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Parametric Optimization of Brake Power and Specific Fuel Consumption on A Single Cylinder VCR Engine By Taguchi Method Using Jatropha Biodiesel Derived From Jatropha Curcas Oil Conducting Experiments As Per IS 10000 Approach

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Abstract: *The main purpose of this research work is to evaluate the predicted values for the corrected Brake power (BP) and corrected specific fuel consumption (SFC) of single cylinder VCR diesel engine operated on diesel and jatropha biodiesel blend (0%, 25%, 50%, 75%, 100%) derived from jatropha curcas oil. Current research work concentrates on the performance parameters of engine 4 stroke single cylinder CI engine, carried out using ISO 10000 approach in which the brake power and specific fuel consumption are corrected via correction factors "α" & "β" respectively. Also examine combined effect of brake power at various blends and loads in order to find out optimal performance of CI engine by conducting experiments as per IS 10000 method. The experimental work will be used to find out load and blend ratio for optimal brake power and lower specific fuel consumption by using Taguchi's approach using Minitab software. A set of experiments have been performed as suggested by the software. Engine variable such as loads and blend ratio (Diesel + % JBD) are the most significant variables for brake power at specific fuel consumptions. After experiments, it is reported that the optimized parameters for corrected BP (2.95 KW) are at 100% blend and 10 kg of engine load, and optimized parameter for corrected SFC (0.26 kg/KWh) are at 0% blend and 10 kg engine.*
Keywords*: Jatropha biodiesel, IS 10000 standards, Taguchi optimization*

I. Introduction

Energy plays a significant role in boosting economic growth, and the demand for fossil fuels continues to increase over the years. The depletion of world oil reserves leads to the development of biofuels since these fuels are promising alternatives to substitute fossil fuels (1). In this regard, it is expected that biodiesels will replace 20% of all on-road diesel fuels by 2020 (2).

However, approximately 95% of the biodiesels produced today are derived from edible vegetable oils due to the abundance of agricultural crops (3). This results in an ongoing debate regarding the use of agricultural lands for fuel purposes as well as growing concern over global food security (4). For these reasons, non-edible feed-stocks are being explored by the scientific community for biodiesel production. However, the sufficiency of raw materials, the type of plants and the harvest capacity per period are among the factors that need to be considered for biodiesel production, along with the sustainability of the program (5). Jatropha is a renewable, non-edible plant. The Jatropha oil can be extracted from its seed which have very similar properties to diesel, but ignition point, flash point, kinematic viscosity is high in Jatropha oil. It can be produced by chemical process known as 'transesterification' (6). It is a process in which the vegetable oil or animal fat reacts with an alcohol such as methanol (7). This reaction requires a catalyst, and it is a strong acid such as sodium or potassium hydroxide (KOH). After this process the new chemical compound which is made is known as methyl ester, and it is also known as a biodiesel.

Biodiesel can be manufactured from Jatropha curcas plants, which can cultivate in drained, semi-arid and waste land in India (8). It requires less water and stimulant and can infertile soil. The Jatropha seeds have 35-40% oil in it and can be produced in the rural areas (9). It will also provide a green cover over the wasteland as well increases the rural economy and reduces the air pollution. The Jatropha oil can directly use in CI engine as well as it can be used after blending with the diesel fuel. Jatropha oil has its own benefits and limitations. It possesses advantages like, easy to develop, can grow in any kind of climatic conditions as well as on any type of soil with less amount of water requirement. It also provides higher rate of output and easy to maintain. Jatropha oil has limitations like, higher toxicity levels than usual oils, poisonous seeds, it can cause diarrhea (10). So, it can't be applied as an edible product, but it can be used as biodiesel in diesel engine.

