IJFANS INTERNATIONAL JOURNAL OF FOOD AND NUTRITIONAL SCIENCES
ISSN PRINT 2319 1775 Online 2320 7876
Research Paper, Journal Volume 11, Iss 10, 2022

PERFORMANCE EVALUATION AND OPTIMIZATION OF KARANJA BIODIESEL FUELLED DIESEL ENGINE

[1]Mallikarjuna Peddauppera,[2]Sowjanya Vadugupalle,[3]Raghunathareddy Chintha
[12]Assistant Professor,[3]Associate Professor
Department Of Mechanical Engineering

Tadipatri Engineering College,Tadipatri,AP

ABSTRACT

Since biodiesel is a sustainable and environmentally friendly energy source, using it to replace diesel fuel is one of the most effective methods to reduce CO2 emissions. The experimental work for this project focuses on biodiesel produced from Pangomia Pinnata oil, also known as karanja oil. The physical and chemical properties of Karanja Biodiesel and its blends are examined in relation to petroleum diesel. Additionally, the performance characteristics of diesel engines fuelled with Karanja biodiesel were evaluated using blends of the fuel (KB5, KB10, KB15, KB20, KB25) comprising 5%, 10%, 15%, 20%, and 25% of Karanja biodiesel, respectively. Under a constant load, brake power, brake specific fuel consumption, and brake thermal efficiency were assessed over a range of engine speeds. Response surface approach was also used to calculate the ideal engine operating settings under normal circumstances. An RSM model with three factors, five levels, two blocks, and a central composite design (CCD) foundation was used. The desirability approach-based response surface optimizer of Minitab®16.2.1 statistical software was used to optimise every goal. The proximity parameter set consisting of S (1900 rpm), B (13%), and T (33 N.m.) was determined to be the most effective for engine performance and efficiency.

Keywords: Central composite design, response surface approach, biodiesel, and Karanja

1. Introduction

The depletion of conventional fuel resources has been caused by the steady rise in the pace of fossil fuel consumption, as well as the world's rising population and urbanisation. Additionally, the greenhouse gas emissions from these fossil fuels are continuously destroying the earth and contributing to other pollution-related issues like global warming. As a result, the scenario calls for a different type of energy that can be employed to get over the anticipated energy crisis in the future. Additionally, the environmental problems will be lessened if the energy source is clean and renewable. Biodiesel-diesel blends as alternative fuels have emerged as one of the solutions that scientists have developed in their search for a new, renewable source of energy**.**

Oils, both edible and non-edible, are used to make biodiesel. Due to the significant disparity between the supply and demand of edible oils in India, it is not practical to use edible oils for the manufacturing of biodiesel. Additionally, the large-scale production of crops for biodiesel fuel may result in an increase in the cost of food and other commodities globally. Contrary to edible oil, non-edible oils including those from jatropha, castor, karanja, rubber seed, and sea mango are hazardous and should not be consumed by humans. Biodiesel made from Karanja is used as fuel in this project work.

The objectives of this study is to evaluate the Engine Performance of four stroke Diesel Engine fuelled with Karanja Biodiesel & its Blends and also to determine Optimal engine operating parameters at standard conditions by using Response surface methodology model.

2. METHODOLOGY USED :

2.1 Response surface methodology :

The response surface methodology (RSM), which models and analyses processes in which the response of interest is influenced by many variables, is a commonly used statistical and mathematical technique. The goal of this approach is to optimize the response. The responses are referred to as Dependent variables, whilst the elements thathave an impact on the process are known as Independent variables.

The Design which we use in the present thesis is Central Composite Design

2.2 Central Composite Design :

The most popular fractional factorial design employed in the response surface model is called the central composite design. First-order and second-order terms can be approximated fast with this design.

A Second order polynomial regression equation :

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i k_i + \sum_{i=1}^{3} \beta_{ii} k_i^2 + \sum \sum_{i<j=1}^{3} \beta_{ij} k_i k_j$$

Where 'Y' : Objective function.
k_i and k_j: Decision variables in the uncoded form and
β_0, β_i, β_{ii} and β_{ij}: Coefficients of intercept, linear, quadratic and interactions.

