Parametric Optimization of CI Engine with BThEff by using Coconut Biodiesel and Diesel Blend

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Abstract— In present research effect on input parameters such as injection pressure and load on the performance of single cylinder diesel engine fueled with coconut biodiesel and also its blend. The number of test are carried out with three different injection pressure (160, 200, 240 bar), load (1, 6, 11) and blend (100%, 50%, 0%). In this study research is completed by use of Response Surface Methodology to optimize the performance parameter such as specific fuel consumption (SFC) and brake thermal efficiency (BThEff). A set of experimental runs was established using a Central Composite Design (CCD) and the response surface method was employed to obtain the regression model for the brake thermal efficiency for different values of input parameter. The experimental results reveal that the coconut biodiesel and its blend provide better engine performance and improve brake thermal efficiency(BThEff) compared to diesel with little change in input parameter.

Key words: Parametric Optimization, brake thermal efficiency (BThEff), Coconut Cooking Oil, Coconut biodiesel, RSM

I. Introduction

Developing renewable energy has become an important part of worldwide energy due to the depletion of fossil fuel. Alternative transport fuels such as hydrogen, natural gas and biofuels are seen as an option to help the transport sector in decreasing its dependency on oil [1]. Alternative fuels for the diesel engines are becoming important due to the diminishing petroleum reserves. Many countries around the world have passed legislations that diesel should contain a minimum percentage of biofuels. The best record available is that of the Czech Republic, which insists on 100% biofuel use for transportation (Paramathma 2004) [2]. Today many countries worldwide, including India, produce and use biodiesel. Biofuel sources, particularly Soybean oil have attracted much attention as an alternative energy source. It is renewable, available everywhere and has proved to be a cleaner fuel and more environment friendly than the fossil fuels. However engine test results showed durability problems with soybean oil because of higher viscosity of soybean oil. Blending and transesterification may overcome this problem. To achieve a better result with biofuel there is some modification made in input parameter.

II. Literature review

1) Yutaka Matsumoto et al In this paper, it was shown that coconut oil as alternative diesel engine fuels can be used successfully without modifications to the engine or the injector system[3].
2) M.A. Kalam et al This paper presents the results of experimental work carried out to evaluate the performance characteristics of ordinary Malaysian coconut oil (COCO) blended with conventional diesel oil (OD) fueled in a diesel engine[4].
3) Kathleen M. Carley et al gives an technical report on response surface methodology. In this work they include RSM design and modeling analysis from CASOS - Center for Computational Analysis of Social and Organizational Systems[5].
4) Mr. Wilks et al The impact of blending techniques, feedstock choice, and analytical techniques on biodiesel blend accuracy[6].
5) João Felipe G. Oliveira, et al in this paper The production of biodiesel by esterification with ethanol using waste oil generated in the refining of coconut oil was investigated[7].
6) Pranil J. Singh, Jagjit Khurma, et al In this paper, hybrid fuels consisting of coconut oil, aqueous ethanol and a surfactant (butan-1-ol) were prepared and tested as a fuel in a direct injection diesel engine. After determining fuel properties such as the density, viscosity and gross calorific values of these fuels, they were used to run a diesel engine[8].
7) M.A. Kalam, et al Performance characteristics were measured in short-term engine testing, and coconut oil was found to be the best waste cooking oil to replace diesel[9].
8) C.V. Subba Reddy et al The experimental investigations reveal that the better performance characteristics among the biodiesel blends are obtained at injection pressure of 200 bar with 20BD of cotton seed oil methyl ester[10].
9) Jian-Jhong Jiang, Chung-Sung Tan et al In this study, the transesterification of coconut oil with supercritical methanol in the presence of cosolvent was carried out in a batch autoclave for production of biodiesel. The autoclave made of stainless steel 316 was found to act as the catalyst for the trancesterification[11].
10) Samani C. Tupufia, Young Jae Jeon, et al The kinetics of the enzymatic conversion of coconut oil to biodiesel (fatty acid alkyl esters) have been inves- tigated using ethanol and 1% (w/v) lipase at 50 °C. Coconut oil is being evaluated for biofuel production and an enzymatic process was selected to minimize side reactions[12].
11) A.M. Liaquat*, H.H. Masjuki, et al This paper represents the engine performance parameters characteristics for direct injection diesel engine using coconut biodiesel blends without any engine modifications[13].

