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Performance and Emission Characteristics Study of Bio Diesel (Mahua Seed) – Diesel Blends in CI Engines

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ABSTRACT - Nowadays, the interest of researchers from all over the world is growing largely in eco- new line friendly bio-fuel (bio-diesel), especially in the countries like India which are still in their new line development phase. Bio-diesel can be prepared from edible or non-edible vegetable oils by newline heir trans-esterification using low molecular alcohols. These bio-diesels can be blended with newline mineral diesel in different proportion to get an efficient bio-fuel blend. In the recent years, a newline significant amount of research has been done on the single bio-diesel and mineral diesel newline blend as a bio-fuel. On the other hand, a limited amount of work is reported in the field of newline bio-fuel prepared by mixing of two bio-diesels with mineral diesel. Therefore, there is good newline scope to further study and research in this area. This present research work was carried out in newlinetwo phases. In the first phase two suitable bio-diesels were selected after literature survey to newline prepare dual bio-fuel as an alternate fuel to conventional mineral diesel. Further, two step newline trans-esterification method was employed and reaction parameters were varied to produce newline improved quality dual bio-fuel sample blends. The physicochemical properties were analyzed newline for the various sample blends and the samples with better quality were recommended for newline testing on a varying compression ratio engine for combustion and emission characterization. Newline The second phase of research work included the performance of engine and emission newline characterization of the dual bio-fuel samples prepared. Mahua (Madhuca indica) newline seed oil has production capacity of approximately 60 MT in India, which has oil content near newline to 35-40% and heat content value almost near to that of conventional diesel.
Keywords: Madhuca indica, Blended oil, Engine Performance

I. Introduction

1.1 Biomass

Biomass in the energy production industry is living and recently dead biological material which can be used as fuel or for industrial production. It has become popular among coal power stations, which switch from coal to biomass in order to convert to renewable energy generation without wasting existing generating plant and infrastructure. Biomass most often refers to plants or plant-based materials that are not used for food or feed, and are specifically called nitrocellulose biomass. As an energy source, biomass can either be used directly via combustion to produce heat, or indirectly after converting it to various forms of biofuel.

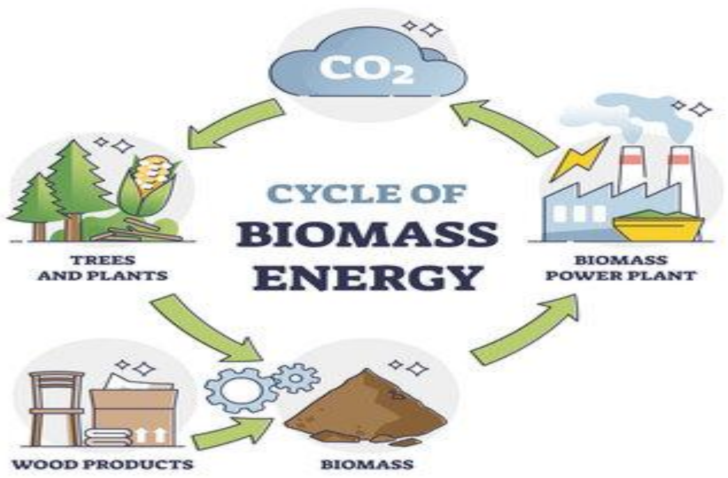

Figure 1. Biomass Cycle

1.2 Bio-Blend Fuels

Bio-Blend Fuels Inc. is a company producing bio-diesel from various materials including beef tallow and vegetable oil. They are based in Manitowoc, Wisconsin and have an annual capacity of 2.6 million US gallons. The company is notable for producing bio-diesel from pig fat recovered from commercial bacon production facilities.

The company was founded in 2005 by husband-and-wife Dan and Tracy Kaderabek. It was originally launched merely to supply the Kaderabek's boat business with cheap fuel. However, in May 2009, a new plant was opened with a capacity of 2.6 million US gallons per year which provides biodiesel direct to the pump for sale to the public.

A number of sources are used in the production of biodiesel, including the more traditional vegetable oils. However, much publicity surrounded Bio-Blend's decision to source its main ingredient from pig fat. This is largely obtained from meat rendering plants are producing cooked bacon from pork in microwave ovens. The fat is an unwanted by-product of this process.

Amongst the claimed advantages of Bio-Blends biodiesel is that it has a sweeter smell than regular biodiesel. The product smells of bacon, unlike regular biodiesel, described by one reviewer, as smelling of "rancid popcorn".

The company has stated that it is researching the possibility of using algae as a raw material.

1.3 E20 Fuel

Figure 1.5 E20 Fuels

1.4 Mahua seeds as a potential feedstock

Numerous crops are produced not just for food and manure, but also for an incredible range of unique industrial goods. The lookout for new oil plant products with higher oil or fat extraction rates for nutritional, medicinal, and other purposes is essential. The life cycle of mahua biodiesel have been shown in Fig. 2.Mahua oil (Madhucaindica) is extracted from the seeds of the Madhucaindica tree, which is native to much of India. Mahua seed has around 35–40% oil, whereas the kernel contains approximately 70% oil. Every year, every tree yields 20–40kg of seed. The color of unprocessed yet processe draw mahua oil has a green is yellow tint. A tree requires 8–15yearsfor a tree to completely grow, and an adult tree may provide fruit for up to 60 years. It is semi-evergreen herbage indigenous to India Mahua oil has around 20% FFAsand has a yield of 181,000 metric tons per year in India.

