels might be related to the higher oxygen concentration of diesel-waste plastic fuel-jatropha biodiesel blends, as stated in the CHNS study in **Table 5**. Combustion is improved in diesel-waste plastic fuel-jatropha mixtures with more oxygen. Because the diesel index and hence cetane number of diesel-waste plastic fuel-jatropha blends are lower than hexane blended fuels, more fuel accumulates in a premixed phase of combustion, resulting in greater EGT.

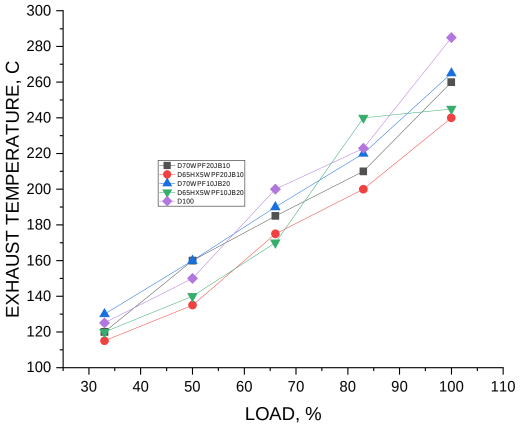

Figure 13. Variations in exhaust gas temperature as a function of load

Figure 14 depicts the relationship between the air-fuel ratio (A/F) and the load. A non-uniform fuel distribution that varies with time and space exists in C.I. engine cylinder and prevails throughout the entire combustion period. The formation of pollutants is strongly influenced by the local A/F ratio during combustion.

At low to medium load situations, diesel has the greatest air-fuel ratio. It is found that the A/F ratio of hexane mix fuel samples are slightly higher than that of diesel-waste plastic fuel-jatropha biodiesel blends specifically for lower to medium loading condition.

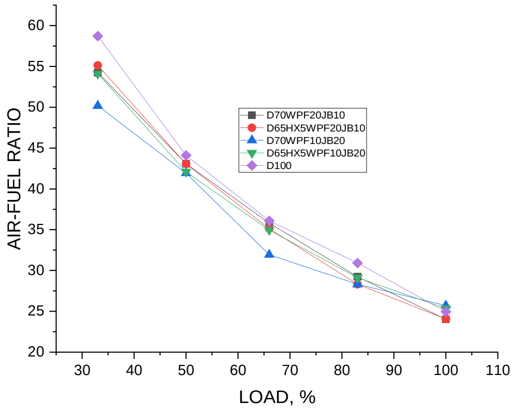

Figure 14. Air-fuel ratio Vs Load

4.4. Features of emission

The variations in hydrocarbon emission with loading for several sample fuels are shown in **Figure 15**. Hydrocarbons are generally thought of as gases, and when they are solid, they are referred to as particulate matter (PM) [23]. HC emissions are lower at partial loads but tend to rise at increasing loads for all of the investigated fuels. This is due to an oxygen shortage brought on by an engine running at a higher equivalence ratio [34]. In comparison to diesel and mixes of diesel and waste plastic fuel with jatropha biodiesel, hexane blended fuels emit more hydrocarbons (HC). Low volatility and a fuel-rich mixture at higher loads are most likely to be accountable for the increased HC emissions of hexane-mixed fuels.