In this study, the key input decision variables that affect the performance of the DI-CI engine are three parameters: engine operating speed (S), KB-PD fuel blends (B), and torque (T). So, for the design of trials, a complete factorial three-factor, five-level, two-block, central composite design (CCD) based RSM model was used. The objective function, response, was predetermined by the model's design to fit as a quadratic surface. Additionally, in order to analyse their factorial interactions, the input decision variables were tuned in a precise range with the best experimental rotations.

Table 1 Diesel engine operating parameters and constraints for optimization

Uncoded variable	Symbol	Levels				
		-1.633	-1	0	1	1.633
Engine speed (rpm)	S	1700	1800	1900	2000	2100
Karanja biodiesel - petro diesel blend (%)	B	B5	B10	B15	B20	B25
Torque (N.m)	T	28	30	32	34	36

Three uncoded choice variables' levels were displayed in Table 1 in both their real and coded versions. With the exception of the centre level, experimental interactions were carried out in random run order for all possible factorial level combinations at the axial and cubic levels. In order to analyse the experimental data on DI-CI engine performance and exhaust emissions, a second order polynomial regression equation was used. Minitab®16.2.1 statistical software was used to analyse the designed models using analysis of variance (ANOVA) and response surface regression.

The multi-response simultaneous optimization approach is necessary for real-time research problems with numerous objective functions. Constrained optimization uses a variety of methodologies, but the contour plot overlay for each answer and desirability approaches are the most common. The desirability technique is noteworthy since it is simple to apply and has accessibility built in via statistical analysis tools.

In the current study, the optimal responses of the DI-CI engine performance (BP, BSFC, and BTE) were predicted for three engine operating parameters (engine speed, KB-PD blending percentage, and torque) by using a desirability approach-based response surface optimizer of Minitab®16.2.1 statistical software. A response's desirability value can be between "0" (undesirable) and "1" (most desirable). Each response function, nevertheless, can be configured to optimise via minimise, maximise, or a particular objective by which its desirability is attained. Multiple response functions' relative relevance ranking in comparison to other replies yields information about their general desirability. At the best operating conditions, the engine's performance and emission characteristics were assessed, and the results were contrasted with those from petro diesel engines.

3. RESULTS AND DISCUSSIONS

3.1 Engine performance

The performance of the DI-CI engine was experimentally evaluated in terms of brake power (BP), brake specific fuel consumption (BSFC), and brake thermal efficiency (BTE). The experimental and predicted engine performance results are shown in Table 2, together with the respective coefficients of determination (R2) and correlation (R adj2) for each model. There are important terms in a response surface regression model if R2 and R adj2 have a small difference. All of the created models are significant, as evidenced by the analytical findings displayed in Table 2, which follow. The impact on the relevant answer is stronger when a model term's p-value is lower. However, model terms with p-values higher than 0.05 were not considered significant, as the constant term in a model is not affected by changes in the various components.

Table 2 : Experimental and predicted results of engine performance

Exp. Run	Block	Point	Coded parameters			BP (kW)		BSFC (g/kWh)		BTE (%)	
			S	B	T	Exp.	Prd.	Exp.	Prd.	Exp.	Prd.
1	2	Center	0	0	0	3.645	3.691	282.23	281.7	0.302	0.3027
2	2	Axial	0	1.633	0	3.605	3.645	313.38	321.3	0.2935	0.2888
3	2	Axial	1.633	0	0	3.595	3.581	295.01	296.52	0.2913	0.29
4	2	Axial	0	0	-1.633	3.44	3.408	301.3	301.85	0.2883	0.2875
5	2	Center	0	0	0	3.38	3.417	282.23	281.7	0.302	0.3027
6	2	Axial	0	-1.633	0	3.47	3.491	290.83	284.41	0.298	0.3007
7	2	Axial	-1.633	0	0	3.485	3.46	293.74	293.72	0.2913	0.2905
8	2	Axial	0	0	1.633	3.595	3.581	275.45	276.4	0.3034	0.3021
9	1	Center	0	0	0	3.595	3.581	282.23	281.7	0.302	0.3027
10	1	Cubic	-1	-1	1	3.595	3.581	271.57	273.85	0.3091	0.309
11	1	Cubic	-1	1	-1	3.215	3.208	308.95	304.27	0.2933	0.2967
12	1	Center	0	0	0	3.255	3.232	282.23	281.7	0.302	0.3027
13	1	Cubic	-1	1	1	3.66	3.595	303.28	300.06	0.2847	0.2868
14	1	Cubic	1	1	-1	3.508	3.487	314.85	311.07	0.2903	0.2924
15	1	Cubic	-1	-1	-1	3.48	3.487	292.95	297.09	0.2863	0.2844
16	1	Cubic	1	1	1	3.595	3.616	309.86	304.21	0.2817	0.2855
17	1	Center	0	0	0	3.505	3.502	284.55	286.34	0.302	0.2996
18	1	Center	0	0	0	3.075	3.126	284.55	286.34	0.302	0.2996
19	1	Cubic	1	-1	1	3.595	3.616	275.96	279.15	0.3081	0.3067
20	1	Cubic	1	-1	-1	3.415	3.404	294.02	295.75	0.2853	0.2852
R^2						96.28%		92.98%		93.20%	
R^2(adj)						92.15%		85.18%		85.64%	