Figure 2. Lifecycle analysis of mahua oil biodiesel

1.5 Production of biodiesel from mahua oil

Many researchers have investigated Mahua biodiesel as a substitute fuel in diesel engine. Researchers used various techniques to convert crude mahua oil into a useful biodiesel. Bahadur et al. produced mahua oil by two step transesterification. 100 mL of raw mahua oil and 35 mL of methanol were combined. 1.5% v/v conc.$H_2SO_4$was added to this mixture. Using a magnetic stirrer, the produced sample washeated to 45°C for an hour. The pre-treated mahua oil was combined with alcohol in a 1:5 ratio, as well as 0.75% v/v KOH catalyst. A magnetic stirrer was used to heat the mixture to 45°C at 500 rpm.

Chandrasekaran Muthu kumaran et al. optimized the biodiesel production process. The quantity of methanol used and the temperature has a major impact on the output of mahua biodiesel. The highest biodiesel yield of 88.71 % was produced using 1.5 % KOH as the catalyst, 0.32 % v/v methanol, a temperature of 60 C, and duration of 90 min. The ASTM criteria were satisfied by the prepared mahua biodiesel .Sukumar Puhan et al. synthesized Mahua oil biodiesel from crude oil by transesterification process. Mahua oil was heated to 60ºC and added methanol and NaOH to it with magnetic stirrer for 2 hr.

The Biodiesel and glycerine separated and top layer collected and washed. SukumarPuhan et al. Mahua oil was combined with methanol and ethanol in a 20:1 molar ratio, as well as 5% v/v H_2SO_4, and the solution was heated for 5 hr. The produced upper phase was collected, cleaned, and dried in an over at 110ºC. H. Raheman et al. and Deepesh Sonar et al. produced Mahua biodiesel from raw mahua oil in two step transesterification process. A two-step 'acid–base' method was employed to synthesize biodiesel from raw mahua oil in a lab size unit, using methanol as a reagent and H_2SO_4as well as KOH as catalysts for the acid and base reactions respectively. Suresh M. Senthilet al.

Studied the process of calcination or catalytic cracking alters the physiochemical components of a material can be usedas a catalyst. Catalytic cracking was conducted in a catalytic apparatus at 300 °C for 2 h. 200 ml of methanol was mixed with 1000 ml of Mahua oil for the biodiesel production, and the transesterification process was conducted in a reaction chamber at 60 °C for 30 min. KOH and cracked red mud were employed as catalysts at proportions of 15 g in1 liter of Mahua oil, respectively. As a final product, about 0.8 L biodiesel was obtained for 1 L of Mahua oil.

Mahua oil is economical and the manufacturing of biodiesel from it can be ratcheted up to an industrial scale. Mahua biodiesel is an excellent substitute to fossil fuel since it has comparable properties to petro diesel fuel and is less expensive.

1.6 Works on mahua biodiesel as an alternate fuel

Mahua plants can be found in various states in India, including Orissa, Chattishgarh, Jharkhand,Bihar, Madhya Pradesh, and Tamil Nadu, where they have successfully developed. It makes use of waste and dry area that is unsuitable for any other kind of growth. Its plant does not need any particular or specific care since it is highly adaptive to any weather condition, results in a maximum height of 20 m.

In terms of fuel properties, Mahua is equivalent to diesel and is accessible in large amounts that are unused. On a volume basis, it has a calorific value of 96.30 %. Concerning power output, BSFC, and BTE, blending mahua oil with diesel by 20% has no significant effect.

Many researchers investigated on blending mahua oil biodiesel with diesel, adding higher alcohol and diethyl ether, including different nanoparticles into the fuel blend, and changing engine specifications like IP, IT, and CR.

1.7 Mahua oil biodiesel blended with diesel

Several researchers investigated the characteristics of the engine with mahua oil biodiesel as fuel. There are many researches focusing on the composition of biodiesel in the Diesel/Biodiesel blend. SukumarPuhan et al. studied engine performance that Mahua oil methyl ester(MOME) as a fuel is not significantly different from diesel. MOME noticed a little power reduction and an upsurge in fuel intake.

This might be owing to the ester's reduced heating value. CO and HC emissions are too low for MOME. NO_X were quite lower in ester than in diesel. Sukumar Puhan et al.vcompared the mahua oil biodiesel prepared from methanol and ethanol. When esters are compared to diesel on performance and emissions, the findings are favorable. Incompared to diesel, esters burned more effectively. Based on the results of this research, it is determined that methyl and ethyl esters can be employed as alternative fuel in diesel engines. In terms of performance and emissions, methyl ester gave better results over ethyl ester and diesel fuel.

H. Raheman et al. Investigated mahua biodiesel blends as fuel and compared with diesel. The proportion of biodiesel in the fuel mixture raised the BSFC and reduced the BTE. With increasing the load, the CR and IT test showed a reverse trend. The smoke opacity and CO in flue gases decreased with raise inproportion of mahua biodiesel in the blends, while NO_Xincreased. However, when engine load increased, the amount of emissions raised for all test samples. The B20 blend gave enhanced performance and also reduced emissions over diesel and other blends.

Deepesh Sonar et al. Investigated the mahua oil and mahua biodiesel blends. It indicated at higher blends, BSFC raised and BTE reduced. CO and HC in flue gases decreased, while NO_Xslightly increased as the proportion of biodiesel in the fuel blend increased. It was found that may be effectively mixed into diesel fuel up to 20%, making it a good substitute fuel for diesel. The performance and emission characteristics of the engine using mahua biodiesel mixes can be greatly enhanced by altering the IOP. At 226 bar, mahua oil and diesel fuel mixture having up to 30% mahua oil can be employed as a fuel.

