USE OF OPTIMIZATION APPROACH TO ENHANCE THE PERFORMANCE CHARACTERISTICS OF ENGINE

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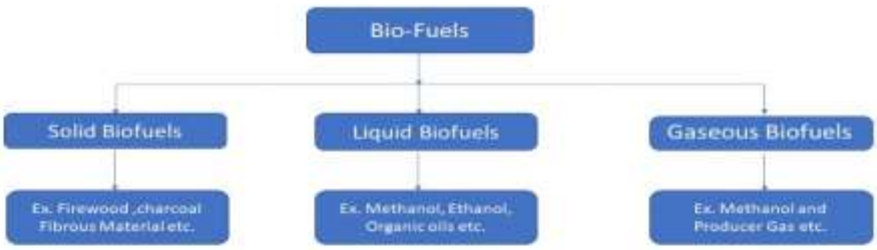
Abstract

The aim of this work was to optimize the performance of castor- diesel blends in a VCR engine by adopting optimized engine parameters. Operational parameters like load, fuel blend, and compression ratio are taken into consideration for engine optimization, while performance parameters like mechanical efficiency, brake thermal efficiency (BTHE), and indicated thermal efficiency are considered responses. Research is conducted in accordance with the Box-Behnken Design (BBD) experimental design. Using the Desirability approach, engine operating parameter optimization is done. According to the results, the VCR engine outperforms the diesel engine in terms of performance and emissions when it is operating at an 18-compression ratio, 40% fuel blend, and full load. The engine's optimized operating conditions resulted in the following responses: 56.818% for Mechanical Efficiency, 28.727% for Brake Thermal Efficiency, and 51.879% for Indicated Thermal Energy. Finally, it can be seen from experimental data and mathematical models that, at optimal engine parameters,



biodiesel blends have the highest efficiency and the lowest emissions.

Fig.1 Systematic Layout of Different Biofuels

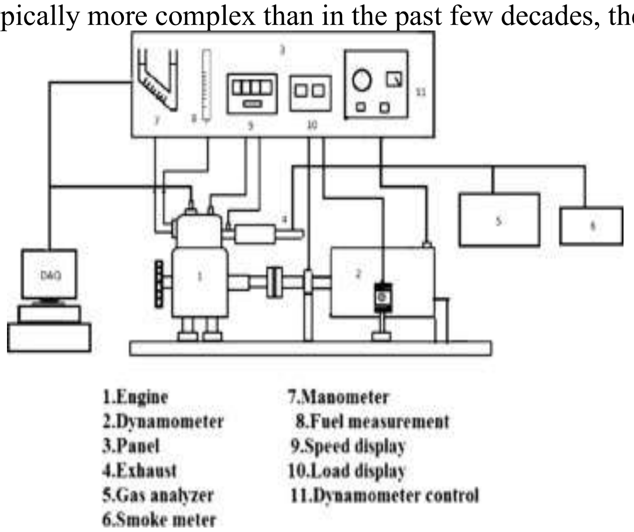
Introduction

Biomass refers to the organic matter that can be used as a substitute for energy. It encompasses various types of biofuels, including solid, gaseous, and liquid fuels. These can be obtained from biomass [1,2].

In contemporary times, it is crucial to deliberate upon the optimal utilization of biofuels and fossil fuels in our daily lives, as both play a vital role in shaping our future generations [3]. The cost of essential commodities, such as oil, is experiencing a significant increase. In this situation, biofuel can be the most favourable alternative to meet the demand for fuel in human necessities. It replaces fossil energy sources and the depleting reserves of fossil fuels. The outcome serves as a means to mitigate the impacts of climate change and establish a sustainable and dependable source of energy. Biofuels are considered perpetual and sustainable resources as they are continuously replenished. Fossil fuels are non-renewable resources that deplete over time as they require millions of years to form and are extracted from underground reserves [4].

