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PERFORMANCE ANALYSIS OF BIO-DIESEL FUEL PRODUCED FROM RAPHANUS SATIVUS SEEDS

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Abstract— **Fuels derived from conventional fossil resources have been the predominant form of energy for a few decades. However, it has been observed that fossil fuel availability would eventually run out. The diminishing supply of conventional fossil fuel reserves, their adverse effects on the ecosystem, which includes the formation of harmful gases and pollutants, together with worries about the economy and energy demand, have prompted the quest for a new, sustainable, readily available, inexpensive, environmentally friendly, and renewable energy source to replace the presently available petro-diesel fuel. Vegetable oil has been found to be one of the potential alternatives for neat diesel in the aforementioned scenario. However, the primary drawbacks of these oils are their extremely high viscosity, poor volatility, and associated problems that arise from employing them for a prolonged duration of time in engines. These challenges can be resolved by converting these vegetable oils into alkyl esters. The alkyl esters derived from vegetable oil are termed biodiesel, the best suitable substitute for petro-diesel owing to their renewable and low-emission facilities.**

Due to the high biodegradability and non-existent toxic substances, biodiesel from renewable sources such as animal fats, edible and non-edible oils, and algae has become a popular replacement for conventional petro-diesel. In the meantime, feedstock alone costs approximately 60 to 70 % of the cost required for biodiesel production. As a result, identifying the appropriate, affordable, and effective feedstock is essential for the continual production of biodiesel with minimum process cost. Subsequently, the cost of production will be drastically reduced when utilising inexpensive, non-edible oils, spent cooking oil, animal fats, and algae as feedstock for producing biodiesel.

Raphanus sativus seeds, which are non-edible and have not yet been thoroughly investigated for their potential use as a feedstock for biodiesel, are the source of the biodiesel used in this study. Oil from seeds is extracted using a mechanical expeller, and the yield was determined to be 46.2±2 weight percent. The physicochemical properties were then examined using the standard AOAC procedures. The current work used a catalytic transesterification reaction to produce the biodiesel. The parameters influencing the biodiesel production processes, like Methanol to Oil ratio, catalyst, process temperature and process time, must be optimised for better process yield.

To investigate the consequences of the influencing parameters and to optimise the biodiesel yield, the Taguchi statistical approach, Response Surface Methodology, and Analysis of Variance table were employed, and the outcomes were compared. The results indicate that the Taguchi method gave the results comparably with the RSM method in a limited set of experimental runs. At the optimised condition, methanol to oil molar ratio 9:1, catalyst concentration 1 wt%, reaction temperature 50 °C and reaction time 30 min, biodiesel yield was 94.58 wt%.

Index Terms— **Bio-Diesel fuel, Performance analysis, mechanical testing of bio diesel fuels, Raphanus sativus seeds etc.**

I. INTRODUCTION

A. GENERAL INTRODUCTION AND ENERGYCRISIS

The most crucial element for the advancement of humanity is energy resources. The biggest worldwide problem that bothers us these days is the energy crisis. Through the process of combustion, fuels are one of the main sources of energy generation. Fuel is essential to many aspects of everyday life as it allows for the efficient movement of people and products. Fossil fuels, which account for about 80% of global energy use, include coal, natural gas, and petroleum fuels. Petroleum fuels are necessary for the manufacturing of many industrial operations. Fossil fuel is often used to power vehicles such as trucks, buses, and ships, contributing to the global reliance on fossil fuels. Fossil resources are expected to run out in less than 50 years due to the exponential rise of the population and fuel use (Raj et al. 2022; Huang et al. 2012).

B. ENERGY SCENARIO IN INDIA

India is now the world's third-largest energy user, after the United States and China. India has abundant natural gas resources and coal reserves, but its growing energy needs quickly lead to a greater reliance on imported petroleum fuel. The global list of energy users is shown in Figure 1. In India, diesel fuel was one of the most popular petroleum fuels. Throughout the years, the transportation, electricity generating, and agricultural sectors have all used diesel fuel. The persistent use of petroleum fuels in many industries causes a fuel crisis and significant emissions into the environment.

