

Performance and Emission Analysis of Single Cylinder Diesel Engine Utilizing a Blend of Waste Cooking Oil and Non-edible Oil with Al_2O_3 and DEE Additives using Response Surface Methodology

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Abstract

This study examines the performance, combustion, and emission characteristics of a single-cylinder diesel engine powered by various blends of waste cooking oil (WCO) and neem oil biodiesel (B0 to B40). The biodiesel blends were enhanced with aluminium oxide (Al_2O_3) nanoparticles synthesized via a precipitation technique and characterized using TEM analysis. These nano-additives were dispersed using magnetic stirring followed by ultrasonication. Diethyl ether (DEE) was also introduced as an additive at varying levels (0–100 ml), along with Al_2O_3 concentrations ranging from 0 to 100 ppm. The experiments were conducted at a constant engine speed and compression ratio under five different load conditions (0–12 kg). Response Surface Methodology (RSM) based on Central Composite Design (CCD) was used to analyze the influence of blend ratio, DEE, Al_2O_3 concentration, and load on brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), in-cylinder pressure, and exhaust emissions (CO, HC, NO_x , and smoke opacity).

The developed RSM models showed strong statistical significance ($p < 0.05$, $R^2 > 0.95$), identifying optimal operating conditions with moderate DEE (~10% vol) and Al_2O_3 levels (25–50 ppm). Under these conditions, BTE improved by 3–6%, BSFC was reduced by 4%, and combustion efficiency increased with an 8% rise in peak pressure and heat release rate. Emission levels of CO and HC dropped by 37%, NO_x by 4%, and smoke opacity by 12%. These findings suggest that biodiesel blends enhanced with DEE and Al_2O_3 , when optimized through RSM, provide a viable pathway for cleaner and more efficient diesel engine operation.

Keywords: Single cylinder diesel engine, waste cooking oil, non-edible oil blend, additives, performance, emission analysis, investigation, Central Composite Design

1. INTRODUCTION

The increasing demand for energy and the depletion of conventional energy sources have led to a growing interest in alternative fuels [1, 2]. One such alternative is waste cooking oil (WCO), which is readily available and has low cost and environmental benefits [3]. However, the use of straight WCO in internal combustion engines is limited due to its poor performance characteristics, such as its low calorific value and high viscosity [4, 5]. The use of WCO blends with diesel or non-edible oil (NEO) has been proposed to address these issues and improve engine performance [5]. The addition of NEO to WCO has been shown to enhance the performance and emission characteristics of the engine. Furthermore, the use of additives, such as surfactants, has been suggested as a means to further improve the performance and emission characteristics of WCO-NEO blends [6]. This approach not only addresses the performance issues associated with WCO use in engines but also provides a solution to the disposal problems faced in India, where the energy demand is increasing at a rate of 6.5% per annum and sewage blockage and environmental issues arise from the disposal of waste cooking oil [7, 8].

Converting waste cooking oil into biodiesel helps resolve these problems, making it a sustainable alternative to traditional fuels. In addition, reusing cooking oil harms human health due to an increase in cholesterol [9]. Sunflower seed (WCO03) showed the most superior properties, such as fatty acid composition and characterization of the physicochemical transformed into biodiesel by transesterification, as compared to soya bean (WCO01) and cottonseed (WCO02). An ultrasonicator is used to mix the base fuel and two hybridized nano additives like 50 ppm of aluminium oxide (Al_2O_3) and 50 ppm of cerium oxide (CeO_2). while the country's crude oil demand is met by imports to an extent of about 80%. Therefore, energy security becomes a vital issue for the nation [10, 11].

Response surface methodology (RSM) is a mathematical and statistical tool that can be used to optimize the performance of internal combustion engines [13]. RSM has been applied to optimize the performance of engines fueled with various fuels, including WCO-NEO blends with additives [12-14]. This review aims to summarize the research conducted on the combustion, performance, and emission analysis of single-cylinder diesel engines fueled with WCO-NEO blends with additives using RSM. The review will cover various studies on the use of WCO-NEO blends with additives, the optimization of engine performance using RSM, and the emission analysis of the engine.

Biodiesel is a renewable, biodegradable, and non-toxic fuel made from various feedstocks, including vegetable oils, animal fats, and recycled cooking oils. Biodiesel is considered one of the most promising alternative fuels due to its high energy content and low emissions compared to conventional diesel fuel [15-18]. Biodiesel production has been widely studied and is a topic of interest in many fields, including renewable energy, environmental protection, and sustainable development [19-22].

The two-step process of turning used cooking oil into biodiesel. The initial phase was studying the photocatalytic etherification of ethanol with free fatty acids (FFA) in waste cooking oil (WCO) using $\text{La}^{3+}/\text{ZnO-TiO}_2$ under UV irradiation. The transesterification of triglycerides with ethanol was catalyzed by NaOH in the second step [23]. Raman spectra, TG, XRD, SEM-EDS, HRTEM, BET, and UV-vis spectroscopy were used to characterize the $\text{La}^{3+}/\text{ZnO-TiO}_2$ photocatalysts. Orthogonal design was used to achieve the best results. The ethanol/oil molar ratio is high at 35°C, the UV irradiation and reaction times are both three hours, and the FFA conversion rate is 96.14% [24].

Transesterification, which separates the feedstock's glycerol content from its fatty acid content, is one method of producing biodiesel. Fatty acid methyl esters (FAME), the primary constituents of biodiesel, are produced as a result. Although either an acid or a base can catalyze the transesterification reaction, the base-catalyzed method is most frequently employed because of its greater efficiency and more palatable conditions [27]. The feedstock used in biodiesel production is a crucial factor affecting the final product's quality and sustainability [28]. The most widely utilized feedstocks are vegetable oils including soybean, canola, and palm oil, but alternative sources such recycled cooking oils, animal fats, and microalgae oil are also being investigated [29].

The quality of the feedstock, including its free fatty acid content, moisture, and impurities, significantly impacts the performance of the transesterification reaction and the quality of the final biodiesel product [30, 31]. One of the many economic and environmental advantages of producing biodiesel is that it lowers greenhouse gas emissions, decreasing dependence on petroleum-based fuels, and creating jobs in rural areas. However, some challenges need to be addressed, such as the high cost of feedstock, the limited availability of certain feedstocks, and the need for further improvements in the production process to increase efficiency and reduce costs [32].

As for improvement in characteristics of biodiesel blends some additives like CeO, which was mentioned in Table 1. Biodiesel production is a rapidly growing field that offers many benefits to the environment and the economy. Developing sustainable and cost-effective biodiesel production processes is crucial to a more sustainable energy future. The shift to a more ecologically friendly and sustainable energy mix will continue to depend heavily on additional research and development in this field [34].

Biodiesel is made from neem and WCO oil using a two-phase transesterification process. Nanoparticles and DEE with various blends are mixed using ultrasonication. This experiment uses the CCD Methodology of Design Expert to optimize the response parameter by maximizing BTHE and decreasing SFC, CO, Nox, and Smoke. Additionally, confirm the regression equation provided by the design expert using Anova and the Desirability model according to their solution, which they provided through experimentation.

