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Parametric optimization of single cylinder CI engine for specific fuel consumption using mahua oil blend

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Abstract:*An experiment study has been carried out for MAHUA oil blended with diesel used in single cylinder CI engine. MAHUA oil is non edible vegetable oil which is available in large quantities in India. Blending of mahua oil with diesel in maximum possible proportion helps to reduce the specific fuel consumption of diesel fuel. This study applies the L16orthogonal array of the taguchi method to find out the best injection pressure blend proportion and load for minimum specific fuel consumption. The result of the taguchi experiment identifies that 0% blend ratio, engine load 10 kg and injection pressure 160 bar are optimum parameter setting for minimum specific fuel consumption. Engine performance is mostly influenced by engine load and least influenced by injection pressure. Confirmation experiment was done using optimum combination showed that specific fuel consumption was found by experiment is closer to the predicated value*.
Keywords -*mahua oil, injection pressure, specific fuel consumption, and Taguchi method.*

I. Introduction

Recent survey on the world energy consumption highlights that a major portion of the total energy consumed is derived from the combustion of fossil fuels. Unfortunately, the reserves of fossil fuels, specially the liquid fuels are not unlimited and may exhaust, if not utilized economically, within few decades. Efforts are being made throughout the World to reduce the consumption of liquid petroleum fuels wherever is possible. Two general approaches are in use. First is to switch over the energy consumption devices on alternative energy source. The second is to enhance the efficiency of combustion devices The first one is quite easy to achieve.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 for which the other design and operating parameters have to be optimized. The most common optimization techniques used for engine analysis are response surface method, grey relational 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 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 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 engine speed on brake power and smoke were investigated [5]. An increase in injection pressure contributes to fuel economy by improved mixing [6]. Optimal combination of design and operating parameters were identified that can improve brake specific fuel consumption. This method was found to be useful for simultaneous optimization. It has been studied the effects of injection pressure load and biodiesel blend on brake specific fuel consumption. Without considering the combustion parameters engine design and operating parameters can be optimized and engine efficiency can be increased by applying Taguchi method. It is known from DOE procedure that for 3 parameters with 4 levels, the number of trial runs will be 64. In this present work an attempt is made to carry out an optimization analysis of direct injection diesel engine run by MAHUA OIL blend using a model in combination with taguchi method.

II. Literature Review

Performance and combustion behavior of diesel engine with different edible and non-edible oil has been evaluated by many researcher and scientists to establish suitability and feasibility of vegetable oils and biodiesel as an alternative fuel for diesel engines. The conclusions of previous studies are presented. Gupta et al (2014) conducted experimental work carried out to analyze the emission and performance characteristic of single cylinder engine using karanja oil and find the injection timing of 25º BTDC is found to be the optimum injection timing, as highest brake thermal efficiency and lowest brake specific fuel consumption [7]. Kannan et al (2012) analyzed the emission and performance characteristic of single cylinder engine using waste cooking oil with varying injection pressure and injection timing [8]. Patel et al (2012**)** conducted experiment on diesel engine using biofuel at varying compression ratio as result of experiment it is found that when compression ratio increases brake thermal efficiency (BTHE) increases and brake specific fuel consumption (BSFC) decreases [9]. Kumar et al (2013)were used jatropha as biodiesel and take Comparative analysis of performance and emission of diesel engine by varying Compression ratio by the experiment they get that maximum brake power is obtained at compression ratio of 18:1 using b 50 at full load [10]. Krunal et al (2013) Parametric Optimization of Single Cylinder Diesel Engine for Pyrolysis Oil and Diesel Blend for Specific Fuel Consumption Using Taguchi Method[11].