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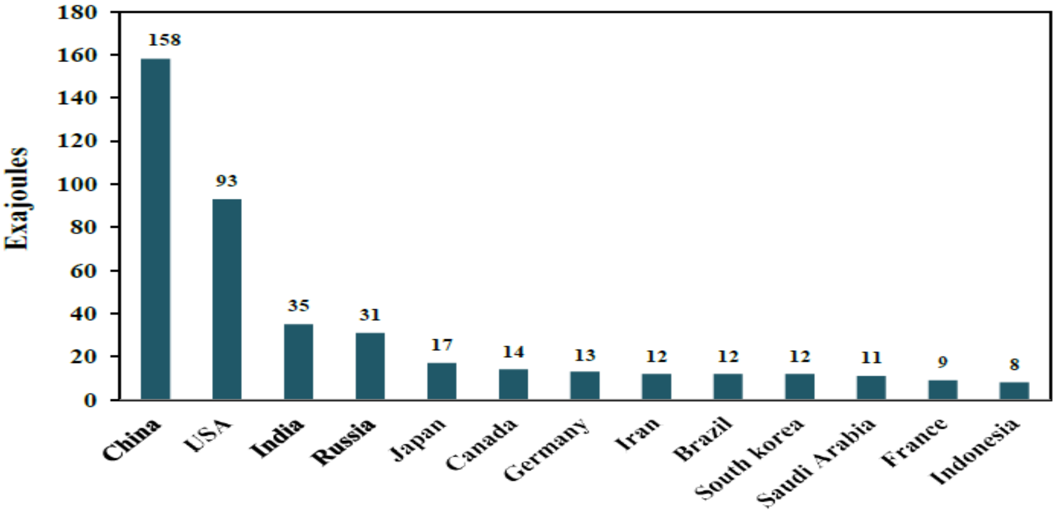

Figure 1 Primary energy consumption worldwide

C. RESEARCH OBJECTIVE

1. As per the authors' knowledge, the use of R. sativus seed oil as a raw feedstock for biodiesel synthesis is unique and has not been the subject of any study.
2. Using accepted techniques, the physicochemical characteristics of both raw oil and biodiesel were investigated.
3. When R. sativus biodiesel was used to analyse the performance of diesel engines, it was discovered that adding nano additives to improve emission characteristics was innovative.

II. LITERATUREREVIEW

An extensive research was conducted in order to determine the best feedstock for biodiesel, taking into account the energy requirements as well as the conflicts that edible oil has with the food chain. The significance of various vegetable oils' availability, place of cultivation, fatty acid composition, and oil content were all covered. It is crucial to manually choose the most effective way to turn seeds or kernels into oil using several extraction techniques after locating acceptable feedstock. To choose the best technique, a thorough analysis of the various forms of oil extraction and their oil output capacity was conducted.

To determine the likelihood of replacing petro diesel, the physicochemical characteristics of the vegetable oil extracted from seeds must be determined. A thorough discussion was held on standard techniques for evaluating ASTM and EN codes and processes. Subsequently, the attributes were contrasted with the typical petro diesel attributes. Whether the SVO needs further chemical transformations or may be used directly in diesel engines depends on its qualities. With the exception of oil's viscosity and calorific value, the review makes it evident that the primary physicochemical characteristics of SVO are related to diesel fuel. Therefore, in order to prevent injection issues related to the fuel injection system, it is essential that oil viscosity be reduced by a chemical conversion process.

Through trans esterification, vegetable oil triglyceride transforms into ester and extracts the very viscous glycerol. Parameters influencing the trans esterification process were examined from the study of different kinds of research, and some literature provides the appropriate optimization method to get a higher yield. Furthermore, a great deal of study has been done on the many kinds of alcohol that are utilized, as well as the catalysts that are evaluated.

Following the production of biodiesel, they were combined in certain ratios with petro diesel to enhance its physicochemical characteristics. The viscosity, calorific value, density, cloud point, and pour point will all be much enhanced by blending when it comes to using diesel engines. When they are fueled in diesel engines, their emissions and performance were examined. Based on the efficiency of the fuel and the kind of diesel engine, some studies recommend using B20 of biodiesel, while others recommend using more.

As was previously said, the main issue that requires extra care while using biodiesel as engine fuel is NOx reduction (10–15% larger than the petro diesel). It could occur as a result of its propensity for oxidation and the high temperature in the combustion chamber during full combustion. Numerous studies have been carried out to identify potential solutions for lowering NOx emissions.