Diesel has maximum BTE at 23obTDC among all the tested fuels. Among all the polanga biodiesel blends B30 blend shows maximum value of brake thermal efficiency (33.5 %) at 27obTDC B40 blend shows the lowest UHC emission- of 24 ppm volume and While NOx emissions increases with biodiesel blend percentage. By retarding fuel injection timing from 23obTDC to 19obTDC, smoke opacity is reduced. BTE increases at higher fuel injection pressure, and the highest value of BTE (34 %) which are found at 220 bar fuel injection pressure for B40 polanga biodiesel blend. (11) The suitable conditions of the engine control parameters are found out to be:NOx emissions: A2 (200 bar), B3 (17.14oBTDC) and C1 (2.56 kW). Brake thermal efficiency: A2 (200 bar), B1 (12.38oBTDC) and C4 (4.84 kW). Amongst the engine control parameters fuel injection pressure has more effect on the exhaust emissions (NOx)as well as on brake thermal efficiency of engine. Varying the load torque does not have considerable effect on the NOx emissions. (12)

II. Fuel Properties and Experimental setup

Table 1: Properties of Jatropha Biodiesel (JBD) derived from jatropha curcas oil

Parameter	Unit	Value
Density @ 15°C	Kg/m3	896
Calorific value	kJ/kg	39100
Kinematic viscosity @ 40°C	Cp	14.69
Kinematic viscosity @ 100°C	Cp	9.82
Flash point	°C	135
Sulfur content	mg/kg	14
Carbon residue	% by mass	0.015
Sulfated ash	Ppm	26
Water content	mg/kg	1054
Total contamination	mg/kg	11
Acid value	mg KOH/gm	24
Methanol content	% by mass	0.14
Ethanol content	% by mass	0.18
Ester content	% by mass	98.11
Free Glycerol content	mg/kg	152
Total Glycerol content	% by mass	0.14

Figure 1: Experimental Setup

The experimental work was performed on a single cylinder, four stroke and vertical fully computerized VCR Engine. The engine speed was maintained around 1500±3% rpm. A strain gauge load cell incorporated in the restraining linkage between the casing and dynamometer bed plate which measures the rotational torque. The engine was tested for pure diesel, 25%, 50%, 75% and 100% blend with biodiesel for varying load condition. Engine has Separate panel box having two fuel tanks, air box, manometer, fuel measuring unit and hardware interface with test rig having multiple fuel selection options. Data were collected after the engine runs for at least 60 seconds for each test fuel. The experiment was repeatedly done three times. The tests were conducted for the above mentioned fuels at various loads to obtain performance output.

Table 2: Engine Specification

Make and Model	Kirloskar Model AV 1
Number of cylinder	4 stroke Single Cylinder C.I Engine
Swept Volume	552.64 cc
Bore	80 mm
Stroke	110 mm
Power	3.7 KW
Speed	1500 rpm
Compression ratio range	12 to 18
Loading	Eddy current dynamometer, water cooling

III. Methodology

The aim of this research, to analyze the output response parameters like corrected BP and corrected SFC by considering % of BD and Load as input parameters for VCR engine.

3.1 IS 10000 approach

According to IS 10000 (Part IV) standards, brake power and specific fuel consumption must be corrected to standard conditions by considering the correction factors α and β respectively. Value of correction factors for measured climate condition is given below in table 3. Varying loads, diesel blend, calculated brake power and specific fuel consumption and corrected brake power and specific fuel consumption for each load are also shown.