II. Methodology & Objective

The literature review showed that a dual biofuel can be prepared by the blending of Mahua bio-diesel with mineral (standard) diesel. The blending of these oils can improve the overall physicochemical properties of the blended biofuel. Therefore, for the current research work Mahua oils were chosen for study. The research work was carried out in two phases, in the first phase the physicochemical properties of the dual biofuel samples were evaluated and based on their analysis the chosen sample blends were examined for their engine exhaust emissions and combustion characteristics in the second phase.

2.1 Seed oils

The seed oils which were chosen for the production of dual fuel bio-diesel are listed below:
Bio-diesels can be produced from both Mahua seeds, which are found in tribal region of India. The trees of these seeds do not require very fertile land.

2.1.1 Mahua seed oil

Mahua oil is prepared from the seeds of Mahua fruits which are collected from the plant of Mahua. It is second generation feedstock which means non-edible oil, hence not used as feedstock for food in kitchen. Mahua is also known as the Madhuca indica. These trees produce approximately twenty to forty kilograms of seeds per annum. The raw oil has greenish yellow color. Generally, the raw oil contains 36mg/gm acid value with 18% FFA .

Figure3. Mahua flower, Mahua seeds and Mahua tree

Mahua plant can be easily located in many states of India such as Bihar, Madhya Pradesh, Orissa, Uttar Pradesh, Chhattisgarh, Jharkhand, Maharashtra and Tamil Nadu. The Mahua plant can easily grow without any supervision in a kind of vegetation that is not used by land owners and farmers for food crops. It is normally found to grow itself in the dry and waste land which is not vegetative for any other kind of trees or plants. Not only it can grow without any attention from any individual.

2.2 Materials and Methods

The materials used in this research work are as follows:

2.2.1 Material

- Mahua raw seed oil
- Methanol(CH_3OH)
- Sulphuric acid (H_2SO_4)
- Potassium hydroxide (KOH)
- Iodine
- Hydrochloric Acid (HCL)
- Sodium Sulphate (Na_2SO_4)
- Distilled water
- Mineral diesel

Figure 4. Raw oil used

Figure 5. Methanol procured

2.3 Methodology

Mahua oils were procured from M/s. Himani International (New Delhi) in the raw form. Methanol used in the reactions had a purity level of 99% and was purchased from Oswal scientific stores (Chandigarh). The base catalyst used for trans-esterification process was potassium hydroxide (KOH) [63]. For pre-treatment process, catalyst used was sulphuric acid (H_2SO_4) [38]. The experimentation of research was done on laboratory scale in the Chemistry Laboratory, Applied Sciences Department, Chandigarh University Mohali. The apparatus used includes glass flask, burette, stirring rod, beaker, separating funnel, threenecks round bottom flask and the equipment includes magnetic stirrer with hotplate, thermometer and a water bath whose maximum temperature was 100^0C.

2.4 Experimental methodology

To start and run the engine ignition self-start switch was used and initially it was fueled with mineral diesel. When the operating temperature of engine is reached, 50% load is applied on the engine. The warming phase ends, when the cooling water temperature shows a stabilized reading of 60^oC. The engine was tested at a fixed speed of 1500 rpm. During experiments performed the readings were measured and recorded digitally in the computer system. The readings for combustion and emission parameters with respect to different CR were evaluated.

2.4 Test Procedure

- The manual self-start attached to the crank is used for starting the variablecompression engine.
- The engine is made to run at an idle load for a while, so as to reach the optimum engine

conditions.

- The VCR engine is kept at a fixed speed of 1500rpm.
- The load is gradually applied on the engine till 50%.
- Mineral Diesel, B10, B20, B30 and B40 blends of dual biofuel were used for theengine testing.
- A dial gauge was used to measure the angle of tilt that would eventually change the engine's compression ratio.
- The samples were tested at 4 different compression ratios i.e.13.5:1, 14.5:1, 15.5:1and 16.5:1.
- The consumption of fuel was calculated with the help of a fuel burette which workedby closing the fuel supply valve connected to the fuel tank.
- The fuel burette was also used for running the engine so that the different fuels can betested without mixing into each other and also as a measure to save time.
- The exhaust gas was tested for pollutants using a gas analyzer.

Oils and fats can be processed into bio-diesel in at least four ways transesterification, dilution, micro-emulsions, and pyrolysis. The standard method is transesterification. It is a chemical process that forms fatty acid alkyl esters and glycerine, which is catalyzed by oil or fat and an alcohol [13]. In Fig.2, steps associated in synthesis of biodiesel and simple transesterification process was indicated.

