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Experimental Investigation on Engine Performance Fuelled with Biodiesel-Diesel Blended and Parametric Optimization of Engine Performance Using Taguchi Method

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Abstract

The fuel properties and engine performance of blended Calophyllum biodiesel (CB) and Macadamia biodiesel (MB) blended with diesel at various percentages such as 10%, 20%, 30%, 40%, and 50% were investigated in this study. The engine was tested at a constant speed of 1500 rpm. According to ASTM standards, the properties of B20 blended (CB10%+MB10%+80% Diesel) fuel were superior to other tested blends. The engine test results show that when compared to base diesel fuel, B20 blend resulted in 3.92%,4.68% with stronger performance characteristics of brake thermal efficiency, brake specific energy consumption, and a higher emission reduction of 4.63% of HC, 15.62% of CO, 5.8% of smoke, in spite of a small penalty of 4.86% of carbon dioxide and 3.9% of oxides of nitrogen emission at full load condition. Normality analysis was used to check the distribution of the response data, and regression analysis was used to derive the mathematical model for the selected engine parameters (BSFC, BTE, NOx, and Smoke). The desirability approach of the taguchi method was employed to optimize independent variables to minimize emissions and maximize performance parameters.

Keywords: *Calophyllum biodiesel (CB) and Macadamia biodiesel (MB)*

1. Introduction:

The steady and sustained growth of the Indian economy influences and increases the demand for energy resources, energy systems and infrastructure. Over the years, the energy demand continuously increased in every sector including the agricultural, industrial, commercial and residential sectors. Considering all these, the Government of India visions to increase the usage of alternative fuels in the transport sector. This will eventually decrease the dependence on oil imports and reduce carbon emissions. The new bio-fuel policy of India is designed to achieve a national average of 20% ethanol blending with gasoline and 5% blending of biodiesel with diesel by 2030 [1].The impact of Mustard oil biodiesel on different attributes, including combustion, performance, and emissions in diesel engines, was investigated. An elaborated experimental study was taken for M10, M20 and M30 blends at different loads [2]. Results showed that the Indicated Thermal efficiency decreased for M10 blends and NOX emission increased with the increase in the fraction of biodiesel in the fuel blends.The experimental study on combustion and emission characteristics of Castor Oil Methyl Ester (COME) in diesel engines. The variation of surface tension and viscosity with temperature were experimentally determined. From the experimental analysis, they reported a much stronger variation in the viscosity with temperature when compared to diesel. The results also showed that the surface tension of COME blends varied linearly with temperature. The usage of fish oil ethyl ester in various proportions from B20 to B100 in the increment of 20% and showed a slight decrease in brake thermal efficiency for the B20 blend. They reported that the rate of pressure rise was lower for fish oil ethyl ester (FOEE) blends due to the earlier onset of ignition. They mentioned that the NOx emission decreased by 5.2% for the B100 blend due to the highly viscous nature of FOEE and also reported that the smoke emission increased for all the FOEE blends due to their poor volatility characteristics [3].The experimental study focused on the utilization of ethanol waste milk scum oil methyl ester blends in a diesel engine. The researchers investigated the effects of blending biodiesel and ethanol with diesel fuel on various engine parameters, including the start of injection, ignition delay period, performance, and emission characteristics. The researchers also observed that blending 5% biodiesel with 15% ethanol in diesel fuel resulted in a brake thermal efficiency of 36.2%, which was comparable to that of conventional diesel fuel. This indicates that the blended fuel mixture exhibited promising performance characteristics [4].The synthesized isobutanol using corn starch and used 40% by vol. Isobutanol with diesel. They carried out statistical and experimental studies to evaluate the impact of different operating parameters such as injection pressure, timing and EGR on a CI engine using isobutanol diesel blends. The ANOVA results indicated that all the arrived regression models for CO_2, smoke opacity, BTE and BSFC were statistically significant under 99% confidence level [5].Limited studies conducted the performance of Calophyllum inophyllum biodiesel diesel blends in a diesel engine at different compression ratios. By using design expert software, they analyzed statistically a designed set of experiments using the RSM design of experiments technique. They reported that the Oleic acid content in the Calophyllum inophyllum biodiesel promoted oxidation resistance. They mentioned that better performance can be achieved up to compression ratio 19 and also found that the optimum performance was obtained for B30 fuel blends at compression ratio 19 for the developed statistical model which was tested and validated [6].

The Taguchi design method is widely recognized for its effectiveness in solving optimization problems and improving processing performance while reducing the number of experiments and overall cost. By employing Taguchi methods, researchers can significantly decrease the number of required experiments, saving both time and resources [7].The Taguchi approach offers valuable support in developing high-quality processes and products from multiple perspectives. It minimizes sensitivity to variations in process or manufacturing conditions and uncontrollable factors, enabling the provision of necessary tolerances at the lowest cost. The Taguchi loss function provides a unique understanding of the quality process, allowing for effective optimization. The Taguchi optimization method has been successfully applied in numerous experimental design studies. Researchers have utilized this method to modify various parameters such as compression ratio, injection timing, blend ratio, injection pressure, and exhaust gas recirculation. The aim of these modifications is to enhance engine performance and reduce emissions [8].Furthermore , authors focused on , to enhance the engine performance researches focused on biodiesel blend with nanoadditives, this could be improve the fuel property with catalytic reaction of nanoparticle [9-13].The researchers looked into the performance of an IC engine that was running on plastic pyrolysis oil combined with a magnesium oxide(MgO2) nano additive. Their research discovered that adding 75 ppm magnesium oxide nano additive to plastic pyrolysis oil increased the BTE by 2.5% and curtailed the engine emissions [14].

Apart from this, few authors investigated the engine performance by providing Thermal barrier coatings [15,16] and piston bowl modifications fuelled with various biodiesel blends and revealed that there is enhancement in BTE and curtailed the emission magnitudes.[17]. The adaptable single-cylinder engine was extensively studied to determine the impact of injection pressure (IP) and injection timing (IT) on performance, and emission when running on diesel fuel. Several studies indicate that delaying injection timing diminishes NOx pollutant [18,19].The researchers conducted the experiment and applied the optimization of the influence of of Low Heat Rejection Diesel Engine (LHR) by means of Biodiesel through Taguchi Method. To predict suitable factor proportions with regard to performance and emission characteristics, the Taguchi method was applied [20]. The authors optimized operational variables on engine performance and emissions of a diesel engine driven by Mimusops Elangi biodiesel with Doped TiO2 Nanoparticle and Varying Injection Pressure. The attractiveness processes of Taguchy and response surface methodology were used to optimize parameters for superior efficiency and reduced emissions. At full load, MEB20 @ 25ppm TiO2 nanoparticle fuel blend and a 220 bar injection pressure [21].