3.1.1 Brake power

The significant effect and variations of brake power (BP) with respect to the interactions of experiment variables engine speed, KB-PD blending ratio and torque are shown in Figure 1(a-c). The changes BP in respect to engine speed and KB blending ratio given in Figure 1(a). Higher BP was observed over medium engine speeds and KB blending percentages as compared to lower or upper parametric combinations. Additionally, as seen from Figures 1(b) and 1(c), higher BP was noted when the engine was operated at torque values above 30 N.m

$$BP = -36.4142 + 0.016S + 0.407\mathrm{B} + 1.295T - 0.000004S^2 - 0.001295B^2 - 0.015977T^2 - 0.000014\mathrm{SB} - 0.000028\mathrm{ST} - 0.010688BT$$

The aforementioned quadratic regression equation is used to present the regression model that was constructed for ideal BP. As can be observed in Table 2, the "BP" regression model's fitness coefficients R2 (96.28%) and R adj(92.15%) indicate a strong connection between the modelled terms and the "BP" response parameter As indicated in Table 2, a minimum BP of 3.075kW was noticed for a centre point (1900 rpm, B15, 32 N.m) under full load conditions. Additionally, it should be noted that a maximum BP of 3.66kW was obtained at the cubic point of the parameters given (1800 rpm, B20, 34 N.m). Due to their lower calorific values, which cause inefficient combustion, biodiesel blended fuels typically have lesser power than PD. Along with poor KB-PD blend mixtures, the variation in BP cased was linked to biofuel's increased density and kinematic viscosity. Additionally, as a blend's KB ratio grows, it contributes to the fuel blend's rich oxygenation and clean combustion, which raises the BP by boosting engine torque.

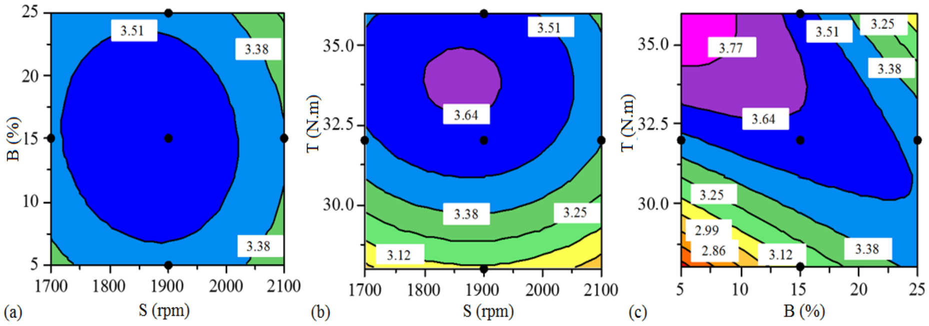

Figure 1 : Brake power (kW) variations in contrast to the interactions of engine speed, KB-PD blending ratio and torque.