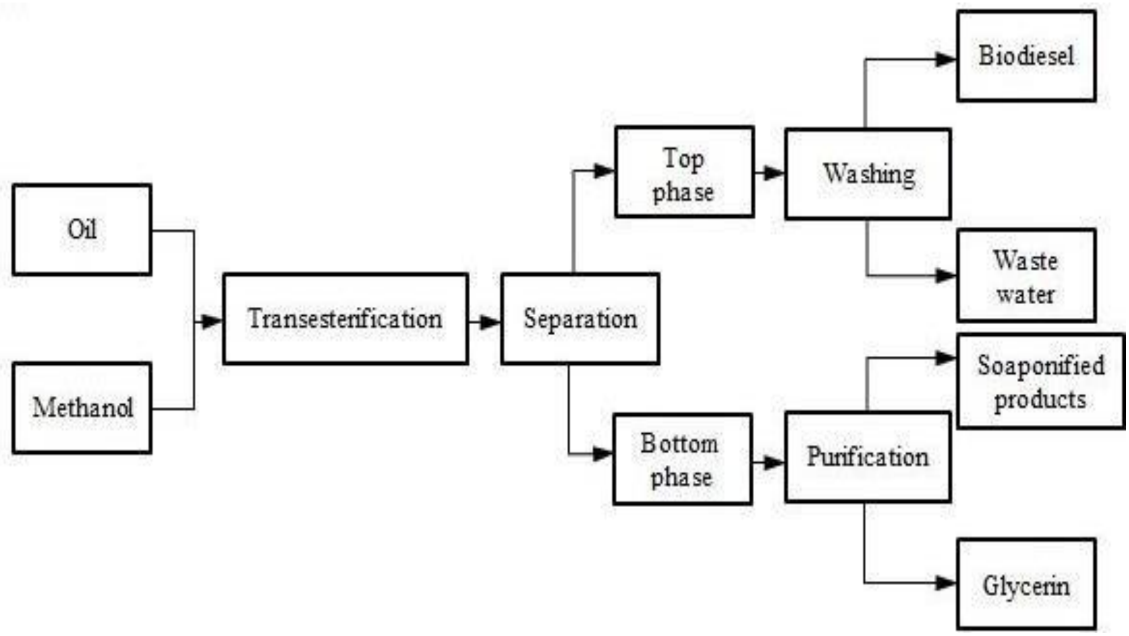

Figure 6. Basic transesterification process

III. Result and Calculation

3.1 DIESEL

% of load	Calculated load		Time taken for 10cc of fuel consumption			EGT	Smoke Density	CO	HC	CO_2	O_2	NOx
	N	kgf	t_1 (sec)	t_2 (sec)	t_{avg} (sec)	ºC	HSU	% by volume	ppm	% by volume	% by volume	ppm
20	33.35	3.4	48.51	48.62	48.56	218	24	0.03	14	3.15	20.55	352
40	67.68	6.9	39.12	39.25	39.18	285	38	0.03	16	3.62	20.43	605
60	101.04	10.3	30.49	30.22	30.35	332	46	0.04	18	3.95	21.48	818
80	135.37	13.8	26.95	26.42	26.63	348	49	0.05	20	4.28	19.35	925
100	169.71	17.3	25.46	25.31	25.38	418	51	0.22	28	4.75	19.42	1012

Table 1. Diesel 100%

3.2 Bio-Diesel 100% – Diesel 0%

% of load	Calculated load		Time taken for 10cc of fuel consumption			EGT	Smoke Density	CO	HC	CO_2	O_2	NOx
	N	kgf	t_1 (sec)	t_2 (sec)	t_{avg} (sec)	ºC	HSU	% by volume	ppm	% by volume	% by volume	ppm
20	33.35	3.4	45.24	45.38	45.31	143	38	0.08	23	20.46	20.46	212
40	67.68	6.9	35.82	35.96	35.89	213	49	0.08	26	20.18	20.18	416
60	101.04	10.3	27.35	27.93	27.64	225	56	0.10	33	20.05	20.05	662
80	135.37	13.8	23.88	23.62	23.75	239	62	0.15	38	19.63	19.63	715
100	169.71	17.3	21.07	21.22	21.14	285	66	0.38	42	18.33	18.33	783

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Table 2. B100 – D0

3.3 Bio-Diesel 80% – Diesel 20%

% of load	Calculated load		Time taken for 10cc of fuel consumption			EGT	Smoke Density	CO	HC	CO_2	O_2	NOx
	N	kgf	t_1 (sec)	t_2 (sec)	t_{avg} (sec)	ºC	HSU	% by volume	ppm	% by volume	% by volume	ppm
20	33.35	3.4	45.11	45.42	45.26	152	35	0.07	20	3.62	20.42	260
40	67.68	6.9	36.34	36.48	36.41	226	46	0.08	24	3.18	20.21	472
60	101.04	10.3	27.05	27.13	27.09	241	56	0.09	31	3.13	20.05	736
80	135.37	13.8	24.03	24.19	24.11	265	59	0.13	34	2.93	19.35	812
100	169.71	17.3	20.78	20.62	20.7	306	62	0.32	38	2.42	18.44	905

Table 5.3 B80 – D20

3.4 Bio-Diesel 60% – Diesel 40%

% of load	Calculated load		Time taken for 10cc of fuel consumption			EGT	Smoke Density	CO	HC	CO_2	O_2	NOx
	N	kgf	t_1 (sec)	t_2 (sec)	t_{avg} (sec)	ºC	HSU	% by volume	ppm	% by volume	% by volume	ppm

20	33.35	3.4	46.99	46.13	46.56	163	33	0.06	18	3.45	20.42	283
40	67.68	6.9	36.08	36.18	36.13	241	44	0.06	22	2.16	21.58	528
60	101.04	10.3	28.04	28.18	28.11	260	53	0.08	28	2.85	20.35	721
80	135.37	13.8	25.14	25.42	25.28	383	58	0.11	30	2.63	19.28	836
100	169.71	17.3	22.19	22.90	22.54	331	60	0.31	36	2.95	18.62	930