Another research has focused on control of NOx emission by addition of various antioxidants. The researchers focused on improvement in fuel properties using some cetane improvers on engine charactarisics fuelled with diesel and biodiesel blends. When compared to DnBH and DPnH microemulsions, the inclusion of EHN cetane improver significantly reduced BSFC and NOx pollutants while increasing CO pollutants , however exhibited a contrary impact o n HC pollutants [22]. In a diesel engine, quantitative assessments of diesel-waste oil biodiesel and propanol, n-butanol, or 1-pentanol blends were performed by the researchers [23] .Their results reveals that all stronger alcohol mixtures decreased NOx pollutants, with 1-pentanol, n-butanol, and propanol being the strongest and most ineffective alcohols, respectively. Nevertheless, the incorporation of the alcohols to the mixes enhanced CO pollutants [24,25].

In this study,mainly focused on extracting biodiesel from nonedible Calophyllum inophyllum oil and Macadamia to be used in an internal combustion (IC) engine. The extraction process was optimized under specific conditions, and the resulting biodiesel was tested in a single-cylinder compression ignition engine.To enhance the performance of the engine, a robust statistical optimization tool known as design of experiment (DOE) was utilized. The DOE helped determine the ideal blend of biodiesel and diesel fuel for achieving improved engine performance. In addition to performance parameters, the study also considered the impact on emissions. Emission parameters such as carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx) were measured to ensure compliance with pollution limits during the testing conditions.By employing the DOE methodology and analyzing the performance and emission parameters, the researchers aimed to optimize the use of nonedible Calophylluminophyllum oil and Macadamia-based biodiesel in the IC engine, achieving better engine performance while minimizing environmental impacts.

2. Materials and Methods

2.1 Selection of Biodiesel

Researchers are eagerly searching for viable alternative to substitute the existing fossil fuels which is the major energy supply for the industrial requirements. A lot of effort is currently being spent towards the study of combustion on substitute fuel, henceforth to become the most promising substitute for diesel fuel in the field of transportation. It is still challenging to predict the combustion characteristics of this fuel such as great variance in their composition and no experimental data of reactions which are involved in the available literature, which makes the task more difficult [26].

2.2 Callophyllum Inophyllum Oil

Calophyllum inophyllum, sometimes known as polanga, is a non-edible oilseed decorative evergreen tree that belongs to the clusiaceae family. Kamani, Alexandrian laurel, honne, tamanu, pinnai, and other names have been given to it in different parts of the world. They usually grow best in deep soil or on open sea beaches, and they need from 750 to 5000 mm of rain every year to thrive. India, Eastern Africa, Southeast Asia, and Australia are among places where this plant has been found. The tree produces 100 to 200 fruits every year, with an oil yield of 2000 kg per hectare. Oil with a high percentage of 65 to 75% is produced from the seed, which is coloured green and thick, with a woodsy or nutty aroma [27].

2.3 Macadamia Integrifolia Oil

The macadamia nut tree, scientifically known as Macadamia integrifolia, is a large, spreading evergreen tree that can grow to a height of 30-50 feet. Its natural habitat is the rainforests of southeastern Queensland, Australia [28]. The macadamia nut has a long history of being used as a food source by Aboriginal people in Australia, well before the arrival of Europeans. In 1837, this tree was introduced to Hawaii for the first time. The macadamia nut tree (Macadamia integrifolia) features glossy leaves that are oblong-lanceolate to oblong-ovate in shape, measuring around 8-10 inches in length. The margins of the leaves are slightly wavy. The leaves grow in whorls of three, creating an attractive foliage arrangement. Hand nutcrackers can't crack the shells because they're too hard. Powerful husking machines are used to open commercial fruits.Step by step process of transesterification process shown in Fig.1.

2.4 Calophyllum Inophyllum and Macadamia transesterification process [29]:

A 100 mL of Calophyllum oil was measured and poured into a 250 ml conical flask and heated to a temperature of 50°C.A quantity of Ethanol was poured into a round bottom flask and the heater was turned on. It was done to purify Ethanol. (30ml).The sodium hydroxide pellet was placed in the weighting balance to get exactly 0.25g. The mixture of ethanol and NaOH catalyst is added by using a pipette into a solution of Calophyllum oil.

After adding the solution, it should be magnetic stirred at room temperature and the maximum time is half-hour. After that the tested fuel was taken into ultrasonicator for better mixing for maximum of 45minutes. The combination was then given a 24-hour period in a separating funnel to settle.

The lower layer, which is made up of glycerol and soap, was then collected from the bottom of the separating funnel, and the biodiesel was then put into a separate beaker.

The biodiesel was then washed with warm water to get rid of any leftover glycerol and soap in the funnel. As soon as pure water could be seen beneath the biodiesel in the separating funnel, it was finished. The excess water still present in the biodiesel was removed, and the cleaned sample was dried by setting it on a hot plate.The amount of biodiesel that was gathered was measured and noted.The same procedure is repeated for Macadamia oil.