The primary objective of the study is to comprehend and analyse various characteristics of bio-diesel. Biodiesel is an environmentally friendly fuel that is widely available and not dependent on geography. Similar to diesel, biodiesel is composed of mono-alkyl esters of long-chain fatty acids derived from renewable natural sources like vegetable or animal fats. Significantly reducing the utilization of fossil fuels can greatly decrease the harmful emissions. This can be achieved by replacing fossil fuels with renewable fuels. Renewable energy sources will play a significant role in meeting the future global energy demand [5]. Biodiesel is a type of clean and sustainable bioenergy that can be produced from various sources such as single edible oil (SEO), hybrid edible oils (HEO), single non-edible oil (SNEO), and hybrid non-edible oil (HNEO). It can be used as fuel for diesel engines in vehicles without requiring any modifications to the engines [6]. In order to enhance the production of biodiesel, numerous innovative technologies are being embraced in the field of bioenergy research [7]. Biodiesel is primarily derived from edible vegetable oil, nonedible vegetable oil, waste or recycled oil, and animal fats. It is relatively less flammable than regular diesel. Biodiesel can be readily blended with conventional diesel fuel. Bio-diesel is biodegradable, thereby rendering it less environmentally hazardous. It lacks sulphur, the primary cause of acid rain. Biodiesel is suitable for application in catalytic converters in numerous instances. The engines, which utilize bio-diesel as a fuel source, typically exhibit a high degree of durability. The refineries are relatively less complex and environmentally friendly. Biofuels exhibit higher octane levels and lubricity scores compared to uncontaminated petroleum-based diesel fuel. It has the potential to enhance the efficiency of the engine and prolong the operational lifespan of the machine [8].

Recent studies have examined the operational and exhaust properties of biodiesel engines under various engine speeds, loads, and biodiesel ratios [9,10]. Using biodiesels as alternative fuels in diesel engines has advantages including reducing or eliminating the sulphur dioxide, carbon monoxide, and unburnt hydrocarbons in exhaust gases. The oxygen present in biodiesel molecules generally leads to a more thorough burning process and a decrease in environmental pollution [11]. Optimizing the biodiesel engine's performance is the main goal of the research. Design software's can be used to calibrate the engine performance. In order to achieve prescribed performance in terms of maximum output power, minimum fuel consumption (FC), minimum pollutant emissions, and noise, internal combustion engine (ICE) calibration is defined as determining the ideal settings of several engine adjustable parameters, such as air-to-fuel ratio (AFR), spark advance, and variable valve timings (VVT), for all operating points of the operating range. In the real world, the engine calibration problem becomes a crucial optimization problem since an engine that is properly calibrated produces fewer greenhouse gas emissions and is therefore preferred over an engine that is not. Thus, engineers and researchers alike are very interested in the engine calibration issue. Unfortunately, dyno performance evaluation takes a lot of time, which makes engine calibration a costly optimization issue. Since engine calibration issues are typically more complex than in the past few decades, the conventional manual method has reached its limit. On the one hand, as engine technology advances, there are more and more engine parameters that can be adjusted [12].



Experimental Set-up

A problem-solving method called One Factor at a Time (OFAT) is used to separate the important causes of an effect from a group of possible causes. Many organizations continue to use the OFAT approach when conducting experiments to identify the primary factors. Finding the performance characteristics with the OFAT approach requires selecting the appropriate range of input variables. A specific range of input variables is selected and fixed prior to the start of the performance characteristics, and this is followed by a methodical arrangement of the experimental performance. To achieve the best results, the variables chosen for the inputs are listed in Table 1. The appropriate ranges of the variables are also fixed. Pure castor oil was bought for this investigation from the market. Transesterification is the process that turns castor oil, which has less than 2% free fatty acids (FFA) and 27% alkaline, into biodiesel [13-15]. The mechanical efficiency of the biodiesel is optimized using the Design-expert 13 model. The output values are obtained using a diesel engine with a displacement of 87.50mm, stroke length of 110.00mm, connecting rod length of 234.00mm, and compression ratio of 18. The engine has a power of 350KW @1500 rpm.

Fig.2 Systematic Engine Layout Diagram [16]

Experimental Methodology

In order to determine the optimal value of the output parameters selected for analysis, three levels of experiment design based on the BBD technique are generated. These levels include speed, load, indicated power, and brake power as input parameters as shown in Fig.3.