Table 4 B60 – D20

3.5 Bio-Diesel 40% – Diesel 60%

% of load	**Calculated load**		**Time taken for 10cc of fuel consumption**			**EGT**	**Smoke Density**	**CO**	**HC**	**CO_2**	**O_2**	**NOx**
	N	kgf	t_1 (sec)	t_2 (sec)	t_{avg} (sec)	ºC	HSU	% by volume	ppm	% by volume	% by volume	ppm
20	33.35	3.4	41.08	41.21	41.14	185	30	0.05	16	3.11	20.42	301
40	67.68	6.9	35.15	35.06	35.10	252	42	0.05	20	2.95	20.21	542
60	101.04	10.3	29.54	29.35	29.44	283	51	0.06	24	2.66	20.10	750
80	135.37	13.8	25.29	25.42	25.35	312	56	0.09	26	3.43	19.42	873
100	169.71	17.3	20.18	20.35	20.58	360	58	0.28	35	3.95	18.12	973

Table 5 B40 – D60

3.6 Bio-Diesel 20% – Diesel 80%

% of load	Calculated load		Time taken for 10cc of fuel consumption			EGT	Smoke Density	CO	HC	CO_2	O_2	NOx
	N	kgf	t_1 (sec)	t_2 (sec)	t_{avg} (sec)	°C	HSU	% by volume	ppm	% by volume	% by volume	ppm
20	33.35	3.4	37.20	37.15	37.17	205	28	0.04	14	2.90	21.06	331
40	67.68	6.9	32.30	32.48	32.39	263	39	0.04	18	3.15	21.25	585
60	101.04	10.3	26.30	26.48	26.48	310	48	0.05	20	3.42	20.41	782
80	135.37	13.8	21.16	21.23	21.23	335	53	0.07	23	3.11	20.05	905
100	169.71	17.3	18.43	18.56	18.56	382	54	0.25	32	4.18	19.11	992

Table 6 B20 – D80

3.7 Calculation

Engine Specifications

Break power = 5.2kw

Re-Mean effective = 0.195meter

Bore = 87.5mm

Stock = 110mm

Speed N = 1500rpm

Break power

$$\text{Break power Bp} = \frac{2\pi.Re.N.T}{60\times1000}$$

$$T = \frac{Bp\times60\times1000}{2\pi\times Re\times N}$$

$$= \frac{5.2\times60\times1000}{2\pi\times0.195\times1500}$$

= 169.85 N.m

= 17.31 kg.force

$= \frac{17.31 \times 20}{100}$

= 3.46%

Fuel consumption

$F_C = 10/t_{avg} \times$ specific gravity of fuel × density of water $\times 10^{-6} \times 3600$

$= 10/47.64 \times 0.835 \times 1000 \times 10^{-6} \times 3600$

=0.618 kg/hours

Engine Break power

$B.P = \frac{5.2 \times 20}{100}$

= 1.04

Fuel power

Fuel power = $F_c \times C_v /3600$

$\therefore C_v$ =4200 kj/kg

=0.618 × 4200 /3600

= 7.21 kw

Break Thermal Effiency

= Break power / Fuel power × 100

= 1.04 / 7.21 × 100

= 14.42 %

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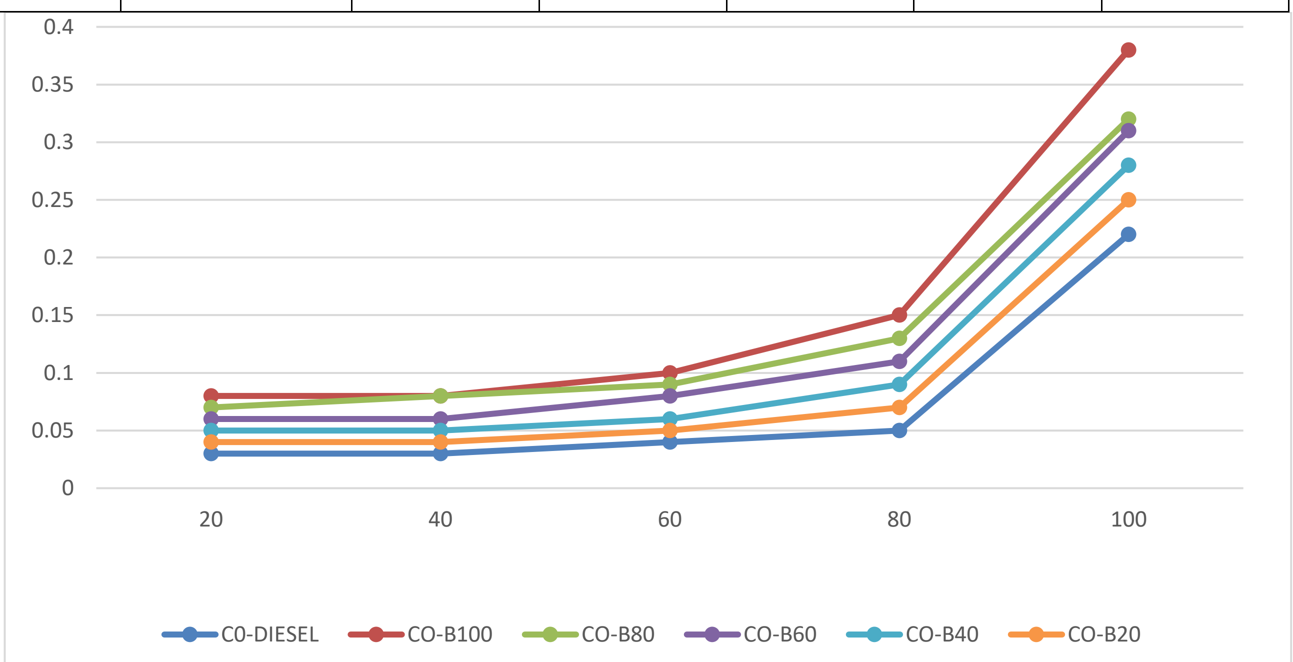
3.8 Load Compare With Carbon Monoxide (CO)