2. Biodiesel Production



Figure 1.Flow chart for Production of Biodiesel

Neem seeds were subjected to cleaning, drying, crushing, and the extraction of raw neem oil. Waste Cooking Oil is collected from Namkeen Shop. Raw neem oil and WCO oil is transformed into neem biodiesel by the process of transesterification by using Magnetic Stirrer. Transesterification of neem oil utilizing methanol in the presence of HCL and KOH as catalysts for acid and base reduction, respectively. Glycerol is removed by Phase separation due to density difference. To remove impurities from crude biodiesel, water washing is used. After 10-12 hours of drying heating is required for remove moisture in biodiesel. A magnetic stirrer at consistent temperatures homogenizes the final product of neem biodiesel with DEE and Al₂O₃ nanoparticles in varying proportions.

3. Experimental Fuel

Waste cooking-oil and Neem oil ` biodiesel blend with diesel fuel of 0, 10, 20, 30, and 40 % by volume had been tested in a single cylinder with 0, 25, 50, 75 and 100 ml of DEE and 0, 25, 50, 75 and 100 ppm of Alumina Oxide nano partials. In order to homogenize the fuel mixtures, the magnetic mixer was used to swirl them for 20 minutes at 350 rpm. This was followed by a 45-minute ultrasonication operation. For as long as a month, the experimental fuel combinations were monitored for visible sedimentation. Table 3 displays the fuel blend's thermal characteristics. The test mixtures were examined for fuel properties, characterisation, and experimental objectives [36].

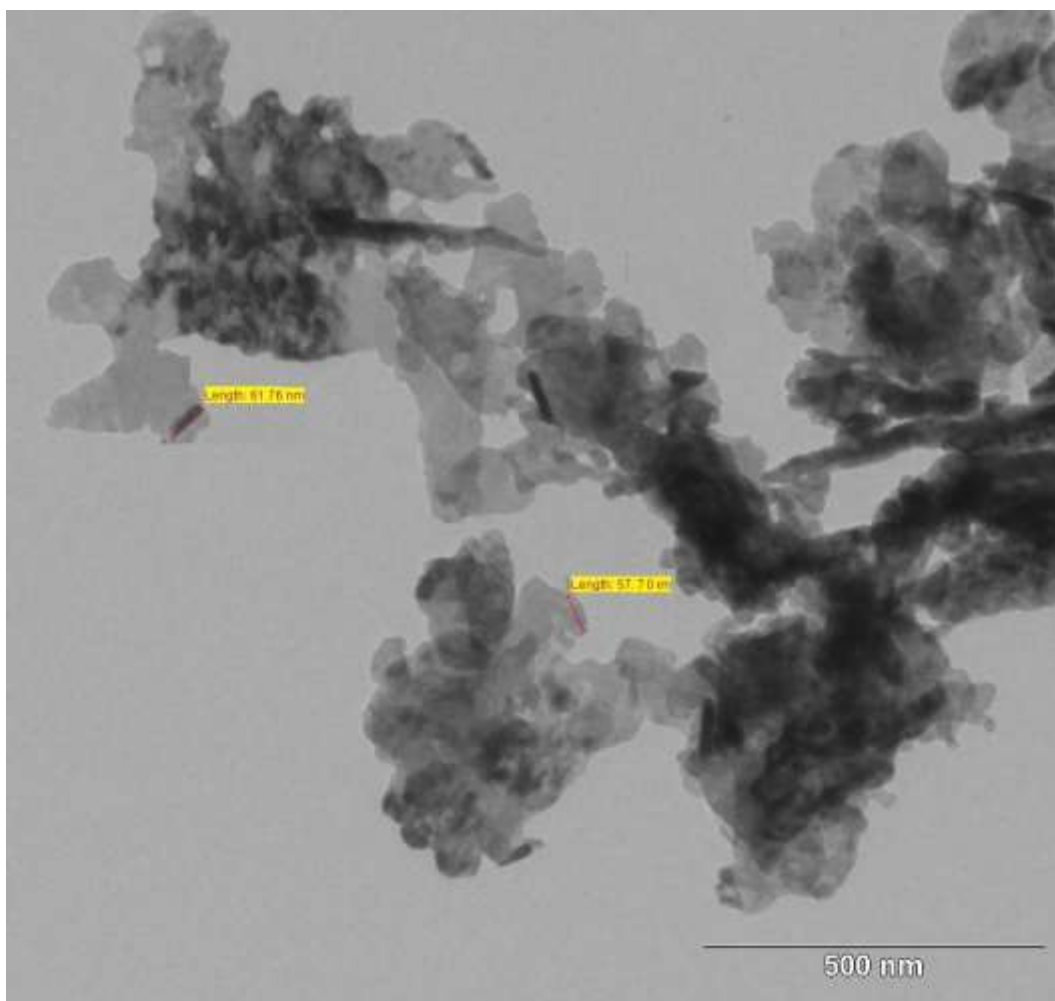


Figure 2. Figure 2TEM Image of Aluminium Oxide (Al₂O₃)

TEM is one of the most precise techniques for analyzing the morphology and particle size of nanoparticles, particularly for the observation at the nano size structure. The Advanced Instrumentation Center for Applied Research and Testing in Anand, Gujarat, India, is where the TEM testing of the nanoparticles is carried out (supported by DST India). Particle sizes of 60 nm, the value is below 100 nm, which is the upper limit for using it as an additive with engine gasoline.

Table 1. Properties of modified fuels (Blend+DEE+Al₂O₃) and diesel

Sample / Properties	Density At 25°C	LCV Calorific Value	HCV Calorific Value	Flash Point	Fire Point	Kinematic Viscosity @40°C	Dynamic Viscosity @40°C
Unit	Kg/m ³	Cal/gm	Cal/gm	°C	°C	cSt	cp
ASTM Standard	D287	D4809	D4809	D93-58T	D93-58T	D445	
Std Diesel (B0)	816	10235	10421	53	56	2.09	1.73
B00 DEE 100 ml (B0D100)	807	9761	10347	52	56	2.78	2.24
B00 DEE 100 ml Al ₂ O ₃ 100 ppm (B0D100Al100)	808	9595	10181	46	48	2.58	2.08
BD10 DEE 50 ml Al ₂ O ₃ 50 ppm (B10D50Al50)	814	9318	9904	46	47	2.97	2.42
BD20 DEE 25 ml Al ₂ O ₃ 50 ppm (B20D25Al50)	821	9434	10020	48	50	3.37	2.77

BD20 DEE 50 ml	819	9182	9768	43	48	3.19	2.62
Al ₂ O ₃ 50 ppm (B20D50Al50)							
BD20 DEE 75 ml	817	9203	9789	41	43	3.09	2.46
Al ₂ O ₃ 50 ppm (B20D75Al50)							
BD30 DEE 50 ml	823	9155	9741	38	42	3.38	2.78
Al ₂ O ₃ 50 ppm (B30D50Al50)							
BD40 DEE 0 ml Al ₂ O ₃	832	8907	9493	53	59	4.25	3.53
0 ppm (B40D0Al0)							
BD40 DEE 100 ml	824	8625	9211	37	41	3.25	2.68
Al ₂ O ₃ 0 ppm (B40D100Al0)							
BD40 DEE 0 ml Al ₂ O ₃	832	8952	9538	56	65	4.23	3.52
100 ppm (B40D0Al100)							
BD40 DEE 100 ml	832	8856	9442	39	39	3.75	3.12
Al ₂ O ₃ 100 ppm (B40D100Al100)							

4. Experimental Methodology

The experimental setup's schematic diagram is displayed in Fig. 2. A four-stroke, single-cylinder, variable compression ratio multifuel engine and an eddy current dynamometer for loading make up the setup. Table 2 displays the engine's comprehensive specifications. Online performance analysis is done using the engine performance analysis software program "Engine Soft".