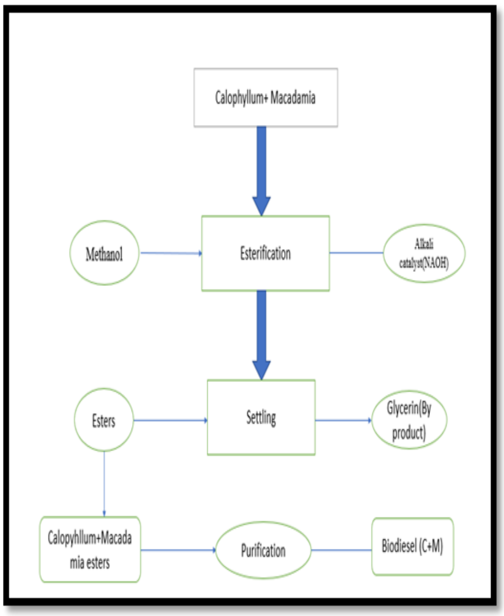

Fig 1. Transesterification Process of Biodiesel

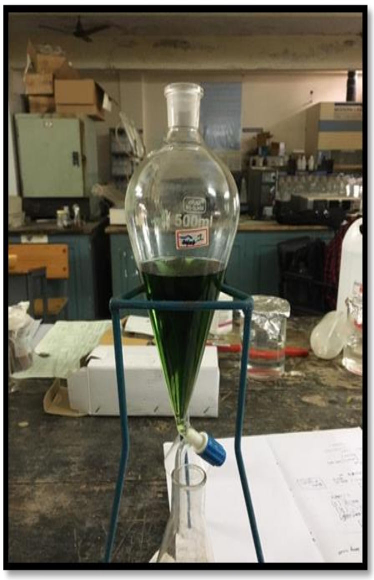

Fig. 2. Biodiesel in Separatory Funnel

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2.5blending Process

Blending refers to the process of combining different components, such as gasoline, gasoline blend stocks, and other chemical additives, through physical and chemical operations to create a final gasoline or gasoline blend stock. This process involves carefully selecting and mixing the components in order to achieve desired fuel properties, performance, and regulatory requirements. Blending is commonly used in the petroleum industry to produce gasoline blends with specific octane ratings, volatility characteristics, and other desired properties. Blending can be done by weight basis or volume basis [30].Fig.2 show the biodiesel is in separate funnel.

Table 1 shows the properties of biodiesels. In this project blending is done by volume basis. The blending process is done by using magnetic stirrer. In a jar of 1000ml, the concentrations of the blends are as follows:

S.No	Blend			Composition	Description
1	B10			10% Biodiesel and 90%Diesel	5%Calophyllum biodiesel& 5%Macadamia biodiesel
2	B20			20% Biodiesel and 80%Diesel	10%Calophyllum biodiesel&10%Macadamia biodiesel
3	B30			30% Biodiesel and 70%Diesel	15%Calophyllum biodiesel&15%Macadamia biodiesel
4	B40			40% Biodiesel and 60%Diesel	20%Calophyllum biodiesel&20%Macadamia biodiesel
5	B50			50% Biodiesel and 50%Diesel	25%Calophyllum biodiesel&25%Macadamia biodiesel

Table 1. Properties of Diesel and Biodiesel blends used in the Experiment [31]

Properties	Diesel	B10	B20	B30	B40	B50
Calorific Valve (kJ/kg)	42500	42050	41605	40190	40105	39685
Kinematic Viscosity at 40°C	2.54	2.85	3.28	5.0	5.8	6.0
Density(kg/m^3)	832	841	859	862	877	882

2.6 Experimental Procedure:

Table 2 gives specifications of test engine. Before starting the engine, the piston must be replaced with the modified piston then before connecting the system, engine and fuel tank must be drained and refilled with pure diesel fuel. The engine must then be run without load for 20 minutes to warm up. The engine's speed was increased while the load remained constant until the engine became stable, as determined by the exhaust temperature. The engine speed was set to 1500rpm, and the engine was run at that speed and loaded for two minutes. The data needed for the analysis was collected using an electronic acquisition system connected to the test engine and loaded with an electrical dynamometer at various load values. The engine is started with no load and allowed to run for at least 10 minutes to stabilize it.Readings such as time taken for 10cc fuel consumption, ammeter, and voltmeter readings, and so on were taken according to the observation table. Fig.3 & 4 displays the schematic and photographic view of test engine.

Table 2 Specification of the Engine [32]

Type	**Specifications**
Make	Kirloskar
Engine Type	4-Stroke Diesel Engine
No. of Cylinders	Single
Ignition System	Compression Ignition
Cooling Method	Water Cooling
Rated power	5.2 kW
Rated Speed	1500rpm
Bore Diameter (D)	87.5 mm
Stroke (L)	110mm
Compression ratio	17.5:1
Fuel	Diesel
C.V of Diesel	42,000 kJ/kg
Density of Diesel	830 kg/m3

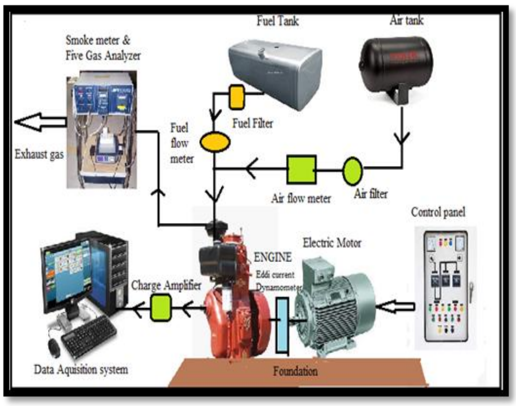

Fig.3 schematic diagram of engine set up

Fig.4 Photographic view of engine set-up

2.7 Statistical method

The Taguchi method uses several formulas and statistical techniques to analyze experimental data and determine optimal factor settings. Here are a few key formulas commonly used in the Taguchi method. Table 3 displays design parameters of taguchi method [33].

Signal-to-Noise (S/N) Ratio: The S/N ratio is a metric used to evaluate the quality characteristics of a system. It quantifies the relationship between the mean response and the variability of the response. The formula for the S/N ratio depends on the type of characteristic being analyzed. There are three common types of S/N ratios:

a. Smaller-the-Better (Minimize) S/N Ratio:

S/N = -10 * log10((1/n) * Σ(y_i^2)), where y_i is the response for the i^{th} experiment and n is the number of experiments. The goal is to minimize this ratio.

b. Larger-the-Better (Maximize) S/N Ratio:

S/N = 10 * log10((1/n) * Σ(y_i^2)), where y_i is the response for the i^{th} experiment and n is the number of experiments. The goal is to maximize this ratio.

c. Nominal-the-Best (Target) S/N Ratio:

S/N = -10 * log10((1/n) * Σ((y_i - T)^2)), where y_i is the response for the i^{th} experiment, T is the target value, and n is the number of experiments. The goal is to minimize this ratio

Table 3 Design parameters

Factors	**Levels**				
	1	**2**	**3**	**4**	**5**
Fuel	B10	B20	B30	B40	B50
Load	0	25	50	75	100

3. Results and Discussions:

3.1 Brake Thermal Efficiency

Figure 5 illustrates the relationship between brake power and brake thermal efficiency (BTE) for different percentages and loads of Calophyllum Inophyllum and Macadamia blends. The percentages of the blends include 10%, 20%, 30%, 40%, and 50%.It is observed that BTE increases as the load increases, aiming to reduce heat loss. With the increase in load, the suction pressure developed also rises, resulting in more efficient combustion. Among the different blends, B10 is nearly equal to Diesel at full load, while B30 to B50 show lower BTE values. The graph suggests that B20 is a suitable blend considering all considerations [34].At low loads, the lower BTE values are attributed to the combined effect of higher viscosity, higher density, and lower calorific value of the Calophyllum Inophyllum and Macadamia (C+M) biodiesel blends. These factors affect the combustion efficiency and result in reduced BTE at lower loads.