According to the literature, some of the techniques used to minimize NOx and other harmful emissions include the introduction of the EGR technique, the use of the urea-SCR system, decreasing the temperature of the combustion chamber, and the effect of nano-based additions in biodiesel blends.

III. MATERIALSANDMETHODS

A. INTRODUCTION

The features of the internal combustion engine and the optimisation of the input parameters using various statistical techniques with respect to the engine's efficiency and emissions characteristics are covered in depth in the next phase of this project. Figure 2 shows the sequential methods used during the whole operation.

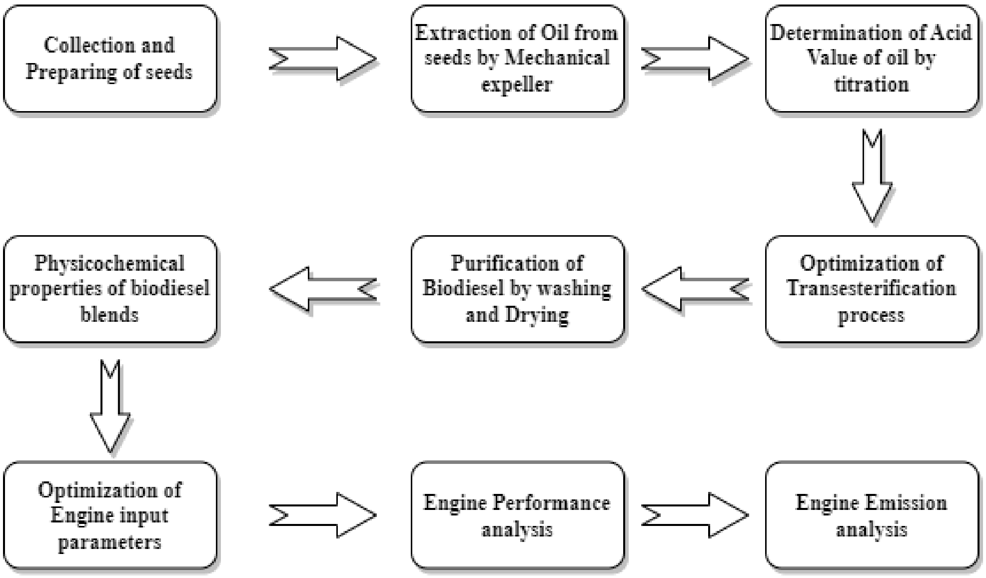

Figure 2 Block diagram of entire process methodology

B. TRANSESTERIFICATIONPROCESS

For the purpose of producing biodiesel, a 500 mL round-bottom flask with three necks and a reflux condenser, temperature-controlled heating mantle, and magnetic stirrer were attached (Figure 3). The flask is first filled with oil and heated to the proper temperature. Then, after being completely dissolved in a premeasured quantity of methanol, the precisely measured amount of KOH catalyst is introduced gradually to the hot oil in a flask.

To guarantee a homogenous combination of the catalyst and oil with a methanol mixer, a magnetic stirrer with a steady 500 rpm stirring rate is used. A reflux condenser is used in this procedure to ensure that no methanol vapour is lost. After the reaction was complete, the product was allowed to cool before being placed in a separating funnel (Figure 4) and left for a full day. Following the settling process, the funnel had two separate layers, one with biodiesel at the top and glycerol at the bottom. It was then simple to isolate the final product as biodiesel by removing the glycerol layer. It was then given a water wash and allowed to dry at 85 °C until the moisture content reached 0.05 weight percent.

$$\text{Biodiesel Yield (wt\%)} = \frac{\text{Weight of biodiesel produced (g)}}{\text{Weight of oil used (g)}} \times 100$$

Figure 3 Trans esterification setup

Figure 4 Separation of bio diesel and glycerol

Similarly, 10 mL samples were obtained at regular intervals for kinetic investigations. The reaction was quickly stopped by neutralising these samples with 5 mL of acetic acid (1 N). After further centrifugation, washing, vacuum drying, passing through sodium sulphate in anhydrous, and storing for conversion analysis, it was all done. To ensure that the findings could be repeated, three tests were performed on a single sample. The standard deviation of the results was computed for future study.