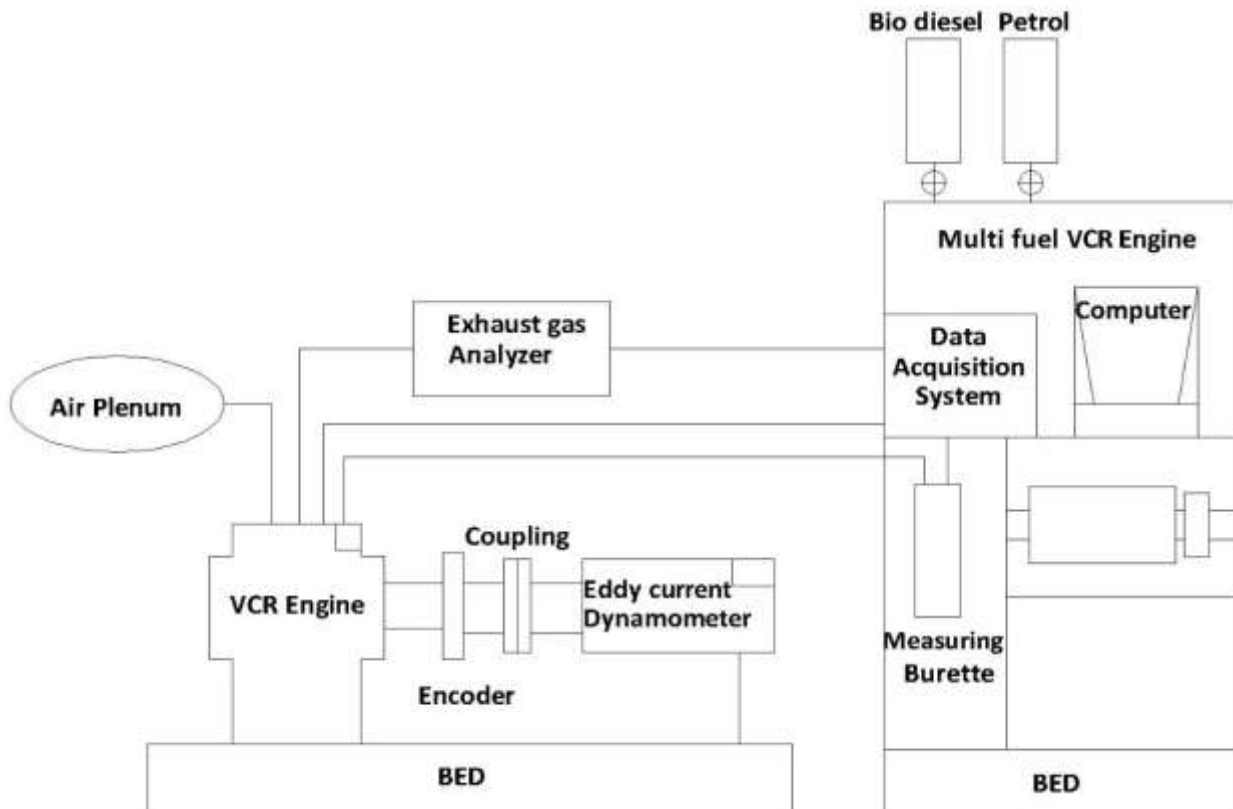


Figure 3. Schematic diagram of the experimental set up.

The tests have been conducted at the rated speed of 1500 rpm under varying loads. The variable compression ratio engine is started with regular diesel and given time to warm up. When the cooling water temperature

reaches 60°C, the warm-up phase is over. After that, measurements and records are made of the engine's operating parameters, including exhaust gas temperature, mechanical efficiency, indicated mean effective pressure (IMEP), brake power (BP), brake thermal efficiency (BTE), and specific fuel consumption (SFC) in relation to various loads for various blends. A Five gas analyser is utilised to measure HC, CO₂, CO and No_x.

Table 2. Specification of the variable compression ratio engine

General Details	Make Kirloskar, Single cylinder, 4-Stroke, water cooled, variable compression ratio engine, compression ignition
Rated power	3.5kW
Speed	1500 rpm (Constant)
Compression ratio	17.5
Bore	87.5 mm
Stroke	110 mm
Dynamometer	Type eddy current, water cooled
Data acquisition device	Analog inputs: 16 SE/8 DIFF; Digital I/O: 8; Analog outputs: up to 2; counters 2 x 32 bit; Sample rate: 250 kS/s; Resolution: 16- bit; Analog input V _{max} ±10V of AI GND; High speed multifunction USB DAQ card
Temperature sensor	Type RTD, PT100 and Thermocouple, Type K
Load sensor	Load cell, type strain gauge, range 0-50 Kg

Throughout the experiment, a computerized data gathering system uses a variety of sensors to gather, store, and evaluate data. Table 2 provides a summary of the characteristics of the diesel fuel and the biodiesel mixes. The typical values derived from the many sources cited. In the lab, measurements were made of the real density, viscosity, fire point, flash point and gross calorific value.

5. RESEARCH METHODOLOGY

The numerical experiments were designed using the CCD approach. Each variable is kept constant at Five equal intervals using this strategy. For instance, if the Load range is 0-12, it is allocated 0,3,6,9,12 and taken into account while designing a numerical experiment. With Five variables and Five center points, there are 50 experiments total. Table 3 provides information about the experiment design and results.

In the current work, RSM was used to model and analyze response parameters in order to determine the engine's characteristics. Based on the acceptable bounds within which the modifications may be done with the current engine, the input parameter ranges were chosen. In order to assess the engine's performance throughout the whole range of input parameter change with the fewest possible tests, design of experiments was employed. Based on the historical RSM data produced by Statease's "Design expert" trial version 13 software, the design matrix was chosen. Table 3 displays the experimental design matrix and the responses received. Design expert software was used to fit the experimental readings to the second order polynomial equation. To determine the coefficients and the equations that may be used to forecast the answers, a multiple regression analysis was performed. The association between the operational parameters and the various responses was found using the statistically significant model. Lastly, the desirability-based RSM technique was used to assess the ideal engine operating parameter values.