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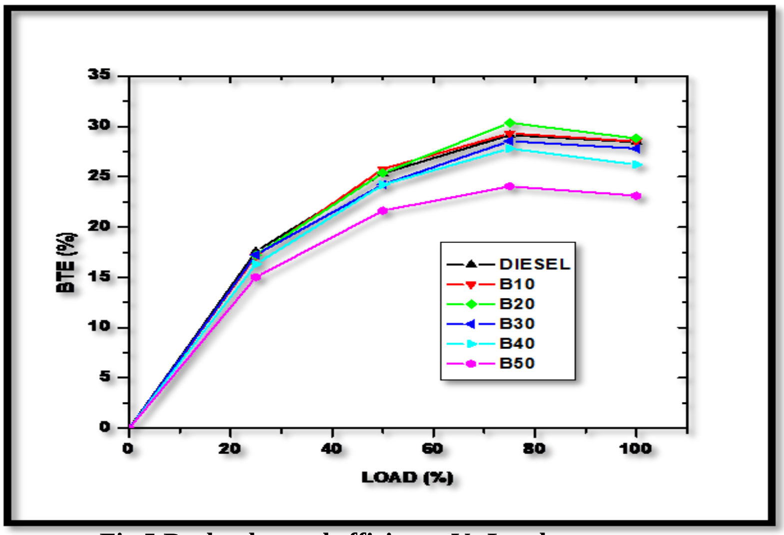

Fig.5 Brake thermal efficiency Vs Load

3.3 Brake Specific Fuel Consumption

Figure 6 shows the relationship between B.P and BSFC for blends of Calophyllum Inophyllum and Macadamia with diesel fuel. BSFC represents the ratio of mass fuel consumption to brake power, and when BSFC increases, brake thermal efficiency (BTE) decreases as they are inversely proportional [35].In the case of Diesel and B10 and B20 blends, they exhibit the same specific fuel consumption at full load as that of Diesel fuel. However, the BSFC of B40 and B50 blends is higher, at 11.37% and 12.37% respectively, compared to base fuel. This is due to the lower calorific value of Calophyllum Inophyllum and Macadamia blends compared to Diesel. As a result, more energy is required to produce the same power output, resulting in higher BSFC.When comparing the different biodiesel blends, it is observed that the B20 blend has a lower BSFC for several reasons. Firstly, the B20 blend consists of 80% diesel and 20% Calophyllum Inophyllum and Macadamia blends, providing higher oxygen content compared to diesel fuel. .

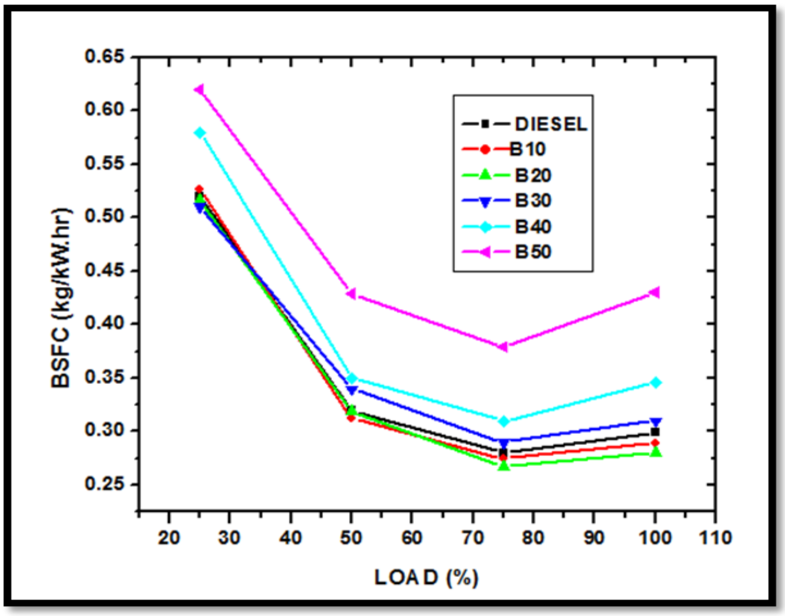

Fig.6 Brake specific fuel consumption Vs Load

3.4 Exhaust Gas Temperature

Figure 7 represents the relationship between B.P andBSFC for blends of Calophyllum Inophyllum and Macadamia with diesel fuel. The figure shows an increase in EGT for all tested fuel combinations. This increase in EGT can be attributed to the amount of fuel burned in the cylinder and the heat energy produced during combustion [11,12].

Furthermore, a noticeable trend is the increase in EGT with the rise in brake power for all blends. B20 blend stands out among the different blends with a comparatively lower EGT than the other blends. This can be attributed to the higher viscosity and poor volatility of B20, which leads to delayed combustion and an increase in EGT. The slower burning characteristics of B20 contribute to a reduction in EGT compared to the other blends.

3.5 Hydro carbon Emissions

Figure 8 illustrates the relationship between brake power and hydrocarbon (HC) emissions for blends of Calophyllum Inophyllum and Macadamia with the addition of cerium oxide as an additive. Across all load ranges, it is evident that biodiesel blends exhibit lower HC emissions compared to diesel fuels. Additionally, it was discovered that the turbulence induced by the piston geometry in biodiesel blends leads to improved combustion and a reduction in emissions.

Concerning specific biodiesel blends, the hydrocarbon emissions are higher for B50, B40, and B30 combinations, while they are lower for B20 and B10 blends. The B20 blend specifically demonstrates lower HC emissions than diesel fuel due to its higher oxygen concentration, which enhances combustion and subsequently reduces HC emissions. However, despite the higher oxygen concentration in the blends, the HC emissions are higher due to their lower calorific value and higher viscosity. This effect becomes more pronounced as the blend ratio increases, leading to higher HC emissions [36].