C. AN EXPERTIAL ENGINE SETUP

In this experiment, a four-stroke, naturally aspirated, direct-injection diesel engine with mechanical stresses was employed to analyse engine performance. Table 1 lists the parameters of the engine used in the experiment. A digital data collecting system and an exhaust gas analyzer, the Dig Gas 444 (AVL India Pvt. Ltd., India), were used to monitor the emission levels. To achieve a homogenous solution, nano-Al_2O_3 is dispersed into the biodiesel and its mixes using ultrasonic cavitation. By adjusting the number of leaves (0.30 mm thickness of shim) in the fuel injection pump, the fuel injection time may be advanced or retarded from the conventional injection timing (23° bTDC). The installed standard injection time of the injection pump was used to monitor the injection timing. The fuel injection pressure was adjusted using the fuel injection's adjustable setting screw and was managed by a pressure gauge arrangement.

Table 1 Engine specifications

Description	**Specification**
Make	KirloskarAV-1
Type	4strokecycle,Water-cooled
No. of cylinder	1
Piston	552.64cc
Bore size	80 mm
Stroke	110 mm
Compression ratio	17.5:1
Power	3.7 kW
Rpm	1500
Cylinder pressure	0-320bar

Figure 5 Diesel Engine Specification

IV. RESULTS AND DISCUSSION

A. EXTRACTIONAND CHARACTERIZATIONOFOIL

The oil that was extracted with the mechanical expeller had a pleasant smell and a light orange tint. With regard to seed weight, the obtained bio-oil yield is 46.2±2 wt%. It was discovered that the extracted oil yield was lower than that reported by Ahuja et al. (1989) and Mundal et al. (2002), but equivalent to that reported by Domingos et al. (2008). Plants often experience these variances in oil output because of changes in the climate and geographic area in which they are cultivated (Sanli&Karadogan 2017). In comparison to traditional oil crops such as cottonseed, soybean, neem, jatropha, sunflower, and Moringaoleifera, the oil output was quite high (Atabani et al. 2012). The extracted bio-oil's physicochemical properties are compiled in Table 2.

Table 2 Physico-chemical properties of R. sativus bio-oil

Properties	**Values**
Density	922kgm-3
Viscosity at 40°C	36.32mm2 s-1
Water content	0.12wt%
Acid value	2.91mg KOHg-1
Saponification value	202mg KOH g-1
Iodine value	161.9 g I100g-1
Unsaponifiables	0.92wt%

The fatty acid content of Raphanussativus oil as determined by gas chromatography is shown in Figure 6. Depending on the level of unsaturation, this profile gives an oblique indication of the cetane number and oxidation stability of the biodiesel made from this bio-oil. In comparison to saturated fatty acids (18.86 wt%), the statistics show that the bio-oil has a larger proportion of unsaturated fatty acids (80.85 wt%). The fatty acid composition of the oil, which has an average molecular weight of 937.12 g/mol, indicates that biodiesel produced from this feedstock will have better cold flow characteristics and less viscosity (Knothe, 2009).