Table 6.1 load & CO

LOAD	CO-DIESEL	C0-B100	CO-B80	CO-B60	CO-B40	CO-B20
20	0.03	0.08	0.07	0.06	0.05	0.04
40	0.03	0.08	0.08	0.06	0.05	0.04
60	0.04	0.10	0.09	0.08	0.06	0.05
80	0.05	0.15	0.13	0.11	0.09	0.07
100	0.22	0.38	0.32	0.31	0.28	0.25



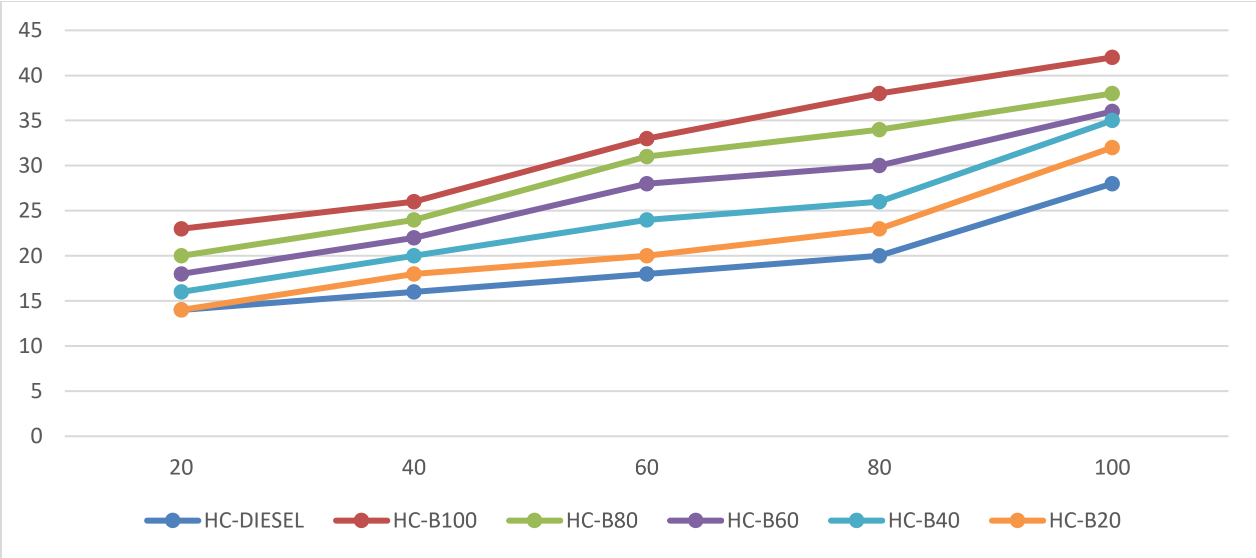
Graph 1 Load & CO

Load increases, leading to an increase in carbon dioxide emissions. This could be represented in a chart as a positive correlation between engine load and carbon dioxide levels. Essentially, as the engine works harder, it burns more fuel, resulting in higher CO_2 output.

3.9 LOAD COMPARE WITH HYDRO CARBON (HC)

LOAD	HC-DIESEL	HC-B100	HC-B80	HC-B60	HC-B40	HC-B20
20	14	23	20	18	16	14
40	16	26	24	22	20	18
60	18	33	31	28	24	20
80	20	38	34	30	26	23
100	28	42	38	36	35	32