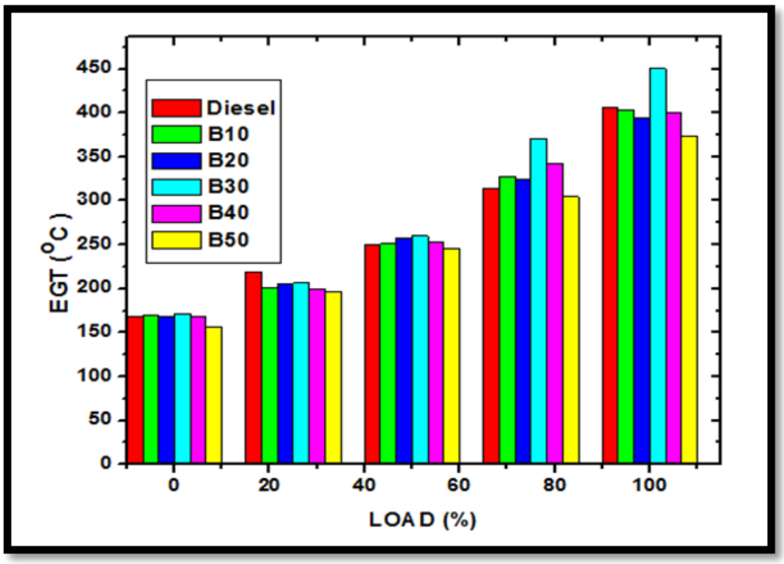

Fig.7 Exhaust gas temperature Vs Load

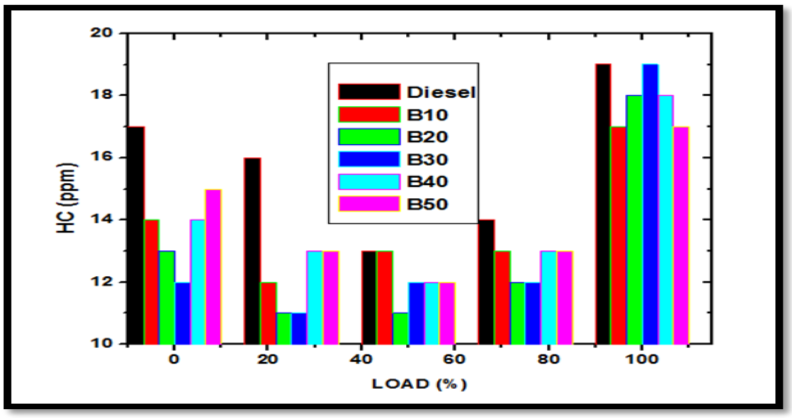

Fig.8 Hydrocarbon Vs Load

3.6 Carbon monoxide Emissions

Fig.9 depicts the brake power versus carbon monoxide of Calophyllum Inophyllum and Macadamia blends with the diesel fuel. CO is typically produced when there is insufficient oxygen to oxidize the fuel. Therefore, the cost of a diesel engine is less than that of a gasoline engine. At full load, the B50 blend released more CO than the Diesel. Low volatility polymers influenced the atomization process and the mixing of air and fuel, resulting in a rich mixture that made atomization and vaporization of Calophyllum Inophyllum and Macadamia blends difficult due to the improper spray pattern produced. Under various loads, the B30-50 mixture and the Diesel emit lower CO emissions.Diesel fuel tends to exhibit higher carbon monoxide (CO) emissions compared to other diesel blends due to the absence of oxygen in its composition. CO emissions increase as the proportion of biodiesel in the blend increases [11,12, 37].

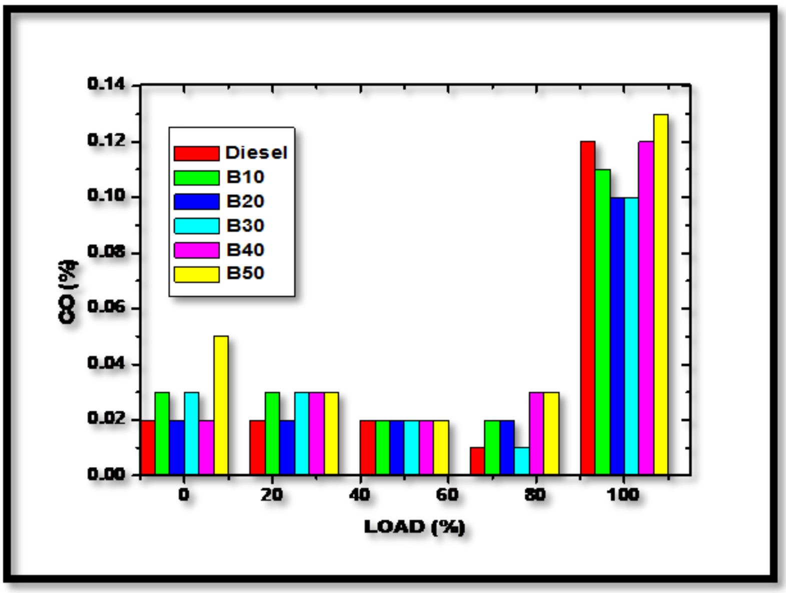

Fig.9 Carbon monoxide Vs Load

3.7 Oxides of Nitrogen

In Figure 10, the relationship between braking power and nitrogen oxide (NOx) emissions for blends of Calophyllum Inophyllums and Macadamia with diesel fuel is illustrated. The formation of NOx emissions is primarily attributed to the oxidation of nitrogen at elevated temperatures during combustion. It is observed that pure biodiesel exhibits the highest NOx emissions, while diesel fuel shows the lowest levels at all loads.The higher NOx emissions in biodiesel blends are primarily attributed to their higher oxygen content, which leads to increased combustion temperatures. Additionally, the NOx levels of all blends, including diesel, are displayed above the baseline (diesel) emission levels. At higher loads, the NOx emissions increased by 2.23%, 3.23%, 3.945%, 4.24%, and 5.21% compared to diesel fuel [11,12].