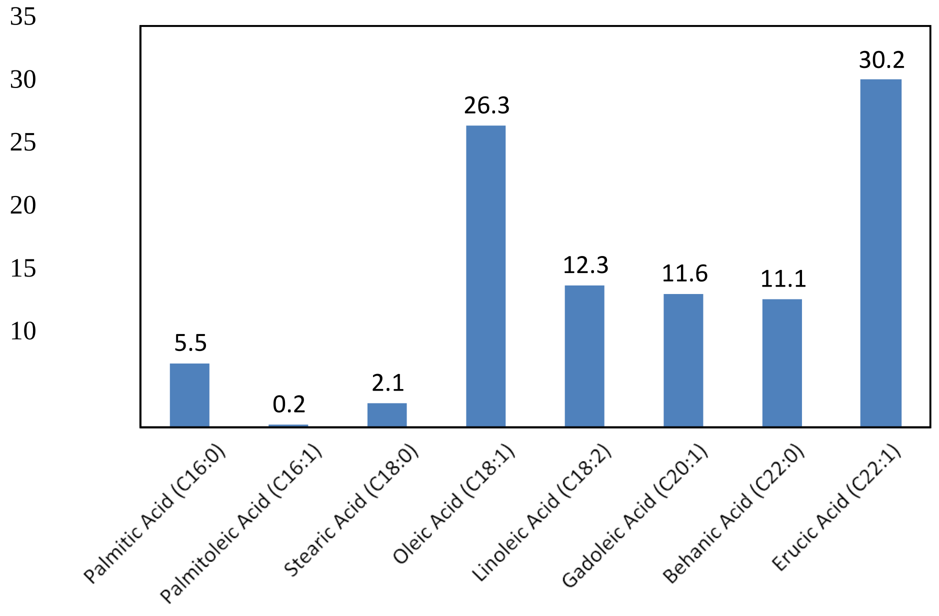

Figure 6 Fatty acid profile of R. sativus bio-oil

B. TAGUCHI OPTIMIZATION FOR BIODIESEL PRODUCTION

Setting various parameters in the Taguchi optimisation process to get optimum values without doing a sufficient number of tests is challenging. In order to identify the optimised parameters shown in Table 3, three tiers of process parameters were chosen.For every experiment, the S/N ratio of process performance was computed using the L9 orthogonal array, as shown in Table 4. Every experiment's S/N ratio was calculated and tallied, as shown in Table 5.

The optimal value for each process parameter and its primary impacts were determined by plotting graphs from the acquired findings, as shown in Figure 7.

Table 3 Levels of parameters

Parameters	Levels		
	1	2	3
M/O ratio	3:1	6:1	9:1
Catalyst(wt%)	0.5	1	1.5
Process temperature(°C)	40	50	60
Process time (min)	20	30	40

Table 4 L9 Orthogonal array for Taguchi optimization technique

Levels	M /O Ratio	Catalyst	Process Temperature	Process Time
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 5 S/N ratio values

Exp. No	Yield wt%	S/N ratio
1	70.95	37.02
2	87.25	38.812
3	61.35	35.756
4	75.79	37.592
5	89.95	39.08
6	87.32	38.82
7	91.83	39.26
8	94.58	39.52
9	91.02	39.18

C. ANOVAFORBIODIESEL PRODUCTION

It is important to confirm the inferences made from the half-normal plots and the related diagnostics of residual error by using ANOVA in order to minimise false findings. This has produced the results that are shown in Table 6 (Anderson & Whitcomb 2015). According to Armstrong et al. (2002), the primary drawback is the challenge of experimenting with several levels that reduce accuracy. Consequently, the four primary parameters impacting the biodiesel output are taken into consideration for the in-depth assessment while the minor ones are ignored.The measured F value suggests that the yield of biodiesel is more significantly influenced by the M/O ratio. The optimal process parameters for highest yield, however, were an M/O ratio of 9:1, catalyst of 1 weight percent, process temperature of 50 °C, and process duration of 30 minutes, as shown by the interpretation of the major effects plot. At this optimal condition, the greatest production of biodiesel was 94.58 weight percent. This yield is somewhat lower than the yields reported in the literature for other oils (Deepalakshmi et al. 2015; Chandrasekaran Muthukumaran et al. 2017; Sivakumar et al. 2013).

This is because, with an acid value of less than 2 mg KOH g-1, the base-catalyzed transesterification process makes the most sense. Our analysis revealed that the acid value of R. sativus seed oil was 0.847 mg KOH g-1. Compared to the two-step method, there will be a reduction in the total cost of manufacturing. Taking this into account, the investigation is carried out in a single-stage alkali-catalyzed process.

Table 6 Percentage contribution of each factor on maximum yield of biodiesel

Factors	**SS**	**DF**	**Mean Square Variance**	**F**	**Percentage**	**Rank**
Methanol to oil molar ratio	6.87	2	3.435	3.4077	53.12	1
Catalyst concentration	2.87	2	1.437	1.425	22.22	2
Reaction temperature	0.42	2	0.210	0.208	3.24	4
Reaction time	2.76	2	1.380	1.369	21.34	3
Error	6.05	6	1.008			

D. CHARACTERIZATIONOFBIODIESEL

Together with the characteristics of commercial Type 2 diesel fuel, the attributes of the biodiesel that was generated were assessed using ASTM procedures and are shown in Table 7. The most significant fuel characteristic is viscosity, which decreased to 4.95 mm2 s-1 (biodiesel) from 36.32 mm2 s-1 (bio-oil).When biodiesel is fed into the combustion chamber, this promotes full fuel atomization. Biodiesel's cetane value 51 indicates that it ignites more readily than diesel fuel. With a flash point of 97 °C, the biodiesel that is generated is safer to handle, store, and transport than diesel fuel, which reduces the danger of fire.The R. sativus biodiesel's fuel properties fell within the ASTM D6751 standard's bounds. This suggests that, with few or no changes, it may be used as a fuel source for internal combustion engines.

