

# Performance analysis and mathematical modelling engineering essay

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**ABSTRACT** –The main objective of this work is to do experimental investigations and DOE methods to optimize the direct injection (DI) single cylinder diesel engine with respect to brake power, fuel economy and emissions through. For test A single cylinder 5.2 kW diesel engine was selected for test. Five parameters, Power (P), Static injection pressure (IP), Injection timing (IT), Fuel fraction (B) and Compression ratio (CR) was varied at four levels and the responses brake power, fuel economy & emissions were investigated. The optimum values of the response could be predicted using Signal-Noise ratio(S/N ratio) and optimum combination of control parameters were specified. Results of confirmation tests showed good agreement with predicted quantities. Thus the relationship between the diesel engine parameter, brake power, b. s. f. c and Emissions could be understood using design of experiments. The best results for brake specific fuel consumption (BSFC), brake thermal efficiency (BTHE) were observed at increased CR, IP, and IT. The emissions CO, HC were reduced while NO<sub>x</sub> emissions increase. The results of the study revealed that the combination of a blend of 30% karanja biodiesel (B30), a compression ratio of 17.9, a nozzle opening pressure of 230 bar, injection timing of 27° bTDC and at 70% load produces maximum multiple performance of diesel engine with minimum emissions from the engine.

Keywords- biodiesels, Karanja, diesel engine performance, emissions,

Taguchi approach.

## **I. Introduction**

Biodiesels such as Jatropha, Karanja, Sunflower and Rapeseed are some of the popular biodiesels currently considered as substitute for diesel. In the <https://assignbuster.com/performance-analysis-and-mathematical-modelling-engineering-essay/>

present energy scenario lot of efforts is being focused on improving the thermal efficiency of IC engines with reduction in emissions. [1-3]. When biodiesel is used as a substitute for diesel, it is highly essential to understand the parameters that affect the combustion phenomenon which will in turn have direct impact on thermal efficiency and emission. Direct injection diesel engines occupy an important place in the developing countries since they power agricultural pumps, small power tillers, light surface transport vehicles and other machineries. The problem of increasing demand for high brake power and the fast depletion of the fuels demand severe controls on power and a high level of fuel economy. As far as the internal combustion engines are concerned the thermal efficiency and emission is the important parameters for which the other design and operating parameters have to be optimized. Many innovative technologies are developed to tackle these problems. Modification is required in the existing engine designs. Some optimization approach has to be followed so that the efficiency of the engine is not comprised. The most common optimization techniques used for engine analysis are response surface method, greyrelational analysis [1], non linear regression [2], genetic algorithm [3] and Taguchi method. Taguchi technique has been popular for parameter optimization in design of experiments. DOE has introduced the loss function concept which combines cost, target and variations into one metric. The signal to noise ratio (S/N) is a Figure of merit and relates inversely to the loss function. It is defined as the ratio of the amount of energy for intended function to the amount of energy wasted [4]. Orthogonal arrays are significant parts of Taguchi methods. Instead of one factor at a time variation all factors are varied simultaneously as per the

design array and the response values are observed. It has the ability to evaluate several factors in a minimum number of tests. Design of experiments (DOE) approach is cost effective and the parameters are varied simultaneously and then through statistical analysis the contribution of individual parameters towards the response value observed also could be found out. The engine operating parameters play an important role to reduce the emissions the design and operating parameters are the main factors responsible for the engine emissions and fuel economy. The fuel injection parameters like injection valve opening pressure and the compression ratio also have influence on emissions and fuel economy. In this work DOE approach is used to find the effect of design and operating parameters on brake power and specific fuel consumption (BSFC) A second order weight equation is formulated where several parameters are used to make sensitivity analysis. Design optimization is also done with several design parameters. BTHE varied widely with different injection timings than with different load, Static injection pressure, Compression ratio, were taken as parameters for the design optimization study. The effect of the parameters- injection pressure, Compression ratio, Load, and enginespeed on brake power and smoke were investigated [5]. An increase in injection pressure contributes to fuel economy by improved mixing [7]. Simultaneous reduction of NO<sub>x</sub> and particulate emissions were reported by combining the varying compression ratio and retarded injection timing [8]. Optimal combination of design and operating parameters were identified that can regulate emissions and improve brake specific fuel consumption. For identifying the optimal combination of injection schedule and fuel spray cone angle, genetic