3.1.2 Brake specific fuel consumption

Table 2 shows the experimental and expected results for brake specific fuel consumption (BSFC). At the specified cubic parameters (1800 rpm, B5, 34 N.m), a minimum BSFC of 271.57 g/kWh was reported, while a greater BSFC of 314.85 g/kWh was obtained at the cubic point (2000 rpm, B20, 30 N.m). Through its goodness coefficients, such as R2 (92.98%) and R adj2 (85.18%), the BSFC response surface model's fitness was demonstrated. Increased fuel usage causes the KB ratio in fuel mixes to rise, which lowers the fuel's heating value. Additionally, BSFC rises at high engine speeds due to diminishing combustion and losses from friction heat.

$$BSFC = 2397.33 - 1.374S - 15.621\mathrm{B} - 41.267T + 0.000336S^2 + 0.211529B^2 + 0.463777T^2 \\ + 0.00175\mathrm{SB} + 0.0025\mathrm{S}T + 0.243567BT$$

According to the aforementioned BSFC regression equation, the model factors engine speed and KB-PD mixes were both significant. The positive sign of both the quadratic and interaction terms reveals their beneficial effect, but it is constrained. The response surface plots of the biofuel-fueled DI-CI engine are shown in Figure 2(a–c). A BSFC of 275–281.1 N.m over operational settings, including engine speed of 1850–1950 rpm, blending ratios of 7.5–12.5%, and torque of 33–36.25 N.m, was determined from the surface plots. The BSFC and engine torque had a reverse influence relationship. Additionally, when toque increased, poorer BSFC was seen on interactions between blend ratios and engine speed.

Additionally, the fuel features of fuel blends, such as their lower density and kinematic viscosity, increase combustion rate and raise BSFC. However, for a given volume and injection pressure, fuels with higher densities result in higher fuel injection into the combustion chamber. Additionally, a biofuel's BSFC increases because a fuel with a lower calorific value requires more fuel to create the same amount of power as a fuel with a greater calorific value. As a result, it is evident that the BSFC of an engine running on B-PD blends decreases at mid-operating parametric values of engine speed and blend ratios.

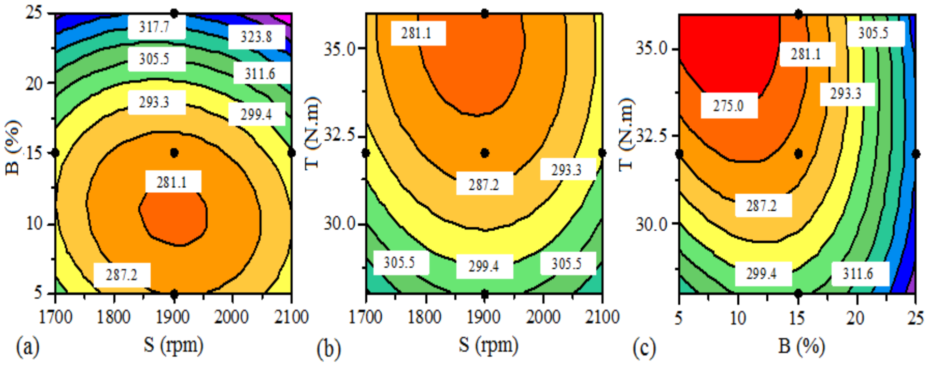

Figure 2: Brake specific fuel consumption (g/kWh) variations in contrast to the interactions of engine speed, KB-PD blending ratio and torque

3.1.3 Brake thermal efficiency

The effectiveness of an engine in converting the chemical energy of a fuel into mechanical energy is measured by brake thermal efficiency (BTE). Table 2 displays the BTE experimental and anticipated variations in relation to the operating parameters of the DI-CI engine. A maximum BTE of 0.302% was found at the parameters' centre (1800 rpm, B5, and 32 N.m), while a minimum BTE of 0.2817% was recorded at the parameters' cubic point (2000 rpm, B20, 34 N.m). As can be observed from Table 2, the goodness coefficients for the BTE regression statistics, which include R2 (93.20%) and R adj2 (85.64%), indicate the suitability of the BTE response surface model. With an increase in the KB ratio in the biofuel blends, the BTE% rises noticeably. This has a relationship to the fuels' cetane rating. Superior cetane numbers in fuel blends show good combustion properties, which are likely to make up for biofuel drawbacks like longer ignition delays. The KB blending ratio and engine torque in relation to engine speed are perceptibly important elements in the BTE response surface model, according to the equation below. However, other than the interactions between engine speed and torque, both quadratic and interaction terms had a minimal negative impact on the final BTE%.