Table 7 Physicochemical properties for R.sativus bio diesel and Type2 Diesel

Properties	**ASTM Test Method**	**ASTM D6751 Standard**	***R. sativus* Biodiesel**	**Type 2Diesel**
Viscosity @ 40 ºC(mm^2 s^{-1})	ASTM D445	1.9-6.0	4.85	2.85
Specific gravity	ASTM D4052	Report	0.848	0.832
Flash point(ºC)	ASTM D93	93.0minimum	97	60
Cloud point(ºC)	ASTM D2500	Report	5	-15
Sulphated Ash (%mass)	ASTM D874	0.02maximum	0.01	0.01
Cetane number	ASTM D613	47 minimum	51	49
Water and sediments (%volume)	ASTM D2709	0.05maximum	0.03	0.02
Copper strip corrosion	ASTM D130	Number 3maximum	1a	1

E. ENGINE PERFORMANCE AND EMISSION ANALYSIS OFRME BIODIESEL

Investigations were conducted on the engine's performance, including BTE, BSFC, and EGT, under different load circumstances and RME mixes.

1) BTE, or brake thermal efficiency

The effect of oxygen-rich biodiesel blends on BTE under various load scenarios is shown in Figure 7. The graph shows that the mix of 20% RME (RME20) with neat diesel produces a higher BTE than the fuel produced neat. This might be connected to the higher oxygen content in mixes of biodiesel. According to this perspective, the engine's BTE is produced by the efficient conversion of fuel into heat, and RME20 verifies that diesel fuel can be burned effectively under intermittent load conditions. The fuel mixture's rapid burning and internal heat escalation are the main causes of the variation in BTE between partial and full loads. Additionally, it is noted that since low load situations have a larger air-fuel ratio than full load conditions, there is less of a difference in BTE for biodiesel mixes and diesel fuel.

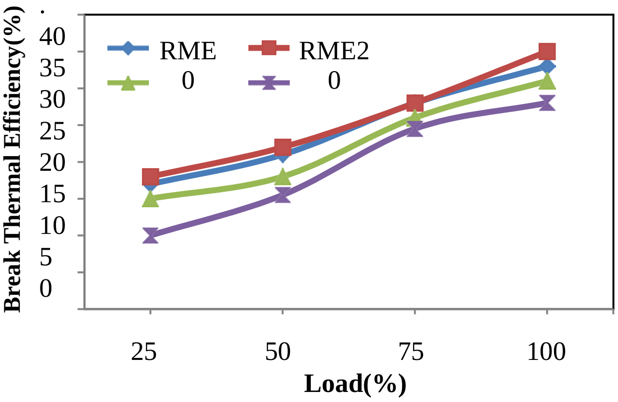

Figure 7 Brake Thermal Efficiency in %vs Load in%

2) Brake Specific Fuel Consumption (BSFC)

The BSFC of mixes of RME biodiesel and plain diesel fuel is shown in Figure 8 with respect to load fluctuations. It is found that BSFC exhibits an inverse connection with rising load and an incremental trend with biodiesel content. The RME100 consumes more fuel than diesel fuel because of the characteristics of the fuel, such as its greater density, lower heat capacity, and higher viscosity of biodiesel. At full load, the RME20 fuel combination yields a value of BSFC that is closer to neat diesel due to the complete combustion and greater cetane value of the biodiesel.