Table 2 load & HC



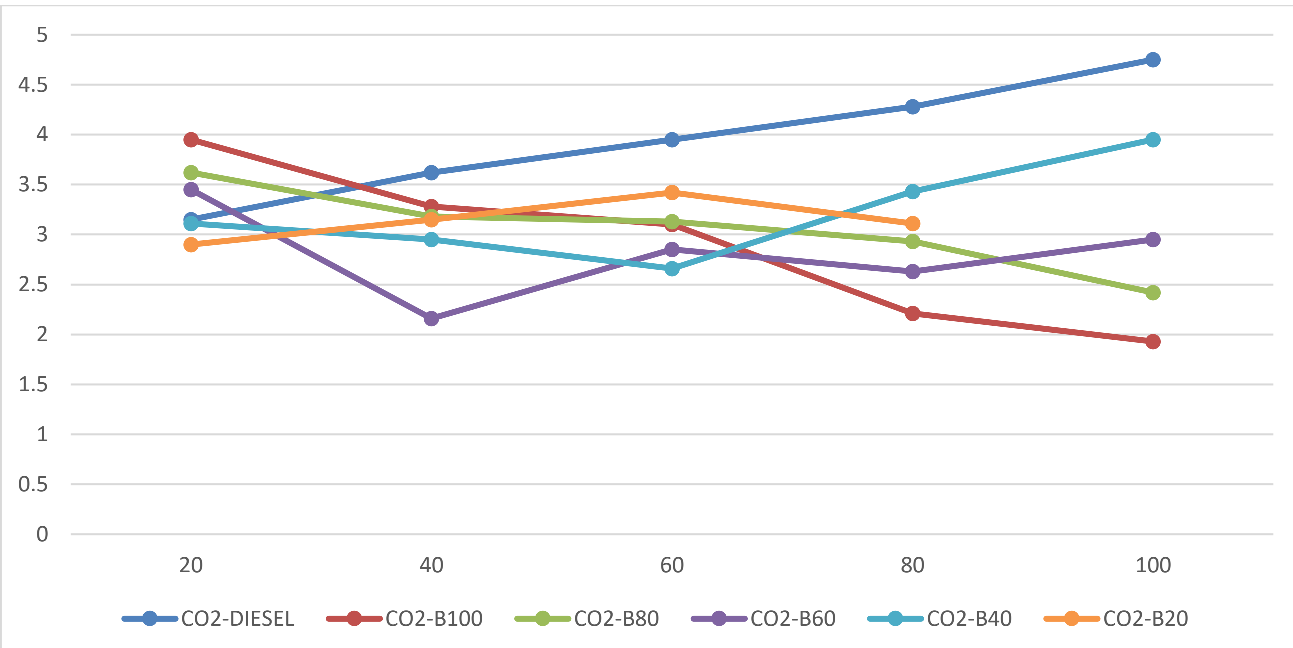
Graph 6.2 Load & HC

When increased engine load leads to higher hydrocarbon emissions, it's typically considered bad, as higher hydrocarbon levels can contribute to air pollution and environmental harm. In a graph, this would be depicted as a positive correlation between engine load and hydrocarbon emissions, indicating that as the load on the engine increases, so does the release of hydrocarbons into the atmosphere.

3.10 LOAD COMPARE WITH CARBON DIOXIDE (CO_2)

LOAD	CO_2-DIESEL	CO_2-B100	CO_2-B80	CO_2-B60	CO_2-B40	CO_2-B20
20	3.15	3.95	3.62	3.45	3.11	2.90
40	3.62	3.28	3.18	2.16	2.95	3.15
60	3.95	3.10	3.13	2.85	2.66	3.42
80	4.28	2.21	2.93	2.63	3.43	3.11
100	4.75	1.93	2.42	6.95	3.95	4.18

Table 3 load & CO_2



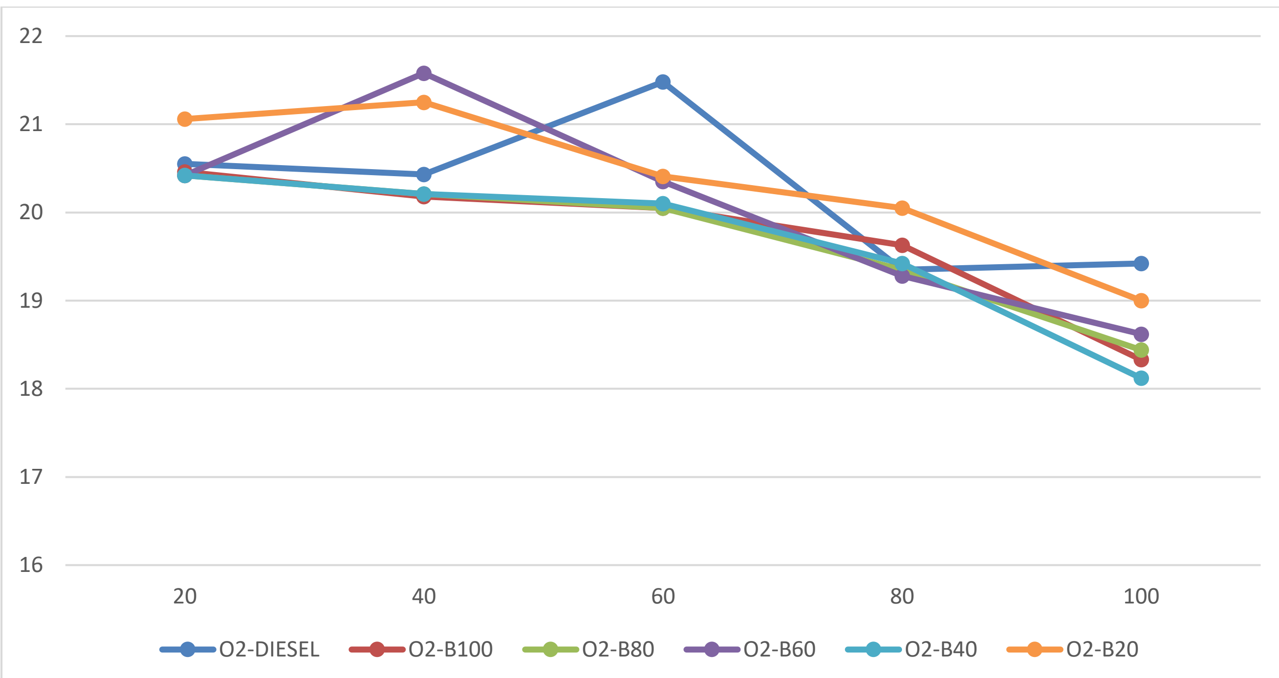
Graph 6.3 Load & CO_2

If the load on the engine increases but the carbon dioxide (CO2) emissions remain relatively stable or decrease, it could be considered a positive outcome. This would indicate that the engine is operating more efficiently, producing less CO2 per unit of work done. So, in the context of engine performance and environmental impact, a variable CO2 level with increasing load can be seen as a good sign if it signifies improved efficiency and reduced emissions.