Table 3: Corrected brake power and Corrected specific fuel consumption

Exp.No.	Density	CalorificValue of fuel	Torque T	Calculated BP	Correction Factor for BP α	Corrected BP	Calculated SFC	Correction Factor for SFC β	Corrected SFC
	(kg/m3)	(kJ/kg)	(Nm)	(KW)		(KW)	(kg/KWh)		(kg/KWh)
1	832	44000	3.81	0.63744864	1.0252764	0.62173346	0.62649753	0.99632824	0.62880636
2	832	44000	7.55	1.25564351	1.0252764	1.22468782	0.39756507	0.99632824	0.39903021
3	832	44000	11.09	1.83378082	1.01833	1.80077266	0.32666936	0.99731914	0.32754746
4	832	44000	14.41	2.3513417	1.01833	2.30901742	0.29722605	0.99731914	0.29802501
5	832	44000	18.58	2.99161307	1.01833	2.93776385	0.28367305	0.99731914	0.28443558
6	848	42248	3.68	0.61658596	1.01181336	0.60938705	0.66015126	0.9982611	0.6613012
7	848	42248	7.15	1.18549719	1.01181336	1.17165599	0.42918702	0.9982611	0.42993463
8	848	42248	10.98	1.80772859	1.01181336	1.78662257	0.36589563	0.9982611	0.366533
9	848	42248	14.41	2.35435818	1.00969088	2.33176136	0.30255379	0.99857053	0.3029869
10	848	42248	18.38	2.96717354	1.00969088	2.93869501	0.27436211	0.99857053	0.27475487
11	864	40496	3.56	0.59718593	1.01263178	0.58973651	0.60764995	0.99814214	0.60878098
12	864	40496	7.77	1.29349001	1.01263178	1.27735475	0.40077619	0.99814214	0.40152216
13	864	40496	11.07	1.82730338	1.01263178	1.80450922	0.36880575	0.99814214	0.36949222
14	864	40496	14.57	2.37341819	1.01828553	2.33079832	0.32762873	0.99732553	0.32850732
15	864	40496	18.33	2.94495649	1.01828553	2.8920734	0.28164762	0.99732553	0.2824029
16	880	39798	3.79	0.63044313	1.01974	0.61823909	0.67000493	0.99711691	0.6719422
17	880	39798	7.46	1.23430595	1.01974	1.2104124	0.42777077	0.99711691	0.42900763
18	880	39798	11.11	1.82283186	1.01664463	1.79298823	0.37655695	0.9975616	0.37747739
19	880	39798	14.72	2.40168529	1.01570697	2.36454545	0.30778387	0.99769684	0.30849438
20	880	39798	18.46	2.99048094	1.01570697	2.94423591	0.28249637	0.99769684	0.2831485
21	896	39100	3.77	0.62070987	1.00969088	0.61475238	0.77949462	0.99857053	0.78061048
22	896	39100	7.75	1.27586795	1.00969088	1.26362234	0.46349624	0.99857053	0.46415975
23	896	39100	10.93	1.79990817	1.00969088	1.78263289	0.35841829	0.99857053	0.35893137
24	896	39100	14.50	2.37525505	1.01169645	2.3477942	0.31686702	0.99827812	0.31741357
25	896	39100	18.40	2.99706855	1.01169645	2.96241877	0.30493797	0.99827812	0.30546394

3. 2 Taguchi Method

The taguchi approach was applied to determine the optimum set of parameters for fuel consumption, sfc, brake thermal efficiency and mechanical efficiency. The experiment was conducted using fuel blend of 25%, 50%, 75% and 100% by volume JBD with diesel fuel. The corresponding response parameters were noted, when experiments are carried out as per the run order of the minitab-17 input parameters given by taguchi method. The model was analyzed by using Taguchi Analysis. Predicted values by taguchi and experimental values are compared to find the % error in the experiments.

3.3 Taguchi optimization with MINITAB

The Taguchi method defines two types of factors: control factors and noise factors. An inner design constructed over the control factors finds optimum settings. An outer design over the noise factors looks at how the response behaves for a wide range of noise conditions. The experiment is performed on all combinations of the inner and outer design runs. A performance statistic is calculated across the outer runs for each inner run. This becomes the response for a fit across the inner design runs.

3.4 Procedure

The Taguchi method delivers simple and effective results for examining the effect of parameters on the performance as well as in the experimental development. In this method, the signal to noise (S/N) ratio is used to signify a performance characteristic and the largest value of the S/N ratio is required. There are three types of S/N ratios:

i) The lower-the better,
ii) The higher-the better and
iii) The more nominal-the better

The criteria for optimization of the response parameters was based on the smaller the better S/N ratio.

$$S/N = -10\log\left[\frac{1}{r}\sum_{i=1}^{r} y_i^{2}\right] \quad \text{--(3.1)}$$

y_iRepresents the measured value of the response variable- i.