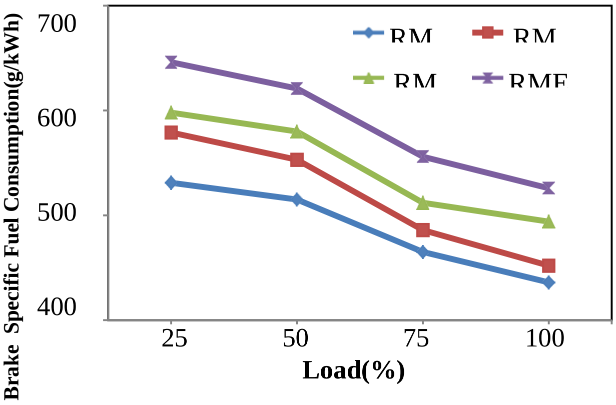

Figure 8 BSFC(g/Kw hr)vs Load(%)

3) Exhaust Gas temperature (EGT)

Figure 9 illustrates the linear connection between the engine EGT and the engine load % for RME mixes. It suggests that in order to meet the energy requirement at a greater load percentage, a larger fuel proportion is required. The more biodiesel incorporated into the fuel mixture, the higher the EGT is due to the fuel's natural oxygen content. The graphic illustrates the link between BTE and EGT and demonstrates how increasing the biodiesel mix results in full combustion and significant heat losses.

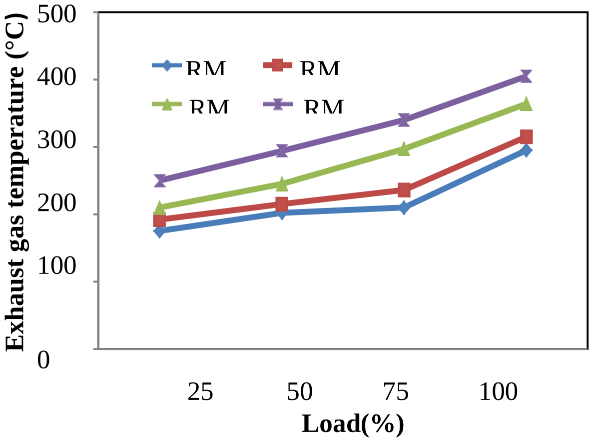

Figure 9 EGT(°C) vs Load(%)

4) CO emission

The quantity of carbon dioxide (CO) released into the exhaust may be used as an indicator of how well a fuel combination in a combustion chamber has burned through. The CO emission rate for different fuel mixes is shown in Figure 10. Compared to clean diesel fuel, RME100 emits much less carbon dioxide since it burns completely thanks to the extra oxygen it contains. It has also been noted that more oxygen starts the oxidation process in biodiesel, which converts CO to CO2. Further increases in engine load result in higher CO emissions from burning more gasoline and producing more smoke.

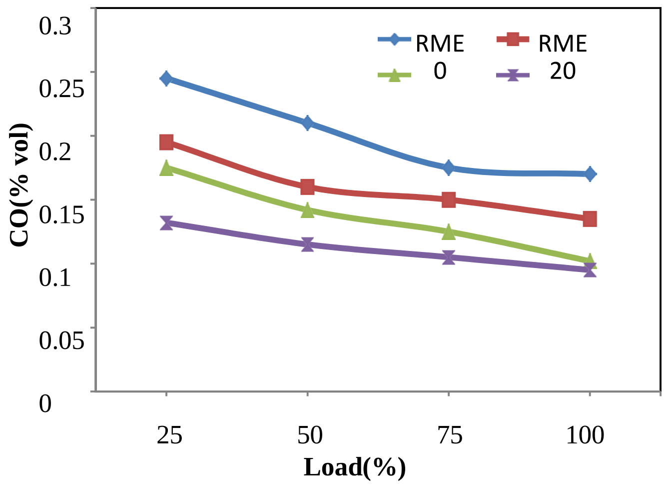

Figure 10 Carbon Monoxidein % vs Load in%

5) HC emission

The quantity of hydrocarbon (HC) emissions from the engine is directly influenced by the combustion temperature in the engine cylinder. The fuel mixer's flame propagation speed is closely correlated with the combustion and temperature rate of combustion. Considering that it affects the pace of combustion and raises the amount of unburned gases. Hydrocarbons are produced when the exhaust gas and the unburned residue in the combustion chamber combine. The HC emission rate for biodiesel blends under different load circumstances is shown in Figure 11. Enhancing the rate at which biodiesel is blended with clean diesel gradually lowers the hydrocarbon emissions. The engine cylinder's increased combustion temperature and full combustion may be the cause of this. According to the graph, the HC values of biodiesel blends B20, B40, and B100 are lower than those of plain diesel (B0).