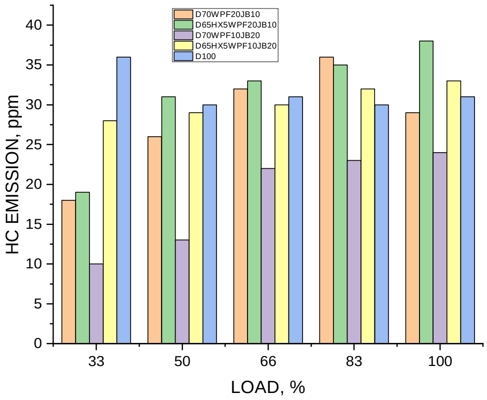

Figure 15. Alterations of HC emission with load

The variance in CO emissions for different test fuels as a function of load is shown in **Figure 16**. The gas carbon monoxide (CO) is poisonous, colorless, and odorless. Carbon monoxide (CO), which also signifies lost chemical energy, is regarded as sensible emission.CO emissions from all fuels decrease as the load is raised. This may be due to the fact that the cylinder temperature was lower at low load but rose as the load increased due to the addition of additional fuel to the cylinder. As fuel burned more smoothly at higher temperatures and engine performance improved, CO levels decreased. It can be demonstrated that hexane blended fuels emit less carbon monoxide (CO) than diesel, diesel-waste plastic fuel, and diesel. The A/F ratio, engine temperature, and physico-chemical properties of the fuel all affect CO emissions from a diesel engine [36]–[38]. Due to diesel-waste plastic fuel-jatropha biodiesel blends' low calorific value, more fuel must be injected for the same load, which leads to poor atomization and higher CO emissions. The lower CO emission of hexane blended fuel as compared to diesel-waste plastic fuel-jatropha biodiesel blends may be attributed to hexane blended fuel's higher calorific value.

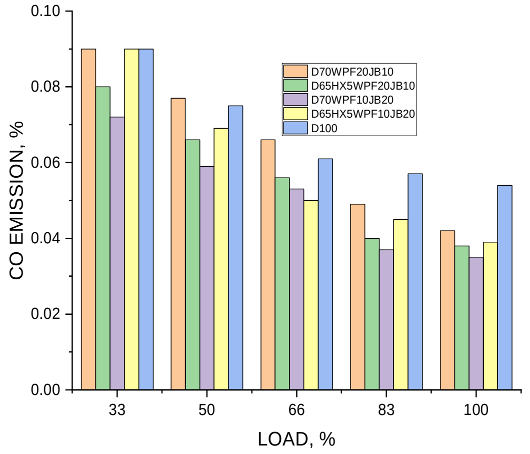

Figure 16. CO emission variations as a function of load

Figure 17 depicts how NOx emission changes as a function of load. Engine exhaust has significant levels of nitrogen oxides, which can reach 2000 parts per million. Nitrogen oxide (NO) and a small amount of nitrogen dioxide make up the majority of nitrogen oxides (NO_2). The nitrogen oxides, abbreviated as NOx, also contain certain additional nitrogen-oxygen mixtures. Because NOx has a propensity to combine with other substances and produce ozone in the atmosphere, it is not at all desired. This is one of the prime concerns in the formation of photochemical smog. The reaction between an automobile's exhaust and the air in the environment produces smog. NOx splits into NO and Oxygen. Ozone is created as a result of this monatomic oxygen. Every year, crops are lost due to the formation of ozone, which is prevalent at ground level and extremely hazardous to plants. Because nitrogen and oxygen react at high temperatures, the lack of oxygen and high temperatures are two of the main factors contributing to NOx production [39]. The type of fuel utilised and factors such as droplet size, rate of penetration, spray properties, evaporation rate, and degree of mingling with air all have a significant impact on NOx emissions. Any of these traits might have an impact on NOx production [40].

According to other researchers as well, one of the main downsides of biodiesel is its high NOx emissions [41], [42]. The graph demonstrates that NOx emissions are an inevitable byproduct of engine load. Hexane blended fuels emit less NOx than diesel, waste plastic fuel, and diesel, for both full and part loads. Following the diesel, D65HX5WPF20JB10 emits the least NOx and D70WPF20JB10 emits the most.