Table 3 Experimental design and their responses for diesel engine

Run	BD (%)	Al ₂ O ₃ (ppm)	DEE (ml)	Load (Kg)	IP (Bar)	SFC (Kg /Kw h)	BTHE (%)	CO (%)	Nox (PPM)	Smoke
1	0	0	100	0	260	40	0.21	0.2	2	0.4
2	0	0 +	0	0	260	46	0.19	0.22	6	0.3
3	20	50	100	6	240	0.41	18.82	0.06	125	0.3
4	40	100	0	0	220	55	0.23	0.2	12	1.1
5	20	50	50	0	240	44	0.2	0.18	65	0.1
6	20	50	50	6	240	0.455	19.02	0.06	98	2.9
7	20	0	50	6	240	0.45	19.78	0.07	169	0.3

8	0	0	100	12	260	0.35	24.62	0.04	422	1
9	40	0	0	0	260	49.48	0.21	0.16	17	0.2
10	20	100	50	6	240	0.42	21.17	0.06	125	0.3
11	40	100	0	12	260	0.31	21.22	0.05	146	3.4
12	0	0	0	0	220	49	0.18	0.25	10	0.3
13	0	50	50	6	240	0.43	20.34	0.07	201	0.3
14	40	100	0	12	220	0.34	25.08	0.07	392	2.9
15	20	50	50	6	220	0.43	20.73	0.07	201	0.6
16	20	50	50	12	240	0.39	22.17	0.04	311	1.4
17	0	100	0	12	260	0.34	24.99	0.05	364	1.3
18	20	50	50	6	240	0.44	20.7	0.07	169	0.3
19	0	100	100	0	260	45	0.19	0.17	3	0.2
20	40	0	100	0	220	41	0.22	0.2	2	0.6
21	20	50	50	6	240	0.42	20.64	0.06	98	2.9
22	20	50	0	6	240	0.49	21.36	0.06	98	2.9
23	40	0	100	0	260	40.86	0.21	0.16	7	0.9
24	40	0	100	12	220	0.37	23.37	0.06	238	2.3
25	0	0	100	0	220	39.73	0.21	0.21	7	0.2
26	0	100	100	12	260	0.34	25.48	0.05	394	0.9
27	0	100	100	12	220	0.33	25.87	0.06	424	1.9
28	40	100	100	12	260	0.44	19.51	0.07	95	3.9
29	40	0	0	0	220	51	0.21	0.22	4	0.9
30	20	50	50	6	240	0.44	19.66	0.06	217	0.8
31	0	0	0	12	220	0.38	26.22	0.03	261	1.2
32	40	50	50	6	240	0.42	20.01	0.07	161	1.9
33	40	100	0	0	260	53	0.22	0.12	9	1.7
34	20	50	50	6	240	0.41	19.65	0.06	215	0.7
35	0	100	0	12	220	0.33	25.95	0.05	408	0.9
36	40	0	100	12	260	0.35	18.57	0.06	2.77	4.8
37	0	0	100	12	220	0.32	26.94	0.035	443	1.5
38	40	0	0	12	260	0.32	22.32	0.05	387	3.1
39	0	100	0	0	260	46.6	0.19	0.17	5	0.9
40	20	50	50	6	240	0.44	19.08	0.06	214	0.7
41	20	50	50	6	260	0.4	20.22	0.06	298	1.3
42	40	100	100	0	220	48	0.22	0.18	9	1.2
43	0	100	0	0	220	51	0.14	0.22	4	0.7
44	40	100	100	0	260	50	0.17	0.14	7	1.4
45	20	50	50	6	240	0.44	19.55	0.06	214	0.7
46	0	0	0	12	260	0.34	24.85	0.04	390	1.2
47	0	100	100	0	220	38.2	0.18	0.2	4	0.3
48	40	100	100	12	220	0.43	24.86	0.09	101	3.1
49	40	0	0	12	220	0.33	25.83	0.05	376	2.6
50	20	50	50	6	240	0.45	19.16	0.06	217	0.8

6. RESULTS AND DISCUSSION

Experiment was done by using input variable levels ranging from 0,10,20,30,40% of Biodiesel (50% of WCO and 50% of Neem Oil) having 0,25,50,75,100 ppm of Al₂O₃ with 0,25,50,75,100 ml of DEE applying 0,3,6,9,12 Kg of Load and 220,230,240,250, 260 bar of Injection Pressure.

6.1 Analysis and evaluation of model

Model adequacy was confirmed using the Analysis of Variance (ANOVA), which yields numerical data on the P value. The models were deemed significant based on the ANOVA as the P values were below 0.05. The model fits the data rather well, according to the regression statistics' goodness of fit (R^2) and quality of prediction (Adjusted R^2).

Table 3 P Value and R2 of Input parameters

Model	P- Value				
	SFC	BTHE	CO	NO _x	Smoke
A-BD	0.0027	0.0313	0.0019	< 0.0001	< 0.0001
B-Al ₂ O ₃	0.0211	0.4502	0.004	0.0192	0.3383
C-DEE	0.0203	0.5646	0.4629	0.4303	0.8755
D-Load	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
E-IP	0.5437	0.4207	< 0.0001	0.9304	0.306
R ²	0.9996	0.9964	0.9955	0.9175	0.962
Adjusted R ²	0.9994	0.9939	0.9924	0.8811	0.8917
Predicted R ²	0.9987	0.988	0.9838	0.816	0.836

Equations (1) to (5) below provide the projected quadratic models for the answers, which were created using non-dimensional non-coded factors. These formulas work with input variable levels ranging from 0,10,20,30,40% of Biodiesel, 0,25,50,75,100 ppm of Al₂O₃, 0,25,50,75,100 ml of DEE , 0,3,6,9,12 Kg of Load and 220,230,240,250, 260 bar of Injection Pressure.

Table 4 Final Equation in Terms of Actual Factors

	Equation 1	Equation 2	Equation 3	Equation 4	Equation 5
=	ln(SFC)	BTHE	CO	NO _x	Sqrt(Smoke)
	-2.2952	59.1236	0.82529	-170.211	18.90339
A : BD (%)	0.00575	0.23543	0.000941	2.29311	-0.0357
B : Al ₂ O ₃ (PPM)	-0.00132	-0.03186	0.000491	2.60798	0.01589
C : DEE (ml)	-0.009378	0.03569	-0.0008	0.204301	-0.017
D : Load (Kg)	-1.115692	8.7985	-0.05119	42.09344	0.069825
E : IP (Bar)	0.0500699	-0.5591	-0.0045	0.569485	-0.16985
BD * Al ₂ O ₃	0.000031	0.000987	3.65E-05	-0.02172	0.000078
BD * DEE	0.0000315	-0.00189	2.21E-05	-0.02022	0.000039
BD * Load	-7.40E-05	-0.00898	0.001111	-0.34662	0.000986
BD * IP	-1.20E-05	-0.00199	-1.10E-05	-0.00023	0.000104
Al ₂ O ₃ * DEE	9.57E-06	0.00851	1.10E-06	-0.00049	-2.80E-05
Al ₂ O ₃ * Load	-4.12E-05	0.000041	3.98E-05	-0.07073	-0.0005
Al ₂ O ₃ * IP	8.37E-06	0.000047	-3.91E-06	-0.00897	4.86E-07
DEE * Load	0.0002125	-0.00099	0.000048	-0.02198	0.00014
DEE * IP	0.0000231	-0.00021	2.66E-06	0.000906	7.32E-06
Load * IP	-2.70E-05	-0.00586	0.000079	-0.02057	0.0158
BD ²	-5.30E-05	0.000381	0.00002		0.000328
Al ₂ O ₃ ²	6.70E-07	0.000181	1.16E-06		-0.00011
DEE ²	0.000013	0.000027	-8.45E-07		0.000117
Load ²	0.062872	-0.2448	0.00133		-0.00228

IP² -0.00011 0.001131 7.22E-06 0.000314

6.2 Response Parameter

In Design Expert software, especially when using Response Surface Methodology (RSM), response parameters are the measured output variables that depend on the input (independent) variables or factors. These response parameters are the key performance indicators you're trying to optimize, predict, or analyze like as SFC, BTHE, CO, Nox, Smoke etc.