Factors

Factor	Name	Units	Type	SubType	Minimum	Maximum	Coded Low	Coded High	Mean	Std. Dev.
A	Speed	RPM	Numeric	Continuous	1433.00	1493.00	-1 ↔ 1433.00	+1 ↔ 1493.00	1463.00	19.64
B	I.P	KW	Numeric	Continuous	2.28	3.93	-1 ↔ 2.28	+1 ↔ 3.93	3.10	0.5401
C	B.P	KW	Numeric	Continuous	0.1000	2.51	-1 ↔ 0.10	+1 ↔ 2.51	1.30	0.7889
D	Load	Kg	Numeric	Continuous	0.3600	9.20	-1 ↔ 0.36	+1 ↔ 9.20	4.78	2.89

Fig.3 Details of factors chosen for Research Analysis

This study looked at torque, load, indicated power, and brake power as input factors that could have an impact on the engine's indicated thermal efficiency, mechanical efficiency, and brake thermal efficiency. For the experimentation, full factorial designs of Design of Experiments (DOEs) are taken into consideration, where each factor is varied in levels of 3x3x5 respectively. The full factorial design from the software "Design Expert" trail version 13, which included 17 runs, served as the basis for creating the design matrix.

ANNOVA for Quadratic Model

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	6915.68	9	768.41	93423.62	< 0.0001	significant
A-torque	6557.99	1	6557.99	7.973E+05	< 0.0001	
B-I.P	0.0001	1	0.0001	0.0061	0.9428	
C-B.P	0.0021	1	0.0021	0.2568	0.6472	
AB	0.0000	1	0.0000	0.0000	1.0000	
AC	0.0132	1	0.0132	1.61	0.2943	
BC	0.0000	1	0.0000	0.0000	1.0000	
A^2	265.56	1	265.56	32286.64	< 0.0001	
B^2	0.0002	1	0.0002	0.0213	0.8933	
C^2	3.571E-06	1	3.571E-06	0.0004	0.9847	
Residual	0.0247	3	0.0082			
Cor Total	6915.71	12				

Fig.3 ANNOVA Table

The Quadratic Model of the ANNOVA technique was displayed in the above table.

Result & Discussion

The foundation of analysis is analysis of variance (ANOVA), which yields the p-value numerically. The alternative term for rejection points that indicates the lowest level of significance at which the null hypothesis would be rejected is the p-value. The maximum value of p is thought to be 0.05, and model terms with p-values greater than 0.05 are thought to be unimportant. Since the p-values for the different responses are less than 0.05, it is determined that the models are significant.

The actual Regression Analysis for different values are as follows:

Mech. Efficiency= 2.307 + 4.836 x Torque - 0.0237 x I.P -0.0302 x B.P -0.000403 x Torque x I.P +0.003458 x Torque x B.P + .0000269 x I.P x B.P -0.0954 x $Torque^2$ + 0 .00317 x $I.P^2$ + 0.000510 x $B.P^2$ **(1)**

BTHE = 0.6274 + 2.720 x Torque -0.0970 x I.P -0.01588 x B.P -0.000047 Torque x I.P +0.000451 x Torque x B.P -0.003849 I.P x B.P -0.062018 x $Torque^2$ + 0.013155 x $I.P^2$ + 0.005614 x $B.P^2$ **(2)**

ITHE = 40.191 +1.81469 x Torque -0.13534 x I.P -0.11562 x B.P + 0.000951 x Torque X I.P +0.003157 x Torque X B.P +0.02021 x I.P x B.P -0.06533 x $Torque^2$ + 0.012701 x $I.P^2$ -0.001021 $B.P^2$ **(3)**

Model Evaluation

ANNOVA modelling is used to analyse the stability of the model as shown in Table below.

Model	Mechanical Efficiency	BTHE	ITHE
Mean	37.96	18.91	47.48
SD	0.0907	0.0362	0.0909
R-Square	1.0000	1.0000	0.9999
Model Degree	Quadratic	Quadratic	Quadratic
Adj.R^2	0.9999	0.9998	0.9996

Table :1 Model Evaluation

The model fits the data well because, according to regression statistics, the difference between goodness of fit and goodness of prediction is less than 0.2 and the value of p is less than 0.0500, indicating that the model terms are significant. The model fits the data well because, according to regression statistics, the difference between goodness of fit and goodness of prediction is less than 0.2 and the value of p is less than 0.0500, indicating that the model terms are significant.

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Table 2: Analysis of variation of C40D60 Biodiesel blend.