III. COCONUT OIL

Coconut oil is an edible oil extracted from the kernel or meat of matured coconuts harvested from the coconut palm (Cocos nucifera). It has various applications in food, medicine, and industry. Because of its high saturated fat content it is slow to oxidize and, thus, resistant to rancidification, lasting up to two years without spoiling. It is an actual nut from the Coconut Palms. They are the most widespread tropical agricultural crops grown abundantly not only in PNG but all parts of the South Pacific and parts of Asia. It is naturally sustainable agricultural resource of tropical islands. Coconut Palms are one of the few crops that can tolerate poor sandy soils with saline water and survives frequent cyclones. Coconut Palms can bear a bunch of fruits each month for about 65 of their 70 to 80 year life span and it require minimum maintenance. Coconuts are and have been way of life for the indigenous island people. They call the coconut palm the “Tree of Life”. Coconut Biodiesel (CB) is a blend of diesel fuel and CME at a certain proportion by volume. Biodiesel in other counties like the US, Germany and other Euro counties their biodiesel is a mixture of diesel fuel and ester derived either from corn, soya, sun flower, rapeseed oil. They use of 5% to 20% blend on their diesel fuel. The Table 1 shows the various physico-chemical properties of biodiesel derived from different feed stocks.

Parameters	**Diesel**	**Coconut oil**
Colour	Orange	Water clean
Cetane Number	62.8	51
Gross Calorific Value (MJ/kg)	46	42
Flash Point	49^{O}C	114^{O}C
Sulfur Content	0.05%	0%
Oxygen Content	0%	11%
Kinematic Viscosity	3-4 cst	2-3 cst
Lubricity	3,800gms	>7,000 gms
Boiling point ºC	248	122.56±0.51
Density at 15^{0}C	820- 950	924

Table 1: Physico-Chemical Properties of Different Biodiesels [2].

IV. EXPERIMENT SETUP

The setup consists of single cylinder, four stroke, multi-fuel, research engine connected to eddy type dynamometer for loading as shown in Fig.1. The operation mode of the engine can be changed from diesel to Petrol of from Petrol to Diesel with some necessary changes. 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. A battery, starter and battery charger is provided for engine electric start arrangement.

Fig. 1: Experimental Setup

The setup enables study of VCR engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, BThEff, 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. Table 2 shows Technical specification of C.I Engine.

Item	**Specification**
Model	TV1
Make	Kirlosker Oil Engines
Type	Four stroke, Water cooled, Diesel
No. of cylinder	One
Bore	87.5 mm
Stroke	110 mm
Compression ratio	12 to 18
Power rating	7.5 HP
Injection timing	≤ 25˚ BTDC

Table 2: shows Technical specification of C.I Engine.

V. METHODOLOGY

There are number of optimization techniques used for engine investigation are like full factorial design, response surface method, mixture design, simplex method, ANN, genetic algorithm (GA) and Taguchi method. The simplex method is started to be efficient for optimization without interaction effects but with insertion of interaction effects, the method becomes computationally expensive and complex. In response surface method, efficient engine control optimization could be achieved by a response surface satisfying the prediction accuracy could be created. RSM technique has been popular for parameter optimization in design of experiments (DOE) for decades due to its excellent characteristics like orthogonality, rotatibility and uniformity. The curvature shapes like cube, sphere etc. can easily solved by Response surface method. Response surface methodology (RSM) gives the relationships between several explanatory variables and one or more response variables. The method was introduced by G. E. P. Box and K. B. Wilson in 1951. RSM comprises of three techniques or methods (Myers and Montgomery, 1995): (1) Statistical experimental design, in particular, two-level factorial or fractional factorial design, (2) Regression modelling techniques, and (3) Optimization methods. Steps for the Experiment for RSM