6.1.1 Specific Fuel Consumption

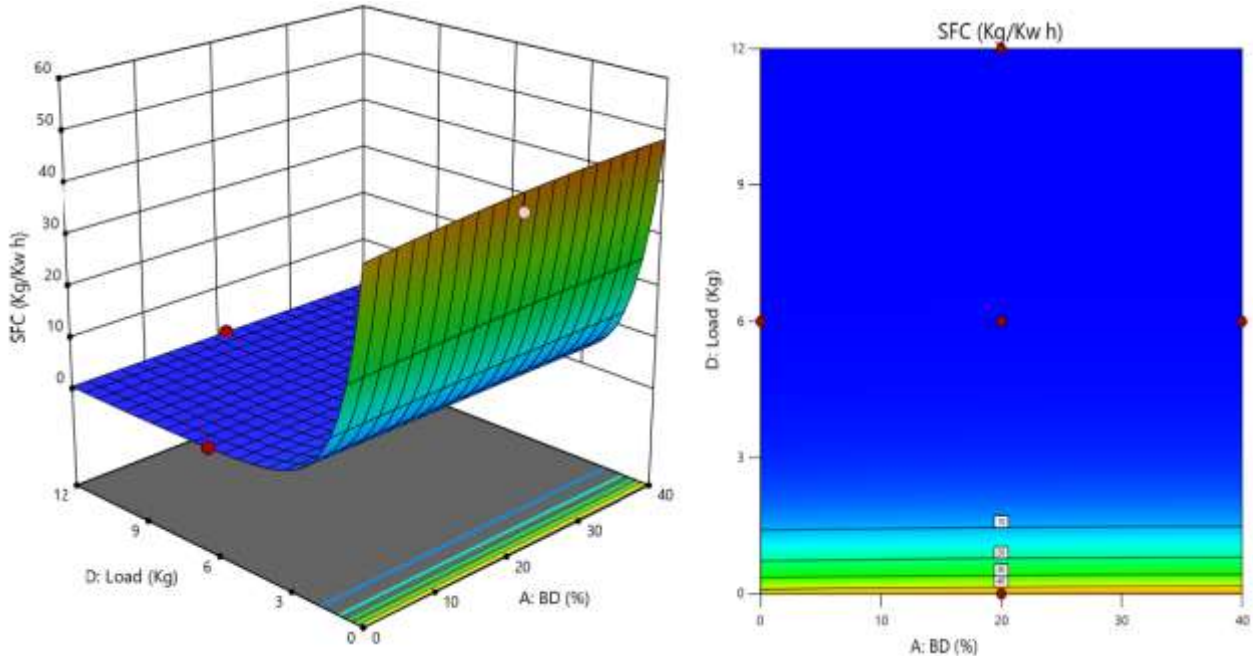


Figure 4 Contour and 3D Surface Plot diagram of SFC vs Load and Biodiesel

The variations in the SFC for diesel blend with Biodiesel from 0 to 40% adding with nano particles at various load conditions are indicated in Fig. 3. It is utilized to calculate the fuel injecting for unit power output. SFC decreases while increasing engine loads from 1 to 12 Kg with falling slope [36]. The nanoparticle has higher surface-volume fraction, and it will act as an oxygen cushion which leads to improve the combustion process. SFC at peak load conditions for B40A1100D0, B40A10D0 , B100A1100D100 blend is 8.82%, 5.88%, 2.3% reduced as compare to Pure diesel at full load. The above quoted factors may reduce the friction in engine parts and thus provide higher output with less fuel consumption.

6.1.2 Brake Thermal Efficiency (BTHE)

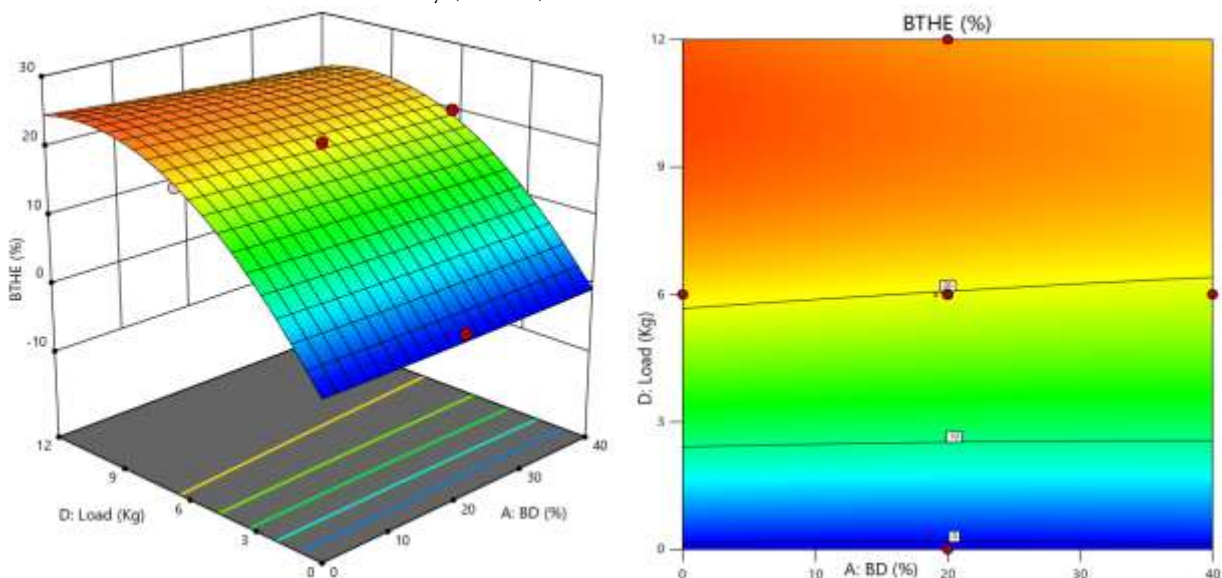


Figure 5 Contour and 3D Surface Plot diagram of BTHE vs Load and Biodiesel

Brake thermal efficiency will be one of the important parameters to measure the energy consumption by an engine related to heat delivered by the fuels. The variations of BTE for different blends at various load conditions are represented in Fig. 4. It is noticed that the thermal efficiency continues to increase while load increases. BTE increases due to effective air-fuel ratio and is possibly obtained by means of better combustion. Owing to the O₂ present in biofuel, B40, B40A100D0, B100A100D100, B40A10D100 is reduced about 1.48%, 4.34%, 5.88% 10.86% [37-40] as compare to Diesel at full load condition. In addition, the BTE is improved by dispersed additives of Al₂O₃ nanoparticle. This may be attributed to the presence of Al₂O₃ nanoparticles, which increased the homogenization of air-fuel mixing inside the cylinder, improved the delay period and enriched the ignition.