The S/N ratio with a higher –the-better characteristic can be expressed as

$$S/N = -10\log\left[\frac{1}{r}\sum_{i=1}^{r} y_i^{2}\right] \quad \text{--(3.2)}$$

y_iRepresents the measured value of the response variable- i.

The negative sign is used to ensure that the largest value gives an optimum value for the response variable and therefore robust design.

3.5 Setting Optimum Conditions & Prediction Of Response Variables

The next step in Design of Experiment (DOE) analysis is to determine the optimal conditions of the control parameters to give the optimum responses. In this task the response variables to be optimized were brake power and brake thermal efficiency has to be maximized and specific fuel consumption and emissions to be reduced as much as possible. Hence, the optimum parameter settings will be those that give maximum values of the brake power, brake thermal efficiency and minimum values of specific fuel consumption.
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 law of additive.

$$OPT = T + \sum_{i=1}^{x}(X_i - T) \quad \text{-- (3.3)}$$

Where T is the overall mean value of the output response variable for the test runs conducted. Xi is the design and control parameter value for the, I level of the parameter X.

3.6 Factors and Levels

The experiments were designed according to the taguchi L25 orthogonal array for blend percentage and load. It has 25 rows corresponding to the number of testes with 5 columns at 5 levels and 2 parameters. This orthogonal array was chosen due to its ability to check the interaction among factors. Selected factors and their levels shown in Table

4. The category lower the better was applied to calculated the S/N ratio for SFC. Taguchi method was applied to select the control factors levels (blend ratio and load) in order to find out optimal response value of SFC.

Table 4: Factors and their Levels

Factors	Level 1	Level 2	Level 3	Level 4	Level 5
% Blend	0	25	50	75	100
Load	2	4	6	8	10

3.7 Taguchi Analysis for Corrected Brake Power

Response tables and graphs for means and SN ratios for corrected brake power are shown in Table 5 and Table 6 and in Figure 2 and Figure 3 respectively.