$$BTE = -1.793 + 0.001209\,\mathrm{S} + 0.026878\mathrm{B} + 0.045053T - 0.0000003S^2 - 0.000076B^2 - 0.000505T^2 - 0.000001\mathrm{SB} + 0.0000001\mathrm{ST} - 0.000728BT$$

Response surface plots showing the percentage change in the engine's BTE in relation to the operating parameter interactions are shown in Figures 3(a) through (c). It can be deduced from Figures 3(a) and 3(b) that higher BTE is attained when the engine is driven over values that are close to the midpoints, such as 1900 rpm, B15, and 32.5 N.m, as opposed to the lower or higher limits of a parameter. It's possible that this results from poor air-fuel mixture creation at higher engine speeds. Similar to Figure 3(b), Figure 3(c) shows an increase in BTE% proportionate to engine torque and KB blending ratio, which is explained by an improved rate of combustion with higher torque as well as the presence of more oxygen in the fuel blends. Thus, it can be concluded that factors like fuel type, biodiesel mixing ratio, engine speed, oxygen content, calorific value, and cetane number of a fuel can affect an engine's optimal thermal efficiency.

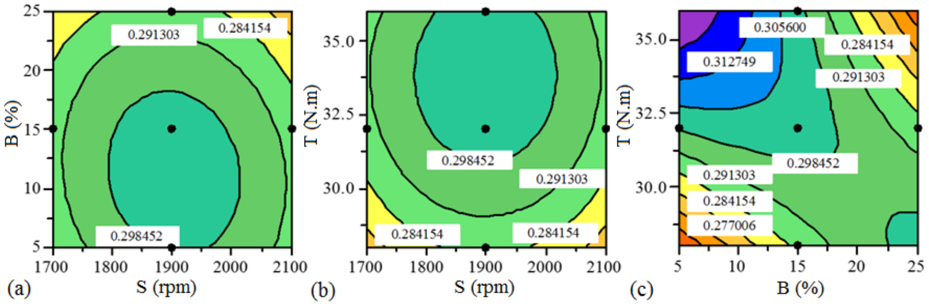

Figure 3 : Brake thermal efficiency (%) variations in contrast to the interactions of engine speed, KB-PD blending ratio and torque.

Table 3: Experimental validation of engine performance at optimal operating parameters.

DI-CI Engine performance/ emission parameter	Optimal predicted operating parameters			Desirability	Result of DI-CI engine performance		
	S (rpm)	B (%)	T (N.m)		Predicted	*Experimental	$^{\#}$Petro diesel
BP (kW)	1880	13.36	32.81	0.985	3.6509	3.617	3.56
BSFC (g/kWh)	1885	11.58	33.11	0.992	276.3	271.8	295.1
BTE (%)	1888	12.54	31.96	0.951	0.3019	0.294	0.289
Engine operating parameters for experimental validation using							
*KB-PD blends: S (1900 rpm); B (13%); T (33 N.m)							
$^{\#}$Petro diesel: S (1900 rpm); T (33 N.m)							

Optimization and validation of engine performance

The replies of each engine's performance were optimised using Minitab®16.2.1 statistical software's response surface optimizer, which is based on the desirability approach. The best level (minimum/maximum) for each of the initial engine operating parameters, engine speed (S), KB-PD blending percentage (B), and torque (T), was projected. Table 10 shows the expected ideal operating conditions together with the matching desirability for each response function. It is clear that the engine speed should be 1890 10 rpm, the KB-PD blending ratio should be 13% (-1.42% to +0.08%), and the engine torque should be 33 N.m. (-2.24 N.m. to +1.69 N.m.). In order to validate the performance of the DI-CI engine, an optimal range of operating parameters set of S (1900 rpm), B (13%) and T (33 N.m) were taken into consideration in order to optimise all the responses. However, the overall desirability for the multiple objectives was estimated to be 0.969. At first, experimental testing on the DI-CI engine were carried out using petro diesel as the combustion fuel at operating parameters of S (1900 rpm) and T (33 N.m). The experimental validation test runs were conducted concurrently while using recently thought-of ideal operating parameters like S (1900 rpm), B (13%), and T. (33 N.m)