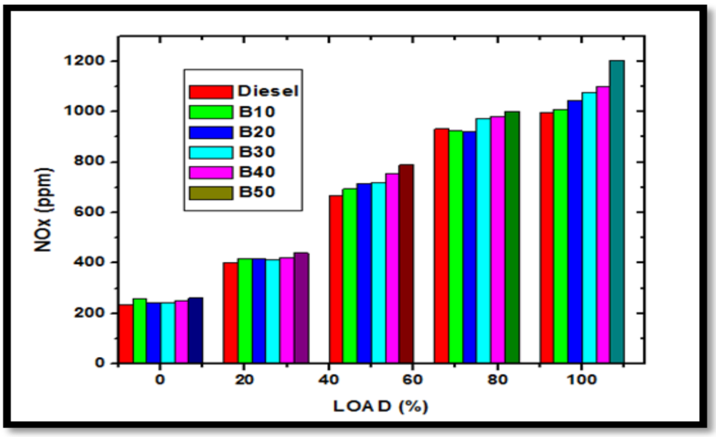

Fig.10 Oxides of Nitrogen Vs Load

3.8 Smoke Opacity

Smoke emission is an undesired byproduct of combustion in a compression-ignition (CI) engine, Arising from incomplete combustion of hydrocarbon fuel, the observed results indicate. The type of fuel and the operating conditions have an impact on the level of smoke emission.The relationship between smoke emissions and brake power is depicted in Figure 11 for various ratios of biodiesel blends and diesel, showcasing the variations. A notable observation is that as brake power increases, smoke emissions show a decreasing trend for all blends and loads. Among the different blends, B50 exhibits lower smoke emissions compared to the other blends. This can be attributed to the higher oxygen content present in biodiesel, which enhances combustion and reduces smoke emissions [11,12].

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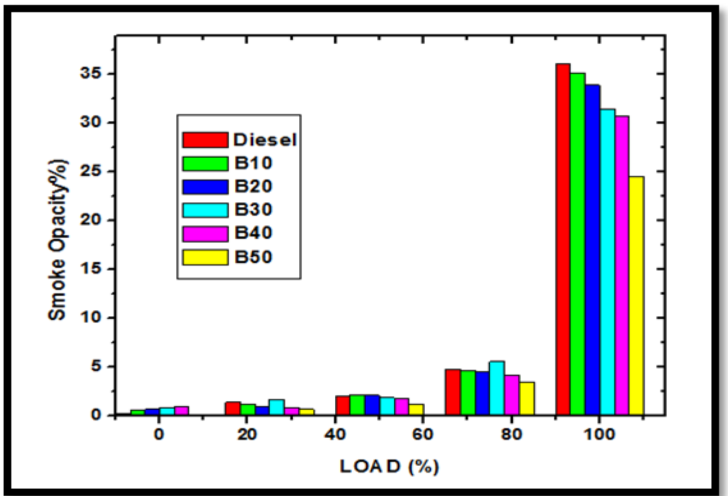

Fig.11 Smoke Opacity Vs Load

4. OPTIMUM ENGINE PERFORMANCE AND EMISSIONS

The study employed the Taguchi method, a statistical technique aimed at optimizing processes through experimentation with available resources. In this particular study, the Taguchi design methodology was implemented using Minitab 19 software. This software facilitated the application of the Taguchi method and enabled the analysis and interpretation of the experimental data.

Table 4 displays the calculated grey relational coefficient & overall GRG.

Exp No	Brake Power	BTH	BSFC	CO	HC	Nox	SMOKE	EGT	GRG	Rank
1	Diesel	0	0	0.02	17	234	0.3	168	0.4806	8
2	Diesel	17.58	0.52	0.02	16	402	1.4	219	0.4645	12
3	Diesel	25.33	0.32	0.02	13	667	2	250	0.4114	29
4	Diesel	29.14	0.28	0.01	14	932	4.8	314	0.4458	17
5	Diesel	28.44	0.299	0.12	19	998	36.1	407	0.7588	1
6	B10	0	0	0.03	14	257	0.6	170	0.4536	15
7	B10	17.1	0.526	0.03	12	417	1.2	201	0.4388	21
8	B10	25.77	0.312	0.02	13	694	2.2	251	0.4121	28
9	B10	29.31	0.275	0.02	13	923	4.71	328	0.4445	18
10	B10	28.51	0.289	0.11	17	1010	35.2	403	0.6807	5
11	B20	0	0	0.02	13	244	0.7	169	0.4433	19
12	B20	17.23	0.516	0.02	11	417	1	205	0.4284	25
13	B20	25.36	0.319	0.02	11	715	2.1	258	0.4066	30
14	B20	30.36	0.267	0.02	12	922	4.6	324	0.4360	22
15	B20	28.8	0.28	0.1	18	1046	33.9	394	0.6746	6
16	B30	0	0	0.03	12	242	0.8	171	0.4418	20
17	B30	17.25	0.51	0.03	11	415	1.7	207	0.4312	24
18	B30	24.21	0.34	0.02	12	720	1.9	260	0.4156	27
19	B30	28.531	0.29	0.01	12	973	5.6	371	0.4607	14
20	B30	27.8	0.31	0.11	19	1076	31.5	451	0.7554	2
21	B40	0	0	0.02	14	249	1	168	0.4499	16
22	B40	16.3	0.58	0.03	13	423	0.8	200	0.4624	13
23	B40	24.2	0.35	0.02	12	755	1.8	253	0.4182	26
24	B40	27.8	0.31	0.03	13	981	4.2	342	0.4647	11
25	B40	26.2	0.346	0.12	18	1100	30.7	401	0.7196	3
26	B50	0	0	0.05	15	262	0.2	157	0.4686	10
27	B50	15.02	0.62	0.03	13	440	0.7	197	0.4819	7

28	B50	21.62	0.429	0.02	12	790	1.2	246	0.4353	23
29	B50	24.048	0.3791	0.03	13	1001	3.5	305	0.4702	9
30	B50	23.11	0.43	0.12	17	1203	24.5	373	0.7063	4