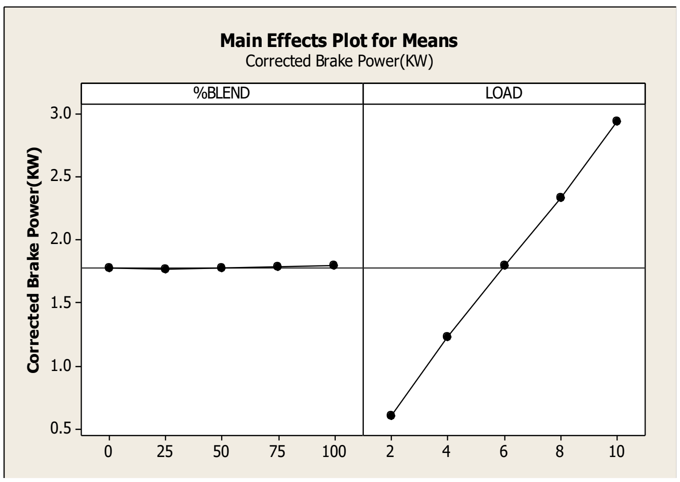

Figure 2: Main Effects Plot for Means for corrected BP

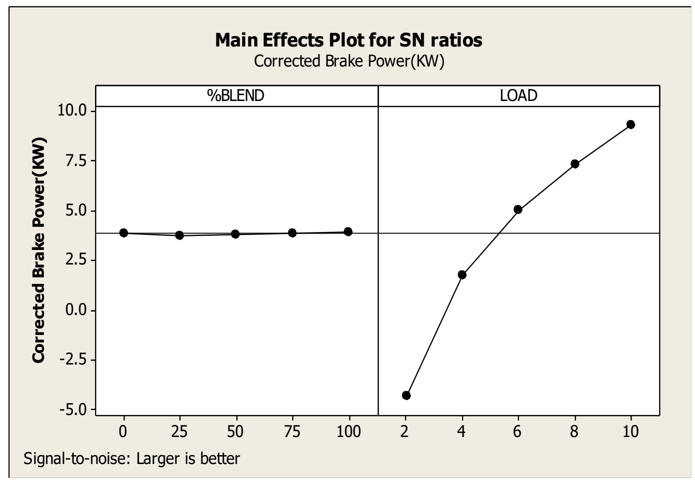

Figure3: Main Effects Plot for SNRatios for corrected BP

From the graph in fig. 2, given above, mean is average value for reading has been taken for the particular parameter. For blend, mean value is maximum (1.7942) for 100% blend and minimum (1.7676) for 25% blend. For load, mean value is maximum (2.9350) at 10 kg engine load and minimum (0.6108) for 2 kg engine load.

Table 5: Response Table for Means for corrected brake power

Level	% Blend	Load (kg)
1	1.7788	0.6108
2	1.7676	1.2295
3	1.7789	1.7935
4	1.7861	2.3368
5	1.7942	2.9350
Delta	0.0266	2.3243
Rank	2	1

Delta is difference of maximum and minimum value of levels. Value of delta is maximum for load (2.3243) and minimum (0.0266) for blend. Hence, the load has maximum and blend has the minimum effect on brake power of the engine cylinder.

Figure 3 shows the response curve for S/N ratio, the highest S/N ratio was observed at 100% blend and 10 kg of engine load, which is the optimum parameter setting for maximum corrected brake power. The delta value is maximum (13.636) for engine load and minimum (0.168) for blend. Engine load has major effect, while blend has the minor effect on brake power of the engine.

Table 6: Response Table for Signal to Noise Ratios for corrected brake power (Larger is better)

Level	% Blend	Load (kg)
1	3.874	-4.284
2	3.766	1.791
3	3.848	5.074
4	3.882	7.372
5	3.935	9.352
Delta	0.168	13.636
Rank	2	1

3.8 Taguchi Analysis for Corrected SFC

Response tables and graphs for means and SN ratios for SFC are shown in Table 7 and Table 8 and in Figure 4 and Figure 5 respectively.