4. Conclusions

i. The two-block, three-factor, five level RSM model, which is based on central composite design, greatly decreased the amount of engine test iterations required and provided a strong statistical basis for the analysis of related data. The desirability approach-based response surface optimizer of Minitab®16.2.1 statistical software was used to optimise every goal. The proximity parameter set consisting of S (1900 rpm), B (13%), and T (33 N.m.) was determined to be the most effective for engine performance and efficiency.

ii. The performance of the DI-CI engine was evaluated at full load while running at various engine speeds (1700 rpm – 2100 rpm) (28 N.m – 36 N.m) using KB-PD fuel blends of (B5 – B25) and Torque. Under ideal circumstances, BP, BSFC, BTE evaluations, and comparison studies utilising pure PD petrol revealed a significant boost in engine performance.

References :

[1] K. Sivaramakrishnan and P. Ravikumar, “Optimization of operational parameters on performance and emissions of a diesel engine using biodiesel,” *Int. J. Environ. Sci. Technol.*, vol. 11, no. 4, pp. 949–958, 2013.

[2] G. Khoobbakht, G. Najafi, M. Karimi, and A. Akram, “Optimization of operating factors and blended levels of diesel, biodiesel and ethanol fuels to minimize exhaust emissions of diesel engine using response surface methodology,” *Appl. Therm. Eng.*, vol. 99, pp. 1006–1017, 2016.

[3] A. Kumar Tiwari, A. Kumar, and H. Raheman, “Biodiesel production from jatropha oil (Jatropha curcas) with high free fatty acids: An optimized process,” *Biomass and Bioenergy*, vol. 31, no. 8, pp. 569–575, 2007.

[4] I. R. Ejilah, A. A. Asere, F. Polytechnic, M. E. Programme, and L. Technology, “The effect of diesel fuel- Jatropha curcas oil methyl ester blend on the performance of a variable speed compression ignition engine,” *Aust. J. Agric. Eng.*, vol. 1, no. 3, pp. 80–85, 2010.

[5] M. S. Shehata and S. M. A. Razek, “Experimental investigation of diesel engine performance and emission characteristics using jojoba/diesel blend and sunflower oil,” *Fuel*, vol. 90, no. 2, pp. 886–897, 2011.

[6] P. D. Patel, A. Lakdawala, S. Chourasia, and R. N. Patel, “Bio fuels for compression ignition engine: A review on engine performance, emission and life cycle analysis,” *Renew. Sustain. Energy Rev.*, vol. 65, pp. 24–43, 2016.

[7] H. C. Ong, H. H. Masjuki, T. M. I. Mahlia, A. S. Silitonga, W. T. Chong, and T. Yusaf, “Engine performance and emissions using Jatropha curcas, Ceiba pentandra and Calophyllum inophyllum biodiesel in a CI diesel engine,” *Energy*, vol. 69, pp. 427–445, 2014.

[8] M. Mofijur, H. H. Masjuki, M. A. Kalam, and A. E. Atabani, “Evaluation of biodiesel blending, engine performance and emissions characteristics of Jatropha curcas methyl ester: Malaysian perspective,” *Energy*, vol. 55, pp. 879–887, 2013.

[9] E. Buyukkaya, “Effects of biodiesel on a DI diesel engine performance, emission and combustion characteristics,” *Fuel*, vol. 89, no. 10, pp. 3099–3105, Oct. 2010.

[10] T. Ganapathy, R. P. Gakkhar, and K. Murugesan, "Optimization of performance parameters of diesel engine with Jatropha biodiesel using response surface methodology," *Int. J. Sustain. Energy*, vol. 30, no. sup1, pp. S76–S90, 2011.

[11] D. H. Qi, L. M. Geng, H. Chen, Y. Z. Bian, J. Liu, and X. C. Ren, "Combustion and performance evaluation of a diesel engine fueled with biodiesel produced from soybean crude oil," *Renew. Energy*, vol. 34, no. 12, pp. 2706–2713, 2009.

[12] D. H. Qi, H. Chen, L. M. Geng, Y. Z. Bian, and X. C. Ren, "Performance and combustion characteristics of biodiesel-diesel-methanol blend fuelled engine," *Appl. Energy*, vol. 87, no. 5, pp. 1679–1686, 2010.