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COMPARATIVE ANALYSIS OF RSM AND MLR PREDICTION MODEL FOR SFC IN CI ENGINE FUELED WITH PALM SEED OIL AND DIESEL BLENDS

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Abstract- *Objectives of this work to comparison of prediction SFC for multiple linear regression and response surface method to single cylinder diesel engine. A single cylinder 3.8 KW engine is selected for experiment. Three parameters CR, BR, and Load are variance and response like SFC optimize completely .The experiments include use of different palm oil blend such as 100D0B (100% diesel 0% palm oil), 50D50B (50% diesel 50% palm oil), 0D100B (0% diesel 100%palm oil) at different CR in range of 16, 17, 18 and load variation from 2, 7, 12 Kg. the result obtained from experiment that better prediction capability of RSM over MLR model. For mathematical and statistical analysis RSM is used. The numbers of experiments run are developed by using RSM approach and MLR in Minitab'18 software. The result obtained from experiment is that load has significant effect on SFC.*

Keywords- *Palm seed oil, Compression ratio, Load, Blend ratio, Response surface method, Multiple linear regression method*

Nomenclatures	
RSM	Response surface method
MLR	Multiple linear regression
CCD	Central composite design
BTHE	Brake Thermal Efficiency
SFC	Specific Fuel Consumption
MECH EFF	Mechanical Efficiency
D.O.E	Design of Experiment
100D0B	100% Diesel 0% Palm seed oil
50D50B	50% Diesel 50% Palm seed oil
0D100B	0% Diesel 100% Palm seed oil

I. INTRODUCTION

In this day clean energy and fossil fuels have interest in alternative energy sources such as vegetable oil. The change in global temperature has serious effect to agriculture production, biodiversity, health and environmental disasters [1]. Energy is most important factor for society. I.C engines have been prime movers generating power for various applications. The increase demands, depletion, price of petroleum have extensive on alternative energy sources for I.C engines. Use straight vegetable oils in C.I engines reduce problems with engine performance because of more viscosity. The best use of vegetable oils as fuel in C.I engine is converting into biodiesel. Biodiesel like rape seed, soybeans, sunflower, and jatropha are popular for diesel [2]. Fossil fuels contribute more than 80% of world total energy. This depends on fossil fuels caused environmental pollution from high greenhouse gas emissions. Currently petroleum fuels have big difficulty due to price increasing. So this causes need to alternative energy sources are increasing to reduces difficulty by fossil fuels. Gaseous fuels are good considered to I.C engine because it's mixing characteristic with air. They have good flammable limits, high self-ignition temperature operate with lean mixtures and higher compression ratios, reason for this improvement of thermal efficiency, reduction in emissions like HC, $CO2$, NO_X, SO_X etc. gaseous fuels include natural gas, hydrogen, biogas and other gaseous fuels that used in I.C engines [3].VCR engine expand CR higher power required with specific capacity to burn more fuel and make more power, at that time having specific ignition. Therefore VCR engine is powerful for enhancing low load engine thermal efficiency and making maximize engine power with high pressure–charge. The purpose of experiment has to know effect of CR on emission and efficiency characteristic of diesel engine at varying different loads and variable compression ratios [4].