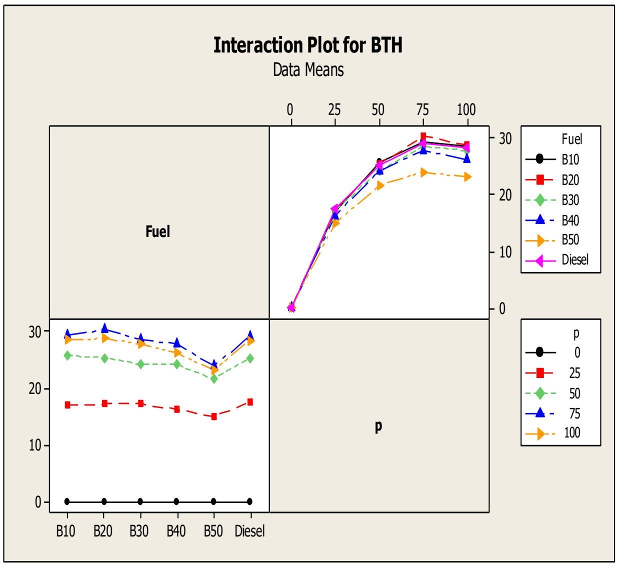

Fig.12. Taguchi graph for BTE(%)

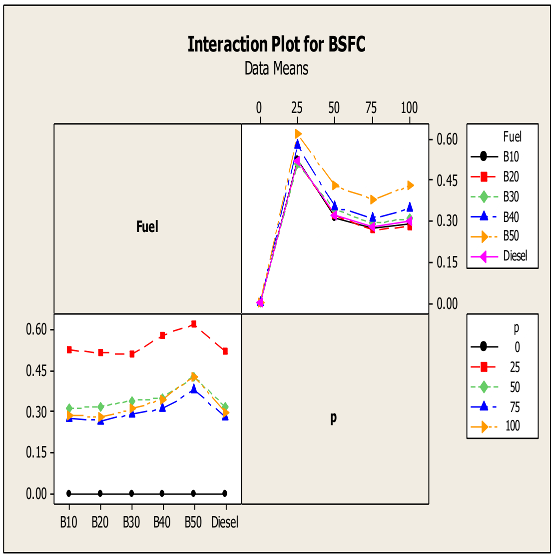

Fig.13. Taguchi graph for BSFC

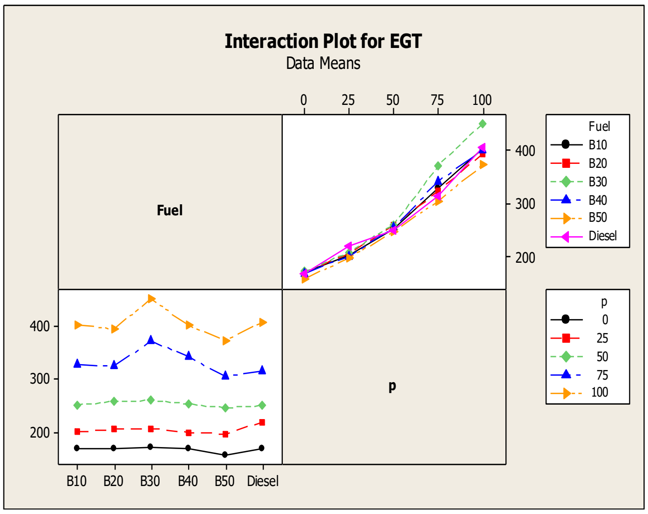

Fig.14 Taguchi graph for EGT

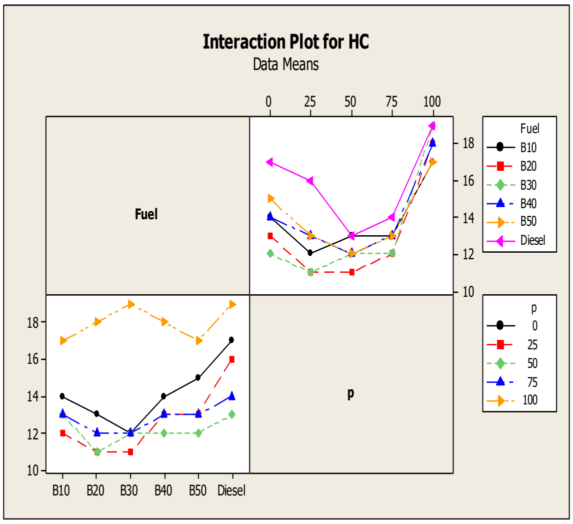

Fig.15 Taguchi graph for HC

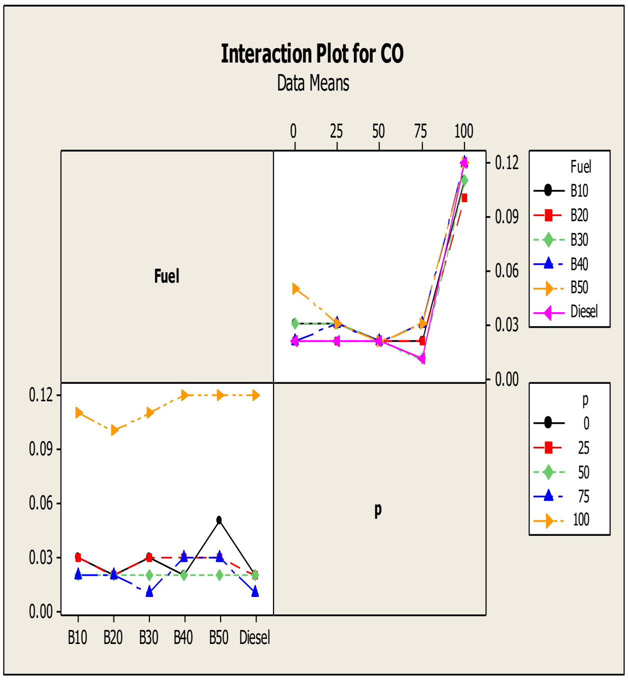

Fig.16 Taguchi graph for CO

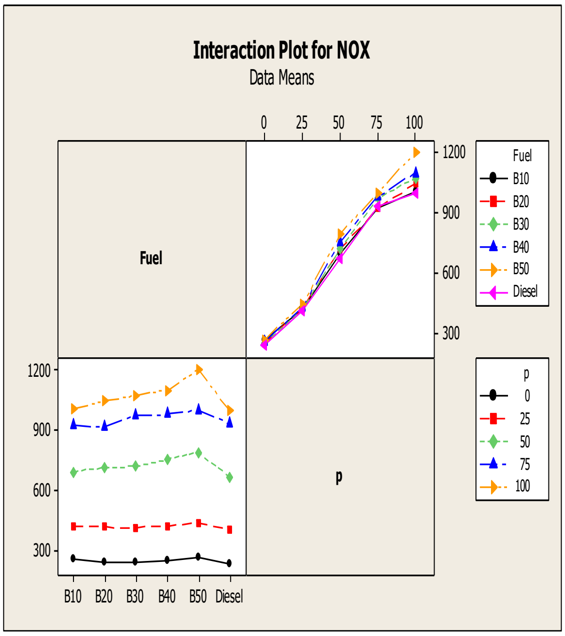

Fig.17 Taguchi graph for NOx

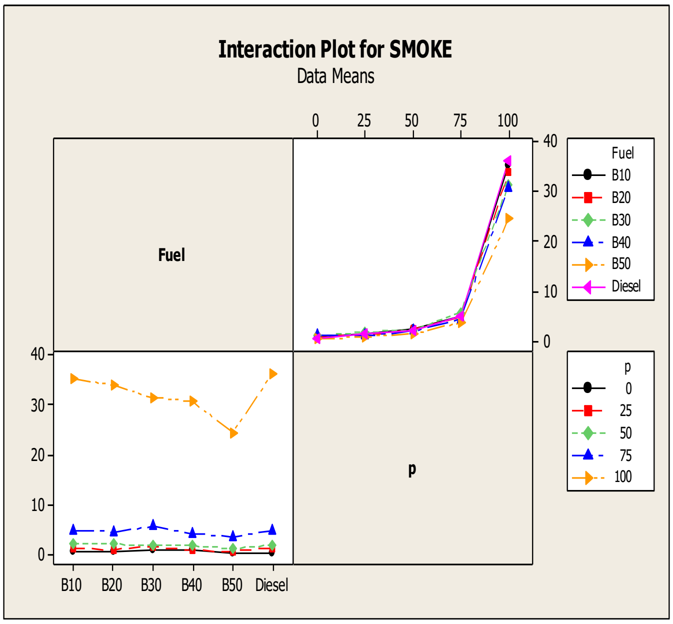

Fig.18 Taguchi graph for smoke

Figure 12 showcases the relationship between different factors and their corresponding levels, which have an impact on the effective efficiency of the engine. The optimal combination of factor levels is determined to be "A2-B5." When the engine operates at full load, it utilizes a richer mixture compared to the 80% load condition. The utilization of the B20 blend leads to an increase in effective power, which, in turn, contributes to the improved efficiency owing to the enhanced power output at the same fuel flow rate [38].

Figure 13 demonstrates that the lowest SFC was achieved at the 80% load condition. Beyond this load, under 100% load conditions, the complete conversion of injected fuel into effective power diminishes, leading to a decline in SFC and effective efficiency. The use of B10 and B20 resulted in reduced SFC compared to the baseline data. However, when B50 was used, SFC slightly increased in comparison. It is clear that the factors impacting effective power play a significant role in this observed change in SFC.

Utilizing the Taguchi technique, Figure 14 effectively illustrates the influence of EGT on all test fuels under different loads for both the baseline and ceramic protective engines. It is apparent that the EGT of the B20 fuel engine was significantly higher compared to the baseline engine when operating with various blends. This indicates that the combustion process in the B20 fuel engine resulted in elevated exhaust gas temperatures when compared to the other fuels tested [39]

In Figure 15, the variations in factors and levels impacting hydrocarbon (HC) emissions are depicted. The optimal combination of factor levels is determined to be "A2-B5". Figure 16 presents the elements and degrees that influence CO emissions, with the optimum CO emission value obtained with the B20 biodiesel blend. The reason behind this can be attributed to incomplete combustion, reduced oxygen content in the cylinder, and decreased flame temperature. The utilization of biodiesel blends as a fuel leads to a reduction in CO and HC emissions. This reduction is believed to be due to the enhanced combustion properties of biodiesel, primarily stemming from its higher oxygen content [40].