III. Property of MAHUA OIL

Mahua oil (MO oil) is an underutilized non-edible vegetable oil, which is available in large quantities in India. The fuel properties of the MO Oil biodiesel were found to be within the limits of biodiesel specifications of many countries. Fuel properties of diesel, mahua oil and blends are comparable. The calorific value of mahua oil was found as 96.30% on volume basis of diesel. It was found that mahua could be easily substituted up to 20% in diesel without any significant difference in power output, brake specific fuel consumption and brake thermal efficiency. The performance of engine with mahua oil blends improved with the increase in compression ratio from 16:1 to 20:1. Based on this study, it has been observed that esters of mahua oil could be used as a substitute for diesel.

The specific gravity of mahua oil was 9.11% higher than that of diesel. The kinetic viscosity of mahua oil was 15.23 times more than that of diesel at temperature of 40^{o}c. the kinetic viscosity of mahua oil reduced considerably with increasing the proportion of diesel in fuel blend.

Mahua Oil

Botanical name: - Madhuca indica
Family: - Sapotaceae
Color: - Pole Yellow
Consistency: - Plastic

Property Of Mahua Oil And Its Compression

Comparison of mahua oil with diesel oil:

a) Caloric value and carbon residue: The calorific value of mahua oil was observed as 88.26% of diesel on weight basis and 96.30% on volume basis. The calorific value of a mahua oil was found nearer to diesel fuel in comparison with other liquid fuel option like ethanol and methanol. The carbon residue of mahua oil was found higher than that of the limit specified for grade-A diesel and this may increase the chance of carbon deposition in the combustion chamber. The higher carbon residue may be due to the difference in chemical composition and molecular structure of mahua oil.
b) Flash point: The flash point of mahua oil was very high as compared to diesel thus indicating its low volatile nature. The result of increase in concentration of mahua oil in diesel revealed that the power output decreases at all compression ratios.
c) Brake thermal efficiency and a/f ratio: Brake thermal efficiency decreased with the increase of mahua oil in diesel at all compression ratio in comparison with pure diesel. Exhaust gas temperature increased with the concentration of mahua oil in diesel. The air-fuel ratio and volumetric efficiency decreased with increase in concentration of mahua oil in diesel.

Table -1: Property of Mahua and diesel

Property	Diesel	Mahua oil
Calorific value(KJ/Kg)	42,500	36,100
Viscosity(mm^2/s)at 40^{o}c	4.3	24.58
Density (Kg/l)	0.815	0.960
Cetane Number	47	61.40
Flash Point(^{o} c)	58	232
Ash content %	0.01	0.09

IV. Methodology

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. 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. As far as the internal combustion engines are concerned the thermal efficiency is the important parameters for which the other design and operating parameters have to be optimized. The most common optimization techniques used for engine analysis are response surface method, grey relational analysis, nonlinear regression, genetic algorithm and Taguchi method.

Taguchi method

The Taguchi method provides simple and effective solutions for investigating the effect of parameters on the performance as well as in the experimental planning. In this method, the signal -to-noise (S/N) ratio is used to represent a performance characteristic and the largest value of the S/N ratio is required. There are three types of S/N ratios-the lower-the better, the -higher-the better and the-more-nominal -the – Better.

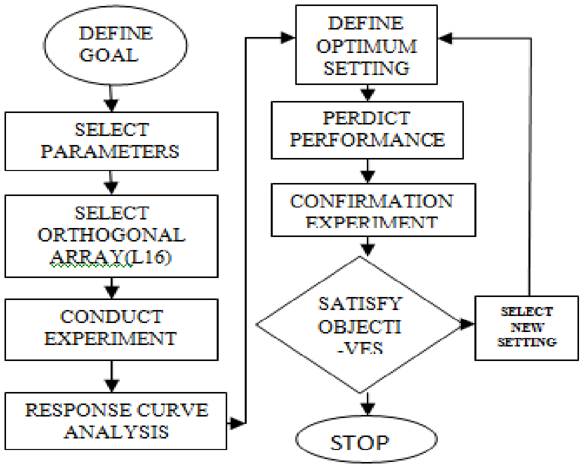

Fig-1 flow chart of taguchi method.