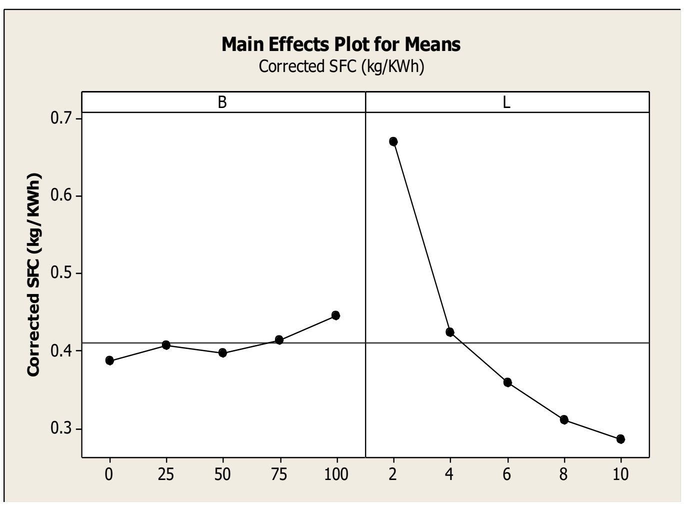

Figure 4: Main Effects Plot for Means for SFC

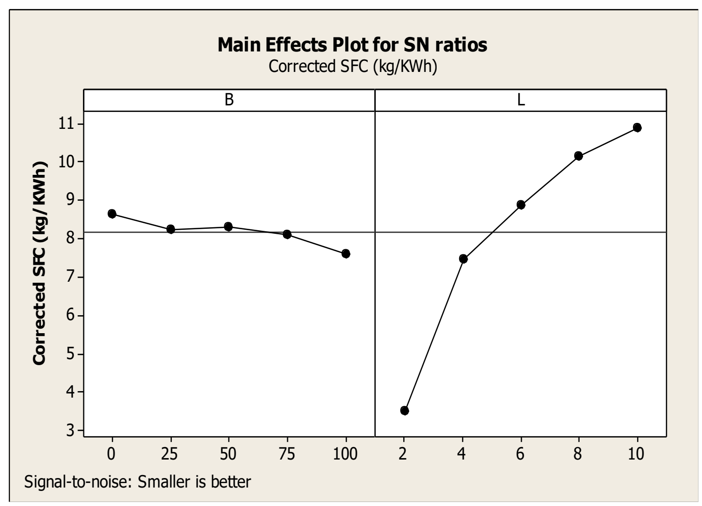

Figure 5: Main Effects Plot for SN Ratios for SFC

From the graph in figure 4, mean is average value for reading has been taken for the particular parameter. For blend, mean value is maximum (0.4453) for 100% blend and minimum (0.3876) for 0% blend. For load, mean value is maximum (0.6703) at 2 kg engine load and minimum (0.2860) for 10 kg engine load.

Table 7: Response Table for Means for SFC

Level	% Blend	Load (kg)
1	0.3876	0.6703
2	0.4071	0.4247

3	0.3981	0.3600
4	0.4140	0.3111
5	0.4453	0.2860
Delta	0.0577	0.3842
Rank	2	1

Value of delta is maximum for load (0.3842) and minimum (0.0577) for blend. Hence, the load has maximum and blend has the minimum effect on specific fuel consumption of the engine.

Figure 5 shows the response curve for S/N ratio, the highest S/N ratio was observed at 0% blend and 10 kg of engine load, which is the optimum parameter setting for least specific fuel consumption. The delta value is maximum (7.369) for engine load and minimum (1.031) for blend. Engine load has major effect while, blend has the minor effect on specific fuel consumption of the engine.

Table 8: Response Table for Signal to Noise Ratios for SFC (Smaller is better)

Level	% Blend	Load (kg)
1	8.628	3.507
2	8.247	7.451
3	8.307	8.884
4	8.088	10.148
5	7.597	10.877
Delta	1.031	7.369
Rank	2	1

IV. Result

4.1 Optimized Parameter Set for Corrected Brake Power

The optimized set of parameter for brake power in order to get better engine performance is shown in the Table 9 given below.

Table 9: Optimized set of parameter for corrected brake power

Blend (%)	Load (kg)	Load (KW)	S/N Ratio
100	10	2.94815	9.42577

4.2 Optimized Parameter Set for SFC

The optimized set of parameter for SFC in order to get better engine performance is shown in the Table 10 given below.

Table 10: Optimize set of parameter for SFC

Blend (%)	Load (kg)	SFC (kg/kwh)	S/N Ratio
0	10	0.263182	11.3313

V. Discussion

5.1 Result Validation for Corrected Brake Power

The result validation for corrected brake power is shown in Table 11 given below.

Table 11: Validation Results for corrected brake power

Predicted Value	Experimental Value	Error (%)
2.94815	2.96242	0.48

5.2 Result Validation for SFC

The result validation for SFC is shown in Table 12 given below.

Table 12: Validation Results for SFC

Predicted Value	Experimental Value	Error (%)
0.263182	0.28443558	7.47

VI. Conclusion

From taguchi analysis, it is observed at 100% blend and 10 kg of engine load are the optimum parameters for maximum brake power. The load has maximum and blend has the minimum effect on brake power of the engine cylinder. Optimize set of parameters for SFC is 0% blend and 10 kg engine load. The load has maximum and blend has the minimum effect on specific fuel consumption of the engine. For brake power conditions almost all the blend with different loads shows nearer values to each other.

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