6.1.3 Carbon Monoxide (CO)

CO was perhaps probable in both lower fuel-to-air ratios and higher fuel-to-air ratios. Though the lower fuel-to-air ratio, assists the flaming propagation is difficult concurrently higher fuel-to-air ratio will have the inadequate capacity of oxygenation to change CO to CO₂ [41-43]. Deviations of CO with loading percentage for virgin diesel, biodiesel, and biodiesel with nanomaterials conditions are displayed in Fig. 5. The CO displays a decreasing trend with all loading percentages for virgin diesel, biodiesel, and biodiesel with nanomaterials conditions Nevertheless, the existence of biofuel assists in the rise of the CO owing to greater oxidation, and this rise with the rise in the fraction of biofuel in the mixtures. It was observed that at 50% loading and above the CO emissions are more in the case of pure diesel when compared to biodiesel blended with oxygenated or nanomaterials. This is because of the less oxygen present in the diesel. Nevertheless, in the case of biodiesel, the presence of inherent oxygen will cause the combustion of carbon monoxide to form carbon dioxide, which will ensure complete combustion and less emission.

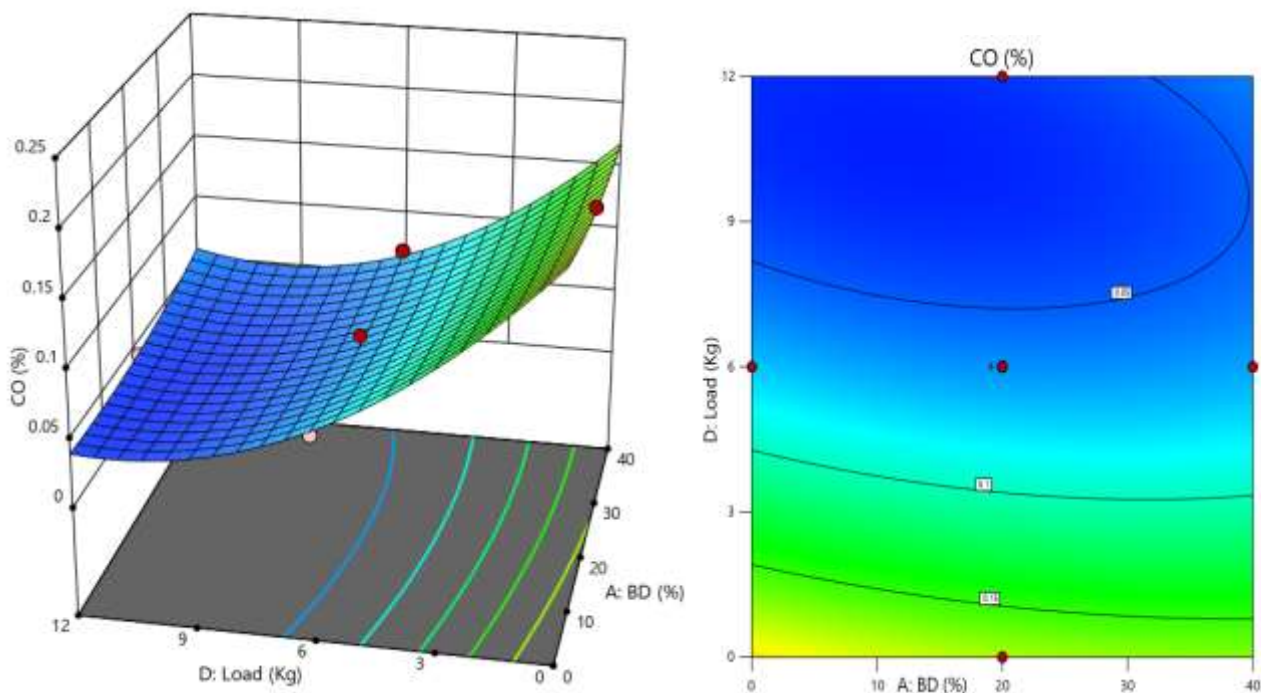


Figure 6 Contour and 3D Surface Plot diagram of CO vs Load and Biodiesel

6.1.4 Nitrogen Oxide (Nox)

Nitrogen oxide (NO_x) emissions variation with different load percentages for biodiesels and biodiesels with nanoparticles are displayed in Fig. 6. It is palpable that NO_x production rises with load percentage for all the experimentation. At maximum load conditions, the topmost smoke temperature is growing up stimulating NO_x generation for experimentation conditions. Zel'dovich NO_x thermal transfer mechanism indicates that the excessive temperature predominating in the burning (combustion) compartment at greater load percentage inducing maximum NO_x production. The lesser NO_x emissions of 50-ppm nanoparticles, the existence of colloidal liquids, which augment