The **Model F-value** of 93423.62 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. **P-values** less than 0.0500 indicate model terms are significant. In this case A, A^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

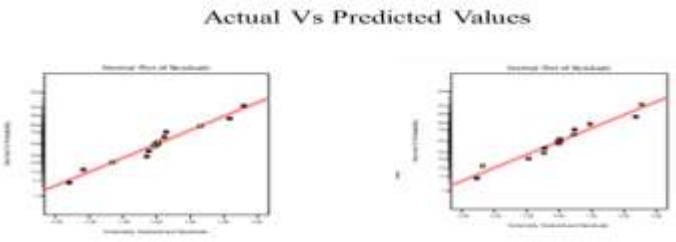

Fig.4 Actual Value Vs Predicted Values for the ITHE and BTHE

The experimental analysis of the graph in Figure 4 provides easy validation of the values by comparing the spread between the predicted and actual values for the ITHE and BTHE for the 40% blended solution that was operated at predefined conditions with a compression ratio18. The graph unequivocally demonstrates that the developed actual models of BTHE and ITHE are adjacent to and close to the theoretical values predicted during the experimental performance. This can be readily verified by observing the spread of the actual values to the predicted actual line.

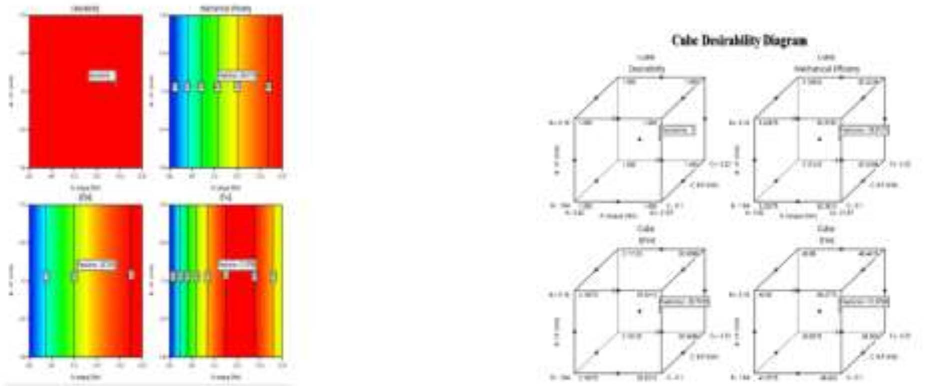

Fig. 5 Desirability Diagram at variable conditions

Optimization

Table displays the optimization criteria that were used in this investigation. Three input variables and three output variables are chosen for the model with the intention of taking into account each output and using optimization techniques to maximize the output variables. Each response in the desirability approach can be given a value between 1 and 5. The mechanical efficiency, BTHE, and ITHE are assigned the highest importance of three for this specific study. Maximum desirability of 1 is achieved with engine parameters such as compressibility ratio of 18, 40% of fuel blend, and full load condition.

	Number	torque	I.P	B.P	Mechanical Efficieny	BTHE	ITHE	Desirability	
	1	*16.931*	*3.611*	*1.417*	56.818	28.727	51.879	1.000	Selected

Optimized Result

Name	**Goal**	**Lower Limit**	**Upper Limit**	**Lower Weight**	**Upper Weight**	**Importance**
A: torque	is in range	0.62	21.87	1	1	3
B: I. P	is in range	1.84	5.16	1	1	3
C: B. P	is in range	0.1	3.23	1	1	3
Mechanical Efficiency		5.11	62.59	1	1	3
BTE		2.09	30.32	1	1	3
ITE		40.8	52.17	1	1	3

Table : Optimization Criteria

Conclusion

The following conclusion is noted after optimization is done to determine the ideal parameters for a biodiesel blend with castor oil:

- The software-designed experiments aided in the precise prediction of the responses.
- The highest desirability of 1 is attained using the RSM's desirability approach using Design Expert.
- As per the study Indicated Thermal Energy should be higher than Brake Thermal Energy, it is clearly observed from experimentation that the value of ITE is higher than BTE.
- During the analysis maximum Mechanical Efficiency observed as 56.818, Indicated Thermal Energy as 51.897 and Brake Thermal Energy as 28.727.
- Efficiency of the engine increased during the process and optimal value for the blended mixture is achieved during the analysis.
- It is observed that the increased value is obtained for the 40 % blended mixture of castor oil in diesel in VCR diesel engine at compression ratio 18 as compared to pure diesel engine.

It is shown that the ANNOVA analysis can be used to identify the variables needed for any IC engine to meet its goals. The current study determines the compression ratio, load, and blend percentage to achieve the highest levels of mechanical and thermal efficiency. This approach was discovered to be successful for multi-objective IC engine optimization.

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