Upon examining Figure 17, it is evident that the minimum level of nitrogen oxide (NO) emissions was observed at the minimum engine load level. The NO emissions were found to increase when biodiesel blends were used, primarily attributed to the higher oxygen content in biodiesel. The experimental results indicated that the lowest NO emissions were obtained when baseline fuel was used. As engine speed increases, the supply of air to the cylinder decreases, leading to a reduction in volumetric efficiency. Moving on to Figure 18, it showcases the variations in factors and their corresponding levels influencing smoke emissions. The B20 biodiesel blend demonstrated the optimum value for smoke emission, and the combination of factor levels "A2-B5" was identified as the best for achieving this outcome [41].

5. Conclusion:

The present study aimed to investigate the impact of various biodiesel blends on the performance parameters and emission characteristics of a DIengine at different loads. The Taguchi experimental design method was employed to analyze the data and assess the changes observed. The analysis revealed that engine load and different blend mixtures significantly influenced the engine's performance parameters and emissions. In summary, the findings can be summarized as follows:

➢ Among the various biodiesel blends examined, B20 demonstrated superior performance and a noteworthy reduction in exhaust emissions, with the exception of NOx emissions. On the other hand, among the different proportions tested, the use of B100 resulted in a significant decline in performance and a simultaneous increase in all exhaust emissions.

➢ At the full load condition, the optimal results for effective power were achieved using B20 fuel. For specific fuel consumption and effective efficiency, the optimum results were obtained at 80% load with B10 fuel. The lowest NOx emissions were observed at 80% partial load with B20-diesel fuel. In terms of smoke emissions, the best results were obtained at 80% partial load using B20 fuel. Lastly, the optimal values at 80% load using B20 fuel, the emissions of HC and CO were measured and analyzed.

➢ The Taguchi method, a statistical experimental design approach, was utilized in this study, which resulted in significant time and cost savings of approximately 70%. The experimental studies were conducted within a confidence interval ranging from 95% to 99.99%. The application of the Taguchi method enabled the identification of the interrelationships between performance parameters and the factors that impact emission characteristics. By utilizing this method, a comprehensive understanding of the relationship between these variables was achieved.

Finally, it is feasible to draw the conclusion that biodiesel is able to be safely employed in a diesel engine.It is acknowledged that Calophyllum Inophyllums and Macadamia biodiesel may be used as a beneficial and partial replacement for a diesel engine when using highly viscous fuels. To lower the NOx emissions by using EGR, SCR, additional testing might be necessary.

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