The objective of the work is to investigate the engine operating and injection parameters having maximum potential for increasing brake power and for improving the fuel economy and to identify the optimized range of input parameters for better fuel economy. 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. In the present study uses three factors at four levels and hence, an L16 orthogonal array was used for construction of experiment lay out (Table 2 column -1, 2, 3). The L16 has the parameter such as load, injection pressure and blend proportions are arranged in column 1, 2 and 3. (Table -2).

Selection of factor levels and orthogonal array

In this experiment, three parameters for four levels were consider (table-1). Control parameter and their level are given in table L16 single orthogonal array shown in table-2(column- 1, 2 &3) was selected for the experimental investigation. "Smaller is better" is being taken as quality characteristics since the objective function is to find minimum specific fuel consumption.

Table-2: process parameters and their lavel

Controlled factors	Injection pressure	Blend ratio	Engine load
Units	Bar	% MAHUAoil in diesel	Kg
Level 1	160	0	1
Level 2	180	10	4
Level 3	200	20	7
Level 4	220	30	10

V. Experimental Setup

The experimental set up consists of a four stroke, multi-fuel, direct injection single cylinder research 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.

The injection point and spark point can be changed for research tests. Setup is provided with necessary instruments for combustion pressure, Diesel line pressure and crank-angle measurements. These signals are interfaced with computer for pressure crank-angle diagrams. Instruments are provided to interface airflow, fuel flow, temperatures and load measurements. The set-up has stand-alone panel box consisting of air box, two fuel flow measurements, process indicator and hardware interface. Rota meters are provided for cooling water and calorimeter water flow measurement. A battery, starter and battery charger is provided for engine electric start arrangement.

The setup enables study of VCR engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio, heat balance and combustion analysis. Lab view based Engine Performance Analysis software package “Engine soft” is provided for on line performance evaluation.

Fig-2 Experimental setup

VI. Experimental investigation

Experiment was done for the three parameter which we are selected and sets of parameters by Minitab software and find maximum fuel economy for those sets of parameters. Brake specific fuel consumption for those sets are given in the table.

Table-3: result table for brake specific fuel consumption

EXP NO	Pressure	Blend	Load	SFC (kg/kWh)
1	160	B0D100	1	1.33
2	160	B10D90	4	0.43
3	160	B20D80	7	0.32
4	160	B30D70	10	0.3
5	180	B0D100	4	0.41
6	180	B10D90	1	0.91
7	180	B20D80	10	0.29
8	180	B30D70	7	0.35
9	200	B0D100	7	0.32
10	200	B10D90	10	0.3
11	200	B20D80	1	1.34
12	200	B30D70	4	0.47
13	220	B0D100	10	0.28
14	220	B10D90	7	0.34
15	220	B20D80	4	0.49
16	220	B30D70	1	1.32

Response Curve analysis

Response curve analysis is aimed at determining influential parameters and their optimum levels. It is graphical representations of change in performance characteristics with the variation in process parameter. The curve give a pictorial view of variation of each factor and describe what the effect on the system performance would be when a parameter shifts from one level to another. Figure- 4 shows significant effects for each factor for five levels. The S/N ratio for the performance curve were calculated at each factor level and average effects were determined by taking the total of each factor level and dividing by the number of data points in the total. The greater difference between levels, the parametric level having the highest S/N ratio corresponds to the parameters setting indicates highest performance