II. LITERATURE REVIEW

Wong et al. (2015) have studied about RSM with CCD was successfully employ in study impacts of different variables and determine of biodiesel production. The optimum biodiesel yield 97.67% was achieved under optimum reaction conditions of 2.67h reaction time, 3.60 wt. % of catalyst and methanol to oil molar ratio 13.04. The high biodiesel yield can relate to high of the catalyst. CaO-Nb_2O_5 mixed oxide catalyst has better reusability than bulk CaO. The enhance stability because interaction between CaO and Nb_2O_5 metal oxides.CaO-Nb2O_5 mixed oxide catalyst is a catalyst for biodiesel industry due to its strong strength and high performance in transesterification process [5]. **Reddy et al. (2015)** have studied about CR of engine is increase, BSFC decreases. At lower of the CR, FC is more due to improper combustion of fuel. The highest FC is measured at CR 14 [6]. **Yusuf et al. (2015)** have studied about combine effect of speed, load, and blend ratio, on the indirect diesel engine performance when fuelled by palm oil mixture based biodiesel performed by RSM. The blends torque, power, and BTE were lower but the BSFC was higher. This is due to minimum heating values of blends which causes more fuel injected into cylinder, and hence higher BSFC [7]. **Patel et al. (2015)** have studied about comparison of RSM and MLR models for surface roughness. The results obtained during preliminary test that RSM approach is tool for accurately estimating surface roughness compare to MLR model. The result shows that RSM technique is far better than MLR method [8]. **Aldhaidhawi et al. (2016)** have studied about thermodynamic model developed for analyzing BTHE and NOX emission. The model compare with experimental results on direct injection single cylinder diesel engine to evaluate performance and exhaust emissions for different fuel blends and compression ratios. They conclude that model showing better result between experiments versus simulated data. For all CR at constant load particularly for maximum pressure and crank angle, the BSFC and thermal efficiency lower with biodiesel blends at all operation condition due to biodiesel has minimum heating value and maximum density [9]. **Adam et al. (2016)** have studied about increasing engine speed, load found increase BT, BP, BTE, CO2, NOX, and EGT and to decrease BSFC and O2. Increasing the fuel blend ratio had opposite trend of engine load and speed. Average biodiesel blends produced lower BT, BP, BTE, and CO, but higher BSFC, CO2, NOX, EGT and O2 at full load compared to diesel fuel [10]. **Aziz et al. (2016)** have studied about on average blends BSFC was 1.4% higher while BTHE was similar or less than diesel fuel. CO emission of blends value of 1.5% lower but CO2 was 1% higher compared to diesel fuel. Exhaust temperature and NOX of blend compared to diesel fuel was 1.1% and 1% higher compared to diesel fuel [11].Patel et al. (2016) have studied that chassis frame is made two sidebars connected with a series of crossbar. The web thickness, upper flange thickness and lower flange thickness of sidebar becomes design variables for the optimization. The finite element analysis is performed on those models. RSM and MLR model are prepared using the results of FEA to predict equivalent stress on the chassis frame. The results indicate that predictions of RSM model are more accurate than predictions of MLR model [12].

III. PALM OIL PROCESS CHART

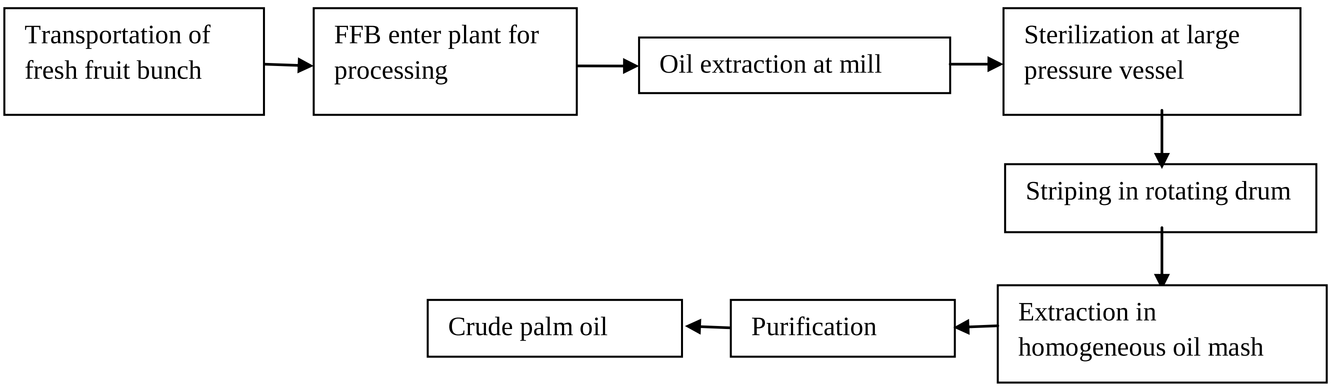

Figure 1. Palm oil process chart [13]

First step of palm oil to transport fresh fruit bunch and then after enter the plant for processing. Then boil palm fruits until they are softening for oil extraction. In this process water is not more than palm fruits. The next step to meshing boil palm nuts to mash in bowl by our hands and mash until get the juice. When complete become juice until see palm oil in floating surface of the water. Finally gating of palm oil further extraction from water surface and boiled it again.