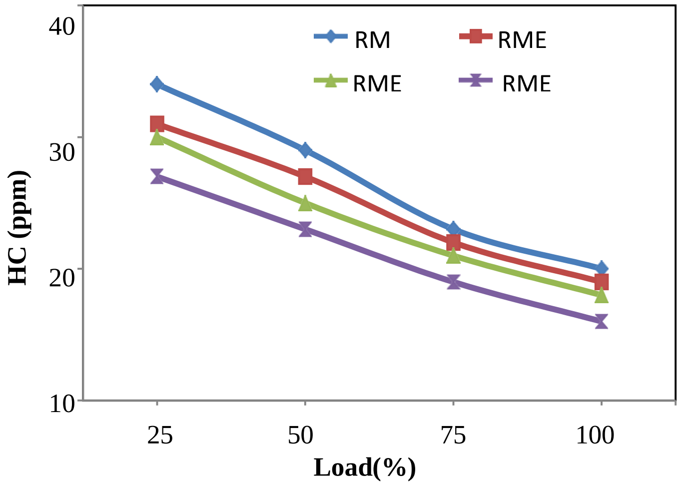

Figure 11 Hydrocarbon in ppm vs Load in%

6) NOx emission

When hydrocarbons, oxygen, and nitrogen combine in hotter, oxygen-rich environments, nitrogen oxides are created. Engine NOx emissions are influenced by the temperature, pressure, time, and oxygen content of the fuel during combustion. The variation in nitrogen oxide emissions with engine load for different fuel mixes is shown in Figure 12. As engine load rises, the biodiesel blend's NOx emissions rise. Given that biodiesel blends are oxygen-rich fuels, a comparison of pure diesel and biodiesel blends shows that all tested RME blends had significant NOx emissions. We might draw the conclusion that diesel emits more NOx than RME20 mix.

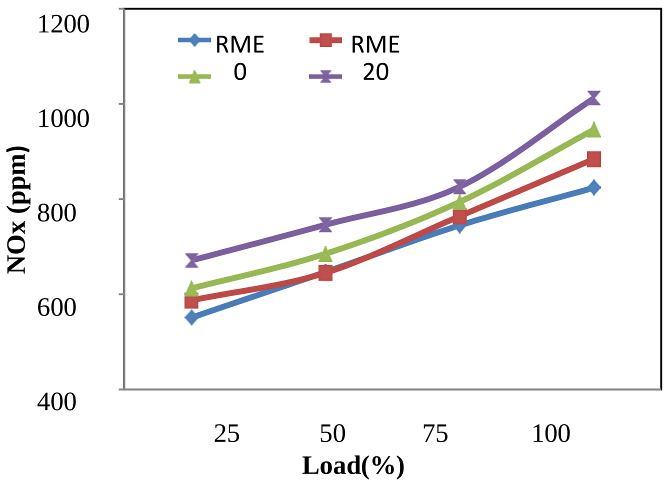

Figure 12 Nitrogen Oxides in ppm vs Load in%

V. CONCLUSION

A. CONCLUSION

The following findings were drawn from this work:

1. The best process parameters for increasing yield include a 9:1 M/O ratio, 1% catalyst, 50 °C process temperature, and a 30-minute process duration.
2. The effects of R. sativus biodiesel blends, including RME0, RME20, RME40, and RME100, on engine performance and emission parameters were tested. This led to the discovery that RME20 produces superior outcomes than the RME0 mix.
3. An increase in BTE at 60 ppm nano-Al2O3, B20, 27 °BTDC injection timing, and 220 bar injection pressure was required due to the biodiesel blend's high rate of heat release. On the other hand, BSFC marginally rose when the blending ratio was raised despite the lower calorific value.

B. SCOPE FOR FUTURE WORK

Further study is necessary to enhance the performance of a biodiesel-powered DI diesel engine, even though major work on the performance, emission, and combustion characteristics of biodiesel fuel has been successful and described in this examination. The following extensions should get special attention in future development.

1. More research is required to determine how to optimise process parameters using innovative optimisation techniques.
2. To create biodiesel, utilise feedstock from the following generation.
3. Analyse the relative cost-effectiveness of the different manufacturing methods.
4. To use several techniques to offset the NOx emission
5. To find more advantageous ways to use mixes of biodiesel than B20
6. Various nano-additives will be used to explore the features of diesel engines.
7. Examine the best engine configuration for running biodiesel using various injector types and combustion geometry.

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