3.11 LOAD COMPARE WITH OXYGEN (O_2)

LOAD	O_2-DIESEL	O_2-B100	O_2-B80	O_2-B60	O_2-B40	O_2-B20
20	20.55	20.46	20.42	20.42	20.42	21.06
40	20.43	20.18	20.21	21.58	20.21	21.25
60	21.48	20.05	20.05	20.35	20.10	20.41
80	19.35	19.63	19.35	19.28	19.42	20.05
100	19.42	18.33	18.44	18.62	18.12	19.11

Table 6.4 load & O_2



Graph 6.4 Load & O_2

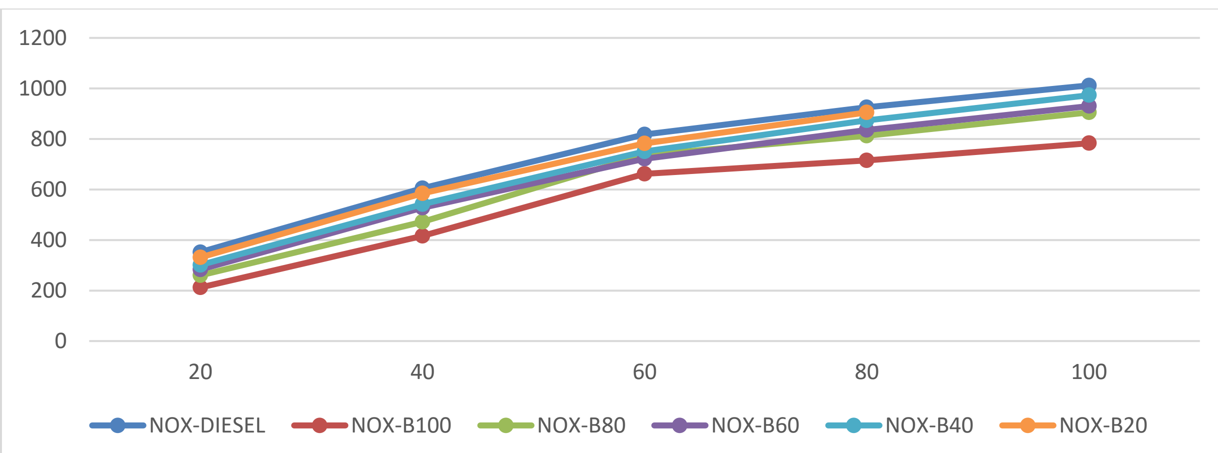
In some cases, a slight variation in O2 levels could suggest that the engine is effectively adjusting its fuel-air mixture to match the changing load demands. This adaptability can be a sign of good engine tuning and responsiveness.

If the O2 levels fluctuate too much or consistently drop below certain thresholds, it might indicate inefficiencies in combustion, incomplete fuel burning, or other issues with the engine's performance. This could potentially lead to reduced engine life or increased wear and tear if not addressed.

3.12 LOAD COMPARE WITH NITROGEN OXIDES (NO_X)

LOAD	NO_X-DIESEL	NO_X-B100	NO_X-B80	NO_X-B60	NO_X-B40	NO_X-B20
20	352	212	260	283	301	331
40	605	416	472	528	542	585
60	818	662	736	721	750	782
80	925	715	812	836	873	905
100	1012	783	905	930	973	992

Table 6.5 load & NO_X



Graph 6.5 Load & NO_X

In summary, an increase in NOx emissions with increasing engine load is generally detrimental to engine life, regulatory compliance, and environmental health. Efforts to reduce NOx emissions are important for improving engine longevity and minimizing negative environmental impacts.

IV. CONCLUSION

The challenge of decreasing crude oil reserves, as well as growing attention to environmental degradation caused by petroleum-based fuel emissions, has prompted an exploration for sustainable substitute fuels to replace petroleum-based fuel. Biodiesel, which is environmentally friendly and made from renewable resources, has rapidly gained popularity.

Non-edible oils like Mahua oil, Calophyllum Inophyllum, Castor oil, Neem oil etc. have gained much attention as an alternative fuel due its adaptability. Mahua oil has been the subject of numerous studies as an alternative fuel.

- Studies on Mahua oil biodiesel blended with diesel indicated Performance near to near to diesel and significantly reduced emissions. Many authors suggested that 20% of biodiesel/diesel blend could be utilised as a fuel in diesel engine without modifications of engine. B20 gives lower exhaust greenhouse gases with compromising on engine's performance.
- Viscosity of biodiesels are higher than diesel, to overcome this drawback researchers used alcohol as an additive to the biodiesel and its blends in order to reduce the viscosity and eventually decreasing harmful exhaust emissions.
- Combustion characteristics with mahua oil biodiesel was studied by numerous researchers which indicated improved combustion with the inclusion of nanoparticles into the fuel blend results in more surface-to-volume ratio and better atomisation and stability leads shorter ignition delay in the combustion chamber.
- Many researchers have worked on engine modifications such as modifying compression ratio, injection timingand injection pressure. Change in engine parameters results in slight enhancement in performance, effective combustion and significant reduction in emissions were noticed.

From this review it can determined that mahua oil biodiesel can be used in diesel engine with no substantial modifications. The criteria of acceptable efficiency, fuel economy and reduction of hazardous emissions of the engine are feasible. However additional studies under correct operating parameters with better design are necessary to explore maximum potential of biodiesel engine.

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