1) Determination of independent variables and their levels :- select the parameters (variable) that have major effects on output. The levels of the parameters are determined. All variable will be tested over the same range. Range of the variable are forced between the range of coded variable -1 to 1. Equation of coding is given below [5]:

$$X = \frac{x-[x_{max}+x_{min}]/2}{[x_{max}-x_{min}]/2} \quad (1)$$

– Where,
– X = coded variable
– x = natural variable
– x_{max} ,x_{min} = maximum and minimum values of the natural variable

2) Selection of the experimental design, and prediction and verification of model equation:- Experimental design are generated as per selection of experimental points, number of runs and blocks. Then the model equation is defined and coefficients of the model equation are predicted. For to compare these data the statical method of root mean square error (RMSE) and coefficient of multiple determination (R2) values are used. These values are determined by following equation [1]:

$$RSME = \left[\frac{1}{n}\sum_{j=1}^{n}\left|a_j - p_j\right|^2\right]^{1/2} \quad (2)$$

$$R^2 = 1 - \left[\frac{\sum_{j=1}^{n}(a_j-p_j)^2}{\sum_{j=1}^{n}(p_j)^2}\right] \quad (3)$$

Where,
– a_j = Experimental Brake thermal efficiency
– p_j = Predicted Brake thermal efficiency

3) Graphical presentation of the model equation and determination of optimal operating conditions:- The prediction of model equation is done by the surface and contour plot. The surface plot is the 3 dimensional plot which showing the relationship between response and the variable.

VI. Experimental Method

Variable	Symbol		Level	
	Actual	Coded	Actual	Coded
BR	A	X_1	0	-1
			50	0
			100	1
IP	B	X_2	160	-1
			200	0
			240	1
Load	C	X_3	1	-1
			6	0
			11	1

Table 3: Actual and Coded Levels of the Independent Variables in the Experimental Design

The selected process variables were varied up to three levels and central composite rotatable design was adopted to design the experiments. Response Surface Methodology was used to develop second order regression equation relating response characteristics and process variables. The process variables and their ranges are given in Table 3. Series of analysis is conducted to obtain the optimum parameter for performance of engine. Central composite design is applied to select the control factors levels (Blend ratio, Injection pressure, Load) to come up with optimal BTHEFF.

VII. Result and Discussion

A. *Fitting the Model and Analysis Of Variance (ANOVA):*

The analysis experiments were conducted, with the process parameter levels set as given in Table 3, to study the effect of process parameters over the output parameters. Experiments were conducted according to the test conditions specified by the second order central composite design. Experimental results for BTHEFF are given in Table 4. Altogether 20 experiments were conducted using response surface methodology.

RUN	Variable properties			
	Blend Ratio	Injection Pressure	Load	BThEff (%)
1	100	160	1	10.07
2	100	200	6	26.27
3	50	200	6	26.3
4	50	200	6	26.3
5	50	200	6	26.3
6	50	160	6	26.26
7	0	200	6	25.8
8	50	200	6	26.3
9	50	200	11	31.79
10	50	200	1	6.81
11	50	200	6	26.3
12	0	160	1	6.9
13	50	240	6	26.23
14	100	240	11	34.53
15	0	160	11	32.87
16	100	240	1	7.66
17	50	200	6	26.3
18	0	240	11	32.5
19	0	240	1	7.3
20	100	160	11	31.79

Table 4: Experimental Layout Of Central Composite Design And Its Corresponding Observed Values Of Btheff

For to evaluate the generated model are good predicted or not the value of the R2 and RMSE are computed. For good predicted model the value of R2 are come closer to 1 and value of RMSE are come close to 0(zero).