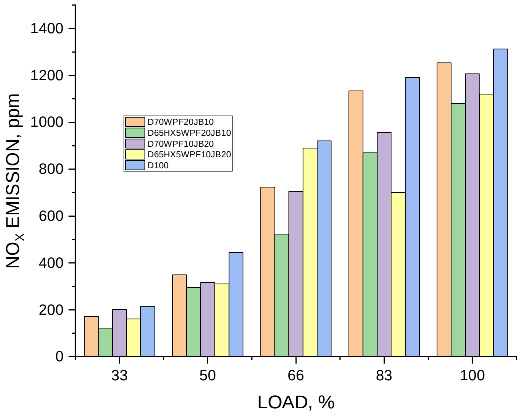

Figure 17. Alterations of NOx emission with load

At full load, D65HX5WPF20JB10 produces 13.87% less NOx than D70WPF20JB10. Less NOx is created while using hexane mixed fuel samples because of the lower exhaust temperature, slower heat release rates, and lower oxygen concentration.

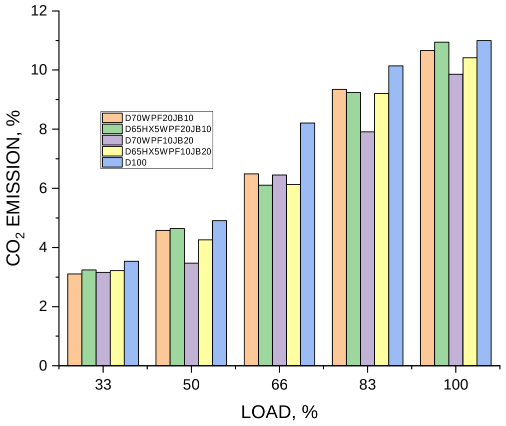

Figure 18. CO_2 emission changes as a function of load

The variation of CO_2 emissions with load for numerous test fuels is shown in **Figure 18**. All the test fuels emit more CO_2 as the load increases, as expected. A byproduct of combustion called CO2 is naturally present in the environment. During ideal combustion, the hydrocarbon fuel should only release CO_2 and water vapor [43]. Of all the fuels tested, diesel has the highest CO2 emissions. The graph shows that the CO_2 emissions from the blends of diesel, waste plastic fuel, and jatropha biodiesel are not considerably impacted by the addition of hexane.

5. Conclusion

The current work's main objective is to investigate the effects of hexane as an ingredient in blends of diesel, waste plastic fuel, and jatropha biodiesel and compare the outcomes to both those blends and diesel as a reference fuel. According to the investigation, the viscosity and density of the diesel-waste plastic fuel-jatropha biodiesel are marginally reduced by the addition of hexane. Additionally, it lowers the flash point while raising the calorific value. Hexane enhances the diesel index in a mix, and in the case of D65HX5WPF10JB20, it is discovered to be greater than diesel. The FTIR analysis of the fuel samples reveals that the diesel, diesel-hexane-waste plastic fuel-biodiesel blends, and diesel all have some functional groups in common, making them all suitable for use as high-quality fuel. According to GC-MS examination of the various fuel samples, all of the blends are thought to contain some aliphatic and aromatic chemicals as well as ester components, diglycerides, and triglycerides. Engine testing reveals that the fuel samples with hexane added have improved thermal and volumetric efficiencies and lower BSFC. The BSEC of the samples of hexane mixed fuel is comparable to diesel. The fuel sample D65HX5WPF10JB20 in particular exhibits the highest volumetric and thermal efficiency of all the fuels. According to engine emission tests, adding hexane to a mixture of diesel, waste plastic fuel, and biodiesel increases hydrocarbon emissions by 34% when compared to diesel, waste plastic fuel, and biodiesel alone, and only 6% when compared to diesel. Hexane is added to the mixture, which reduces CO emissions by 9% when compared to a diesel-waste plastic fuel-biodiesel blend and by 27% when compared to regular diesel. The Exhaust Gas Temperature (EGT) and NOx emissions are reduced by 8% and 7%, respectively, when hexane is added to the blend of diesel, waste plastic fuel, and biodiesel. These reductions are found to be 14% and 15% lower than those of pure diesel.

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Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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The authors declare no competing interest.

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