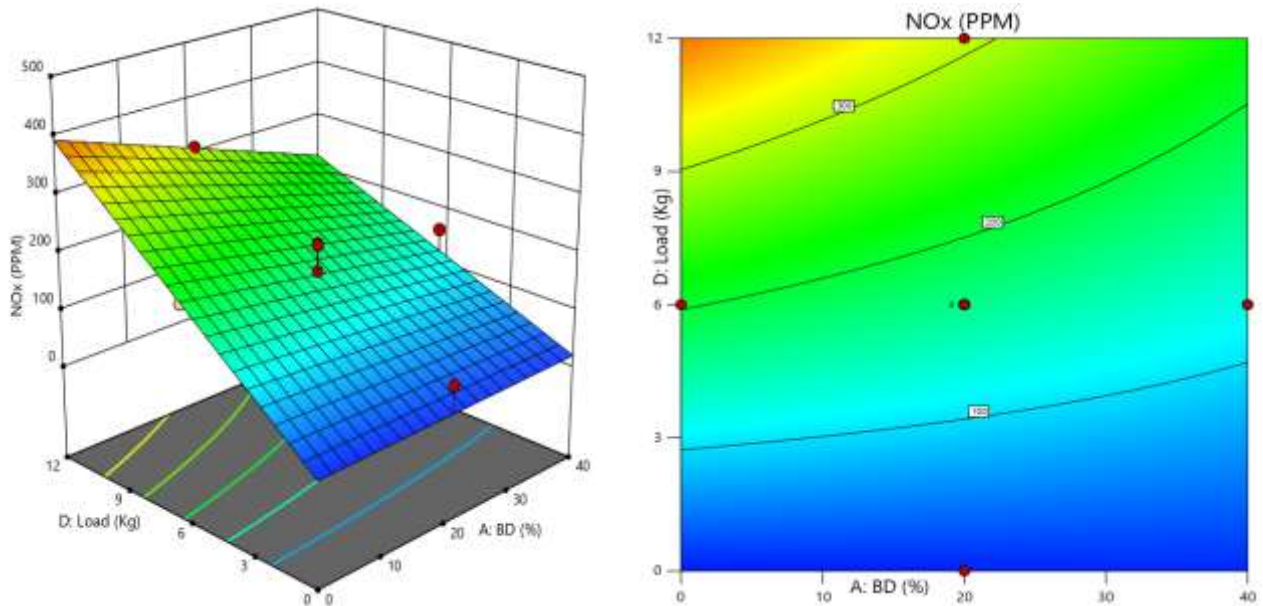


Figure 7 Contour and 3D Surface Plot diagram of NOx vs Load and Biodiesel

good thermal conductivity, helping lesser ignition lag. The major problems in the emission of diesel engines are NOx and smoke emission. This is because in diesel engines usually, the air-fuel mixture is high [44-47]. Therefore, there are more amounts of oxygen and nitrogen in the air-fuel mixture. Nitrogen is inert at lower temperatures but at the higher temperature, its affinity towards oxygen is more. Therefore, the nitrogen in the fuel reacts with excess oxygen forming oxides of nitrogen. In the case of nano additive blend, it acts as a redox catalyst, where it causes reduction of nitrogen oxides (NOx) forming free nitrogen, and later it causes the oxidation of carbon monoxide forming carbon dioxide. While comparing oxygenated additives with 5% and 10% diethyl ether, the biodiesel with 10% diethyl ether has tinier emission characteristics at all loading. Even though the biodiesel blend with the nano additive has very high carbon monoxide emission below 25% loading. After 25% it has very less emission among all the compositions. Both nano additives in 25 and 50 ppm don't have a considerable variation in carbon monoxide emission. At full load engine conditions, the NOx emissions of 40% Blend are lower than Pure diesel and also 10%, 20% and 30% with additives were higher than Diesel, which could be qualified to greater cylinder temperatures attained.

6.1.5 Smoke opacity (Smoke)

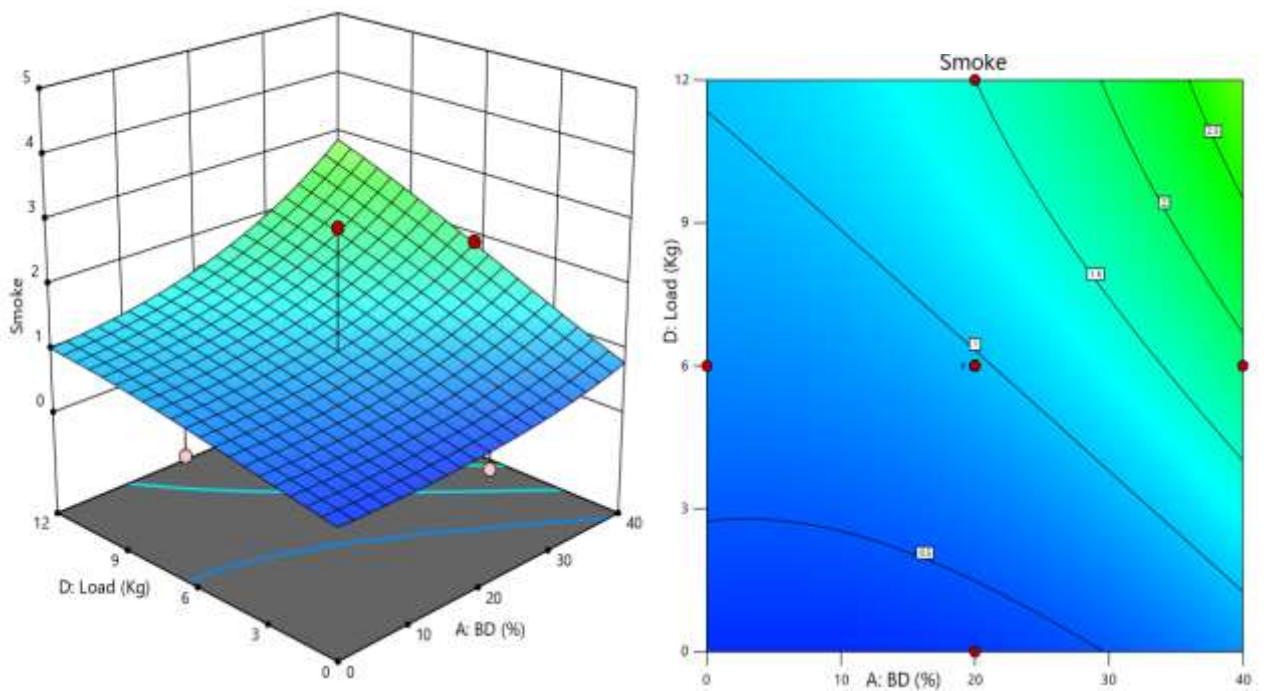


Figure 8 Contour and 3D Surface Plot diagram of Smoke vs Load and Biodiesel

Therefore, the smoke opacity (SO) was performed at various engine loads namely 0, 3, 6, 9 12 respectively. The Smoke is noticed the rising load percentage for all the experimentation conditions. It is detected from Fig. 7, that the smoke opacity (SO) rises with rising engine load percentages owing to inconsistency in firing (combustion) as a result of incomplete air alternative through flue gases. With an increase in load percentage, the amount of fuel (biodiesel) injected is high for the identical amount of air, generating lower oxidization and outcomes in maximum smoke emissions. So, biodiesels and biodiesels with nanoparticles are lesser compared to diesel. This is owing to the inherent concentration of oxygen in DEE that stimulates oxidation-reduction and affects smaller smoking emissions[48-51]. On other hand, owing to the presence of extra oxygen concentration that operates as an oxidation stimulus and caused a significant enhancement in the carbon oxidation, afterward dropping smoking emissions. Both biodiesel blends with oxygenated additives and nano additives reduced the NOx to some extent. It is seen from the graph that NOx emission increases with loading. Due to this the exhaust gas temperature is also increased which in turn causes the reaction of nitrogen with oxygen forming oxides of nitrogen. The reason for less emission by nano additives is that it acts as a redox catalyst that causes the reduction of nitrous oxide-forming free nitrogen. The nano additives have a high surface area that speeds up the reaction time. The soot particle causes several respiratory problems in humans. During heavy loading operations, the fuel required is more because of the high fuel-air ratio, complete combustion does not occur which results in the formation of black smoke[52]. From the observation, it is clear that the addition of oxidative and nano additives to the biodiesel has better smoke reduction characteristics than pure diesel. During full load operations, the smoke emission is very high but with the addition of additives, the smoke emission is drastically reduced. During low load operations, the use of nano additives is preferred because it produces fewer emissions at low load than additives with diethyl ether but during heavy loading conditions, the diethyl ether additives can be used because of their better emission characteristics