algorithm process was used [9]. The effect of changes in the operating parameters like, piston to head clearance, injection pressure, start of injection timing on emissions were studied using Taguchi design of experiment methods. This method was found to be useful for simultaneous optimization [10]. It has been studied the effects of injection timing, fuel quantity per fuel pulse and injection rate on brake specific fuel consumption and has observed that among the various factors relevant to diesel combustion, fuel injection plays a major role in the fuel air mixing and combustion process thus determining the exhaust emissions [11]. It was also observed that the injection timing and injection rate play a major role in brake power using design of experiment method and factorial design the percentage contributions of the effect of parameters - speed, load, injection timing plunger diameter, nozzle valve opening pressure nozzle hole diameter, number of nozzle holes and nozzle tip protrusion were investigated on engine noise, emissions and brake specific fuel consumption [12]. Without considering the combustion parameters engine design and operating parameters can be optimized and engine efficiency can be increased by applying Taguchi method [13]. It is known from DOE procedure that for 5 parameters with 4 levels, the number of trial runs will be 625. In this present work an attempt is made to carry out an optimization analysis of direct injection diesel engine run by karanja biodiesel using a model in combination with taguchi method. Implementation of biodiesel in India will lead to many advantages like green cover to waste land, support to agriculture and rural economy and reduction in dependence on imported crudeoil and reduction in air pollution [14]. The karanja plant having advantages namely; effectively

yielding oilseeds from the third years onwards, rapid growth, easy propagation, life span of 40 years and suitable for tropical and subtropical countries like India [15]. It has been observed from the literature review, both bio-diesel-diesel blends and operating parameters has lot of influence on engine performance and exhaust emissions. But the effects of operating conditions such as injection pressure, injection timing, compression ratio on the engine performance and exhaust emissions of a diesel engine using biodiesel have not been clearly studied. Therefore this focus of research is about modification on engine parameters for the best output using optimization techniques

## **II. EXPERIMENTAL DETAILS AND METHODOLOGY**

### **A. Experimental set up**

The experimental set up consists of a direct injection single cylinder diesel engine connected to an eddy current type dynamometer for loading which is shown in Figure. 1. Details of the engine specification are shown in Table-1. The signals from the combustion pressure sensor and the crank angle encoder are interfaced to a computer for data acquisition. The control module system was used to control the engine load, monitor the engine speed and measure the fuel consumption. Windows based engine performance analysis software package " Engine soft" is provided for online performance evaluation. HC, CO, CO<sub>2</sub>, K (air surplus rate) NO<sub>x</sub> emissions were measured with an infra red gas analyzer with an accuracy shown in Table-2. The fuels properties were tested using standard measuring devices shown in Table-3 and results are shown in Table-4.

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## B. Procedure

Compression ratio is altered by adding different number of gaskets between the cylinder head and the block since this method does not need major modification in the engine. In this study the number of gaskets has been increased from the original one to maximum modification of four gaskets. Injection timing was altered by adjusting the number of shims under the seat of the mounting flange of the fuel pump. When the number of shims were added timing was retarded. Each time the number of shims are added the timing of the start of injection was found by rotating the flywheel and the correct position is marked in the fly wheel when the fuel spray appears first through the spray holes . Thickness of one shim, located in connection place between engine and fuel pump, is 0. 20 mm and adding or removing one shim changes the IT 2°, This exercise was repeated five times to get the correct timings in terms of crank angle. Changing the nozzle spring tension adjusted the nozzle opening pressure. When the spring preload is Increased by tightening the nut above the spring, the nozzle opening pressure increases. Engine cylinder pressure was measured using quartz miniature pressure transducer mounted in the cylinder head of the engine. Figure-1

Experiment Set up Make and model Kirloskar model TV 1 ENGINE TYPE Single Cylinder four stroke direct Injection Bore \* Stroke 87. 5 mm\*110 mm Maximum Power Output 5. 2 kw at 1500rpm Displacement 661 cc CR 17. 5 Loading Eddy Current Dynamometer, Water Cooling Fuel Injection 23 b TD