Table 1. Properties of palm seed oil

Parameter	Unit	Result
Density @ 15°C	Kg/m^3	925
Kinematic viscosity@ 40°C	mm^2/sec	41
Flash Point	°C	260
Cloud point	°C	-
Fire point	°C	341
Iodine value	g/100g	44-51
Melting point	°C	35
Calorific value	KJ/kg	39849

IV. EXPERIMENT SETUP

In experimental purpose experiment setup consist of single cylinder, four stroke, and multi fuel engine connected with eddy current dynamometer for loading. In this engine CR can be varied continuous running of engine. Setup consist instruments for combustion pressure, diesel line pressure and crank angle measurements. These signals are connecting with computer for pressure crank-angle diagrams. The setup also observe VCR engine performance for BP, IP, FP, BMEP, IMEP,BTHE, mechanical efficiency, volumetric efficiency, specific fuel consumption.

Figure 2. Experiment setup [14]

Table 2. Engine specification [14]

Number of cylinder	Single cylinder
Number of stroke	Four
Swept volume	552.64 cc
Cylinder diameter	80 mm
Stroke length	110 mm
Connecting rod length	234 mm
Fuel	Diesel
Power	5.7 KW
Speed	1500 rpm
Orifice diameter	20 mm
Injection point variation	0 to 25 BTDC
Compression ratio range	12 to 18
Dynamometer rotor radius	141 mm

IV EXPERIMENTAL DESIGN

The selected process variable up to three levels and CCD has adopted to design the experiments. RSM has been used to develop a second order regression equation relating response characteristic and process variables. Three parameters considered for this study are CR, BR, and load. The parameters set at three levels each. The summary of the parameters is shown in Table 3.

Table 3. Parameters and their levels

Parameters	Levels		
	(-1)	**(0)**	**(1)**
Compression ratio	16	17	18
Blend ratio	D100B0	D50B50	D0B100
Load	2	7	12

The values of SFC for all variants are measure using Minitab for finding out value of CR, BR, and load central composite design is applied to select the control factor levels to come up with optimal response value. Experiments are designing according to test condition specified by second order CCD, Analysis are conducting for all data sets, with process parameter levels set as given Table 3. To study about process parameters over the output parameters experimental results for SFC are given Table 4. Altogether 20 experiments have been conducted to prepare data set for response surface model.

Table 4. Coded value of variables and response

Run	CR	BR	LOAD	SFC(Kg/KWh)
1	1	1	-1	0.38
2	0	0	0	0.18
3	0	-1	0	0.16
4	1	-1	-1	0.41
5	0	0	0	0.18
6	0	1	0	0.14
7	0	0	0	0.18
8	0	0	-1	0.38
9	0	0	1	0.14
10	0	0	0	0.18
11	0	0	0	0.18
12	1	-1	1	0.14
13	-1	1	-1	0.38
14	1	1	1	0.15
15	-1	1	1	0.14
16	1	0	0	0.16
17	-1	0	0	0.18
18	-1	-1	1	0.14
19	0	0	0	0.18
20	1	-1	-1	0.38

CR, BR, and LOAD represent coded and the real values of various factors and response like SFC

V. RESULTS AND DISCUSSIONS

5.1. Multiple linear regression analysis

A multiple linear regression model correlates the response with factors which have a strong effect on performance of a process. By employing parameters with their levels for each of experimental runs in design matrix general equation for the proposed second order regression model to predict response can be written as,

SFC (coded) = 0.2180+0.0020*CR-0.0040*BR-0.1220*LOAD

Table 5. Estimated regression coefficients for SFC using MLR

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.2180	0.0118	18.45	0.000	
CR	0.0020	0.0167	0.12	0.906	1.00
BR	-0.0040	0.0167	-0.24	0.814	1.00
LOAD	-0.1220	0.0167	-7.30	0.000	1.00
R-sq=76.94% R-sq(adj)=72.61%				R-sq(pred)=60.05%	

With the help of MLR model value of T-test and predicted p-value are represented in Table 5. To check significance of developed models analysis of variance (ANOVA) is employ, the P value of 0.000 (Table 6), which is less than 0.05 represent statistical significance model. Normal probability plot for experiment design are shown in fig. 3 which represents closeness of prediction with a regression line. MLR prediction will be compared with RSM prediction to check the feasibility.

Table 6. Analysis of variance for SFC using MLR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	0.149040	0.049680	17.79	0.000
CR	1	0.000040	0.000040	0.01	0.906
BR	1	0.000160	0.000160	0.06	0.814
LOAD	1	0.148840	0.148840	53.30	0.000
Error	16	0.044680	0.002792		
Lack-of-Fit	11	