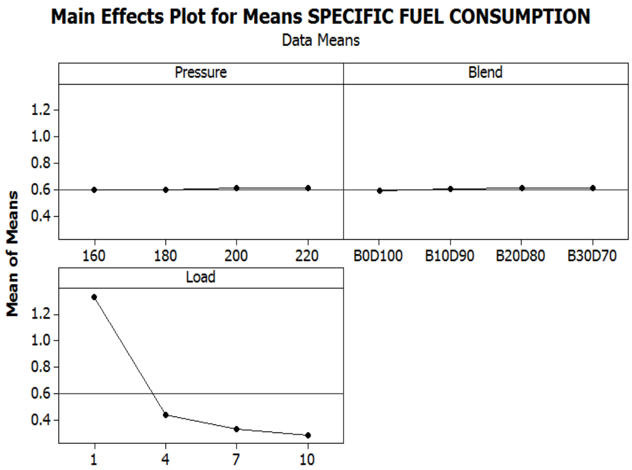

Fig-3: Main Effects Plot for mean ratios of Brake specific fuel consumption

From above figure-3, mean is an average value for reading taken for particular parameter. From graph, mean value is maximum (0.61) for 20% and minimum (0.5925) for 0% blend. Mean value is maximum (0.6075) for 200 and 220 bar injection pressure and minimum (0.5975) for 160 bar injection pressure. Mean value is maximum (1.3350) for 1 kg load and minimum (0.2925) for 10 kg engine load

Delta is difference of maximum value and minimum value. Delta value is maximum for load parameter (1.0425) and minimum (0.0175) for Blend ratio. Delta value for injection pressure is between other two parameter and it is (0.0100).So that effect of load is maximum and effect of Blend is minimum on Brake specific fuel consumption.

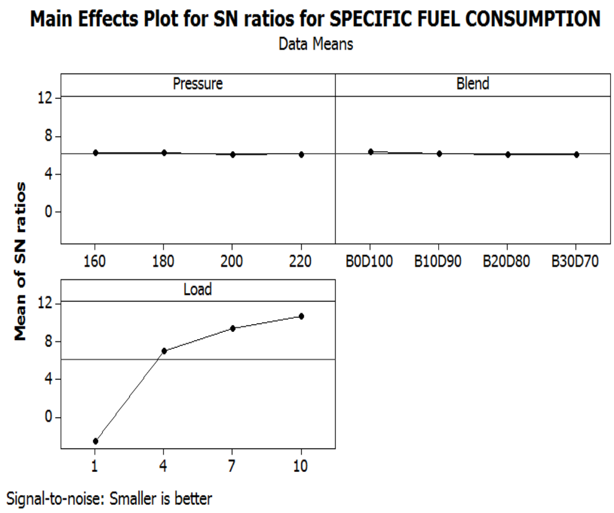

Fig -4: Main Effects Plot for SN ratios of Brake specific fuel consumption

Referring (Figure.4), the response curve for S/N ratio, the highest S/N ratio was observed at 0% blend ratio (6.371), engine load 10kg (10.681) and injection pressure160 bar (6.235), which optimum parameter are setting for minimum specific fuel consumption. From delta values as mention above, maximum (13.191) for engine load and minimum (0.180) for bland ratio. Parameter engine load is most significant parameter and bland ratio is least significant for brake specific fuel consumption.

The term optimum set of parameters is reflects only optimal combination of the parameters defined by this experiment for lowest brake specific fuel consumption. The optimum setting is determined by choosing the level with the highest S/N ratio.

Table-4: Choosing optimum combination of parameter level

LEVEL	INJECTION PRESSURE	BLEND	LOAD
1	6.235	6.371	-2.510
2	6.216	6.154	7.044
3	6.055	6.054	9.372
4	6.081	6.009	10.681
DELTA	0.180	0.363	13.191
RANK	3	2	1

Referring figure-4 and table-3, the response curve for S/N ratio, the highest performance at set 0% blend ratio, engine load 10kg, and injection pressure160 bar, which is optimum parameter setting for lowest brake specific fuel consumption.

Predict performance at optimum setting

Table-5: Optimum Output

S/N RATIO	SFC (KG/KWH)
10.9936	0.27625

Using optimum set of parameters, which was achieved by response curve analysis was used for prediction by Minitab software. Minitab software for taguchi method of optimization was suggested specific fuel Consumption 0.27625 and S/N ratio was 10.9936 for optimum set of parameter as shown in table 4.

VII. Conclusion

The results of the taguchi experiment identifies that injection pressure 160 bar, blend 0% and engine load 10 kg are optimum parameter setting for lowest break specific fuel consumption. Engine performance is mostly influenced by engine load and is least influenced by injection pressure.

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