Table -1: Engine Specification

Measuring Item	Measuring Method
Range	COND IR 0-9. 99% 0. 01% HC ND IR 0-5000ppm 1ppm NOX Electrochemical 0-5000ppm 1ppm

Table -2 : Exhaust



Analyzer Specification Properties Measurement Apparatus Standard Test Method Density Hydrometer ASTM D941 Flash & Fire Point Pensky martins apparatus ASTM D93 Calorific Value Bomb Calorimeter ASTM D240 Viscosity Red Wood Viscometer ASTM D445 Cetane Number Ignition Quality Tester ASTM D613

Table 3: Measuring devices and test methods for measuring fuel properties Biodiesel Kinematic Viscosity Heating value (MJ/Kg) HV Flash Point Density (Kg/l) p Cetane Number B02. 7142. 5550. 83651. 00B204. 0141. 5650. 84951. 70B405. 2339. 9770. 85852. 82B606. 7238. 7880. 86253. 15B808. 1937. 01010. 87853. 86B1009. 6035. 91140. 90054. 53

Table 4-: Properties of Biodiesel –Blends-Karanja

### III. Design of Experiments

DOE technique is used to identify the key factors that make the greatest contributions to the variation in response parameters of interest. It introduced the loss function concept which combines cost, target and variations into one metric. The signal-noise ratio is a Figure of merit and relates inversely to the loss function. It is defined as the ratio of the amount of energy for intended function to the amount of energy wasted. DOE recommends orthogonal array (OA) for lying out of the experiments which is significant part of this method. Instead of varying one factor at a time, all factors are varied simultaneously as per the design array and the response values are observed. It has the ability to evaluate several factors in a minimum number of tests. The results of the experiments are analyzed to achieve the following objectives To establish the optimum conditions for the BTHE, BSFC, HC, NO<sub>x</sub>; To estimate the contributions of individual parameter to the response; To estimate the contributions of individual parameter to the

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response; To predict the response under optimum conditions; To run the confirmation test for validation. The optimum condition is identified by studying the main effects of each of the parameters. The main effects indicate the general trend of influence of each parameter. The steps involved in DOE method are: Identifying the response functions and control parameters to be evaluated; Determining the number of levels of the control parameters; Selecting the appropriate orthogonal array, assigning the parameters to the array and conducting the experiments; Analyzing the experimental results and selecting the optimum level of control parameters; Validating the optimal control parameters through a confirmation experiment. In the present investigation, the S/N data analysis has been performed. The effect of the selected control parameters on the response functions has been investigated. The optimal conditions are established and verified through a confirmation experiment.

#### **IV. Grey Relational Analysis**

The Grey Relational Analysis (GRA) associated with the Taguchi method represents a rather new approach to optimization. The grey theory is based on the random uncertainty of small samples which developed into an evaluation technique to solve certain problems of system that are complex and having incomplete information. A System for which the relevant information is completely known is a 'white' system, while a system for which the relevant information is completely unknown is a 'black' system. Any system between these limits is a 'grey' system having poor and limited information [6]. Grey Relational Analysis (GRA) a normalization evaluation

technique is extended to solve the complicated multi performance characteristics optimization effectively

## V. EXPERIMENTATION AND ANALYSIS

### A. Selection of control parameters

The following control parameters as given in Table-5 were selected for the investigation since they have influence on the objectives of improving brake power and fuel economy. More parameters are related to the fuel injection and these parameters were found to be suitable for the experiment and could be done with available engine configuration. Four levels were chosen for this investigation. Controlled factors

Level 1	Level 2	Level 3	Level 4
A. Compression ratio	17.5	17.7	17.9
B. Static injection pressure	230	220	210
C. Injection timing (bTDC)	23	25	27
D. Fuel fraction (%)	10	20	30
E. Power (kW)	3.6	4.1	4.6

Table-5. Setting levels for design parameters

### B. Selection of orthogonal array

Orthogonal array was selected based on the number of parameters and the levels. Number of experiments =  $(L-P) + 1$  where, L is the number of levels and P is the number of parameters, the array is shown in Table-6.