RUN	Target SFC	Predicted SFC	Error	R^2	RMSE
1	10.07	8.20266	-0.13975	0.9987	0.87473
2	26.27	25.86125	0.033		

3	26.3	26.0858	-0.001		
4	26.3	26.0858	-0.001		
5	26.3	26.0858	-0.001		
6	26.26	26.53325	0.026		
7	25.8	26.85125	-0.025		
8	26.3	26.0858	-0.001		
9	31.79	32.09525	0.018		
10	6.81	7.14725	0.148		
11	26.3	26.0858	-0.001		
12	6.9	8.62266	- 0.00025		
13	26.23	26.59925	-0.028		
14	34.53	32.64666	- 0.05625		
15	32.87	33.12066	- 0.04025		
16	7.66	7.24866	0.01375		
17	26.3	26.0858	-0.001		
18	32.5	34.20666	0.00825		
19	7.3	7.51866	- 0.02175		
20	31.79	31.41066	0.07025		

Table 5: Target Vs Predicted Btheff

Here error is show the difference between the targeted and predicted value of BThEff. The value of R2 and RMSE are calculated by equation (2) and (3). The value of R2 is 0.998 which are close to the 1 and the value of RMSE is 0.874 which is close to 0. So, the model is making a prediction.

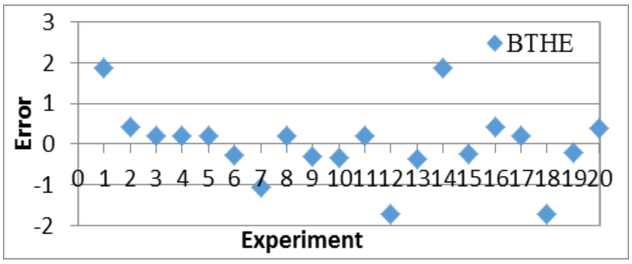

Fig. 2: Experimental vs. Error

VIII. COMPARISON OF RESULTS

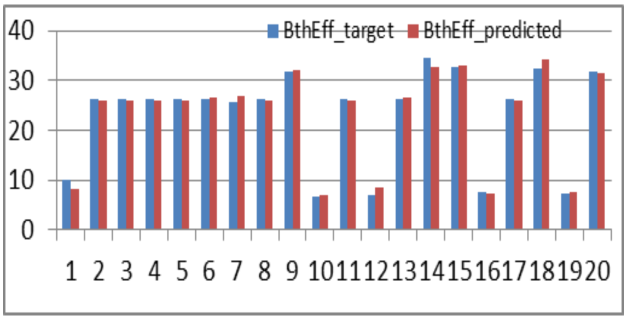

Fig. 3: Experimental & Predicted BThEff

The error of the experiment are shown in graph which are above and below the 0 value. The predicted value of BThEff of model is compared with the actual target value of experiment is shown in figure 3 by different colors. It is clear from graph that predicted results are very close to actual targets. It also concludes that model has good prediction capability.

The second-order polynomial models used to express the BThEff as a function of independent variables (Eq. (4)) is shown below in terms of coded level:

$$BThEff = 26.0858 + 0.4950X_1 + 12.4740X_2 + 0.0330X_3 + 0.2705X_1^2 - 6.4645X_2^2 + 0.4805X_3^2 - 0.3225X_1X_2 + 0.0375X_1X_3 + 0.5475X_2X_3$$

Source of variation	Co-efficient	p-Value probability
% Biodiesel, A	0.495000	0.061
Load, B	12.4740	0.000
Injection Pressure, C	0.0330000	0.891
A^2	0.270455	0.559
B^2	-6.46455	0.000
C^2	0.480455	0.308
AB	-0.322500	0.247
BC	0.0375000	0.889
AC	0.547500	0.063

Table 6: Anova for Response Surface Model

A. *Statistical Inferences:*

1) Values of "p-value" less than 0.0500 indicate model terms are significant. In this case blend ratio A, compression ratio B, load D etc are significant model terms.
2) The coefficient of determination (R2) and adjusted coefficient of determination (R2 adj) were indicated that the estimated model fits the experimental data satisfactorily. Lee et al. (2010) suggested that for a good fit of a model, R2 should be at least 80 %. The R2 for these response variables was higher than 80 %, indicating that the regression models explained the mechanism well.