6.3 Desirability

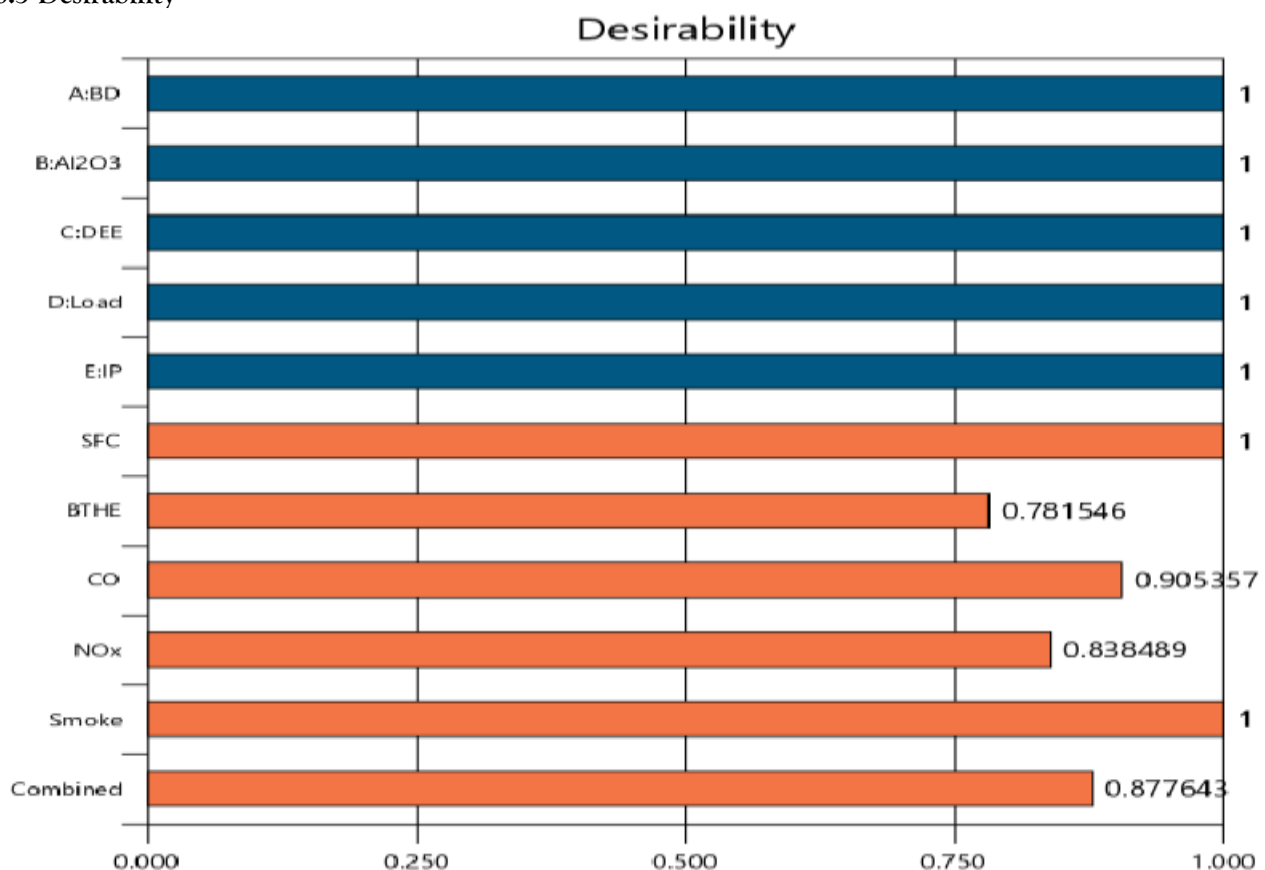


Figure 9 Desirability of Model

In Design Expert (from Stat-Ease), Desirability as shown in Fig. 8 is used for optimization metric used in multi-response optimization problems. It helps find the best combination of input factors (e.g., fuel blends, engine parameters like Load, Injection Pressure) with Al₂O₃ and DEE additives to optimize multiple output responses

(e.g., SFC, NO_x, CO, efficiency) simultaneously. In this Optimization combined desirability is 0.877 which is near about 1 conclude that model is fully desirable.

The answer is reported in Table No. 5 as the response parameter for the particular input used in the experimental setup. Additionally, discover the error, which was close to 5%, between the experimental result and the solution recommended by Design Expert Software.

Table 5 Software Provided Solution and Experimental Response Parameter

Ru n	B D	Al ₂ O ₃	DEE	Load	IP		SFC	BTHE	CO	NO _x	Smoke	
						Solution	0.284	21.09	0.051	73.226	2.742	
	40	100	100	8	260	Experimental	0.275	21.44	0.053	73.204	2.831	
1	Error in %							3.17	-1.68	-3.92	0.03	-3.25
						Solution	0.301	21.18	0.038	111.334	2.631	
	40	98.67	16	7	260	Experimental	0.299	20.66	0.039	112.65	2.729	
2	Error in %							0.66	2.45	-2.63	-1.18	-3.72
						Solution	0.282	22.52	0.066	86.727	2.402	
	40	100	98	8	235	Experimental	0.273	21.98	0.068	86.24	2.437	
3	Error in %							3.19	2.41	-3.03	0.56	-1.46
						Solution	0.256	24.23	0.078	97.264	2.26	
	40	100	100	8.4	220	Experimental	0.266	24.56	0.079	96.88	2.24	
4	Error in %							-3.91	-1.35	-1.28	0.39	0.88
						Solution	0.279	22.13	0.061	85.825	2.523	
	40	99.21	100	8	240	Experimental	0.276	22.56	0.062	86.88	2.54	
5	Error in %							1.08	-1.97	-1.64	-1.23	-0.67

7. CONCLUSIONS

The diesel and biodiesel blend with oxygenated and nanomaterial has experimented with Kirloskar made 3.5 kW power single-cylinder air-cooled Diesel without any modification. The engine is operated at a constant speed of 1500 rpm, it is subjected to various loading from 0 Kg load to 12 Kg loading, and measured readings are analysed.

From the experiments, it was observed that manganese has the stronger effect in reducing the diesel exhaust emissions. Manganese is not regarded as a pollutant and thus can be widely used for doping with diesel fuel. The performance of an engine shows a marginal increase with metal oxide additive doped diesel fuel. The exhaust emission measurements for the fuel with manganese additive showed that CO is reduced 37%, and NO_x is reduced 4%. If additives are applied, they have to be prevented from being emitted in the ambient air by adequate traps.

➤ At the maximum load condition, the BSFC of B40A100D0, B0D100, B40A100D0, B100A10D100, B20D50A150, NBD1, NBD2, NBDN3, and NBDN4 was attained by 0.31, 0.32, 0.34, 0.37, 0.39 respectively, as 0.34 Kg/KW-h is for Diesel.

➤ BTE is increased for addition of nanomaterials blend because of less BSFC consumed and complete combustion.

➤ There is a sizeable lessening in the foremost contaminants namely CO and Smoke owing to the addition of DEE because DEE provides more oxygen that enhances combustion and reduces CO and smoke. The CO is 0.04 PPM at addition of 50 ml of DEE in B20 blend. The smoke opacity was attained to be B20A120D20, B20A1100D50, B20A150D100 is 0.1,0.2,0.3 respectively.

➤ At full load conditions, the emitted NO_x is reduced by addition of additives.

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