Factors	Compression ratio (CR)	Static injection pressure (IP) (bar)	Injection timing (IT) bTDC	Fuel fraction (%)
Run No.	(X1)	(X2)	(X3)	(X4)
(Y)	117.5	230	23	10
	23103.6	217.5	22025	204.1
	16317.5	21027	304.6	8417.5
	19029	505.2	517.7	23025
	305.2	617.7	22023	504.6
	68717.7	21029	104.1	6817.7
	19027	203.6	64917.9	23027
	504.6			

(%)

Power(kW) RunNo. (X1)(X2)(X3)(X4)(Y) 117.5 230 23 10 3.6

23103.6 217.5 220 25 4.1

16317.5 210 27 30 4.6

19029 505.2 517.7 230 25 305.2 617.7 220 23 504.6

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161017. 922029303. 641117. 921023205. 21217. 919025104. 161318.  
123029204. 161418. 122027105. 21518. 121025503. 641618. 119023304.  
68Table-6. L 16 design array of the experiment

### **C. Setting optimum conditions and prediction of response variables**

The next step in DOE analysis is determining optimal conditions of the control parameters to give the optimum responses. Hence the optimum parameter settings will be those that give maximum values of the BTHE and minimum values of B. S. F. C, HC, and NOx. The optimum settings of the parameters were achieved from the S/N Tables of the control parameters. The optimum value of response variable can be predicted using the additivity law.

### **D. Developing a multiple regression model**

The empirically developed mathematical model links a quantitative dependent variable (CR, IP, IT, Fuel Fraction, Brake Power) to the selected independent variables or the design and control parameters (X1, X2, X3, X4, Y) selected. Regression is one of the popular statistical tools. The Minitab regression tool is used for this. Regression analysis provides a method of linking the performance variable with the design parameters through a mathematical model if more than one design parameter affecting the response parameters are there still linear regression can be used to mathematically link the dependent variable to the independent ones. This is termed as multiple regressions. When there are five design parameters involved the regression model becomes,  $Y = 6.8 - 0.65X_1 - 0.0026X_2 - 0.$

0325X3+0. 0041X4 This model is natural extension of the simple linear regression model.

## VI. RESULTS AND DISCUSSIONS

A. Engine performance The engine after obtaining the stabilized working condition fuel consumption, torque applied. Controlled factors Level 1 Level 2 Level 3 Level 4 A. compression ratio 17. 517. 717. 918. 1B. Static injection pressure 230230230230C. Injection timing (bTDC) 23232323D. D. Fuel fraction (%) 10101010E. Power (kW) 4. 354. 344. 334. 31a. Effect of compression ratio Table-7. Setting levels for design parameters Power vs compression ratio b. Effect of Static injection pressure Controlled factors Level 1 Level 2 Level 3 Level 4 A. compression ratio 17. 517. 517. 517. 5B. Static injection pressure 230220210190C. Injection timing (bTDC) 23232323D. D. Fuel fraction (%) 10101010E. Power (kW) 4. 354. 344. 334. 31 Table-8. Setting levels for design parameters Power vs Static injection pressure c. Effect of injection timing Controlled factors Level 1 Level 2 Level 3 Level 4 A. compression ratio 17. 517. 517. 517. 5B. Static injection pressure 230230230230C. Injection timing (bTDC) 23252729D. D. Fuel fraction (%) 10101010E. Power (kW) 4. 354. 344. 334. 31 Table-9. Setting levels for design parameters Power vs injection timing d. Effect of fuel fraction Controlled factors Level 1 Level 2 Level 3 Level 4 A. compression ratio 17. 517. 517. 517. 5B. Static injection pressure 230230230230C. Injection timing (bTDC) 23232323D. D. Fuel fraction (%) 10203050E. Power (kW) 4. 354. 344. 334. 31 Table-10. Setting levels for design parameters

## VII. CONCLUSION

The Taguchi's approach analysis has been carried out for optimizing the performance of karanja biodiesels engine. The various input parameters have been optimized using SNR. Based on this study, it can be concluded that the model made clearly shows that power is directly proportional to fuel fraction(X4), and power is inversely proportional on the rest three parameters as compression ratio, nozzle pressure and injection timing. The results of this study revealed that almost identical combinations of engine parameters give optimum multiple performances for engine. The results are well supported by the findings of our confirmatory test.