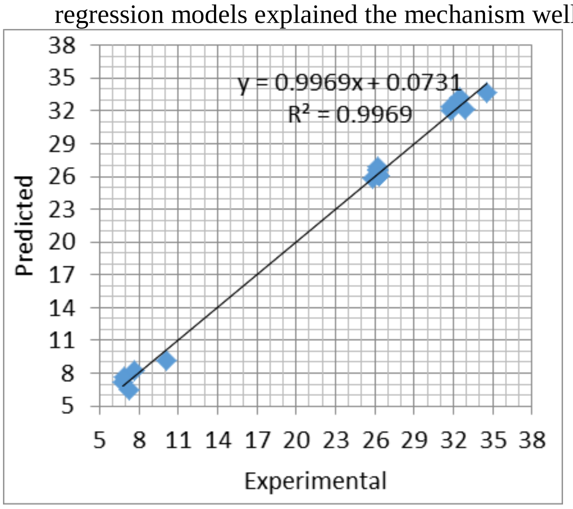

Fig. 4: Experimental vs Predicted BThEff

Fig. 4 shows the experimental versus predicted Brake thermal efficiency obtained from Eq. (4). A linear distribution is observed which is indicative of a well-fitting model. The values predicted from Eq. (4) were close to the observed values of Brake thermal efficiency

B. Effect of Independent Processing Parameters:

The effect of the four independent variables on the BTHEFF is shown in Fig. 6.

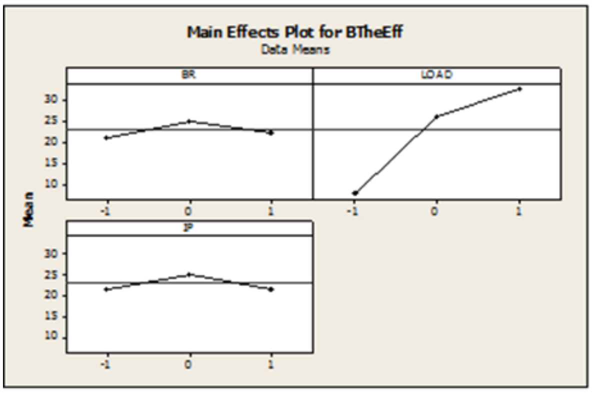

Fig. 6: Independent Variable on the BTHEFF

- BThEff improved with increasing Blend Ratio(A) as shown in Fig. , when the blend ratio was increased from 0 to 50%. However, after that the increase in blend ratio increases the BThEff. So 50 % blend ratio is chosen as optimum blend ratio for BThEff.
- BThEff improves with increasing injection pressure(C) from 160 to 200 bar then after increasing injection pressure increasing BThEff.
- As shown in Fig.6 increasing load increases BThEff. As load increase from 1 to 11 kg the BThEff increases. This can also confirmed by ANOVA table indicating p-value of 0.00 indicating the load is significant value for BThEff.

IX. CONCLUSION

The present investigation aimed at optimization of BThEff for CI engine. This analysis is carried out by developing BSFC models based on L20 orthogonal array in Response surface optimization technique. Model for BThEff prediction draws the following conclusions.

- It is proved that each predicted BThEff values are very close to the experimental results. It is also conclude that the RSM may be used as a good alternative for the analysis of the effects of engine parameters on the BThEff.
- The modeling of the effects of engine parameters (Blend ratio, Injection pressure, Load) on the BThEff depending on various processing parameters, an RSM-based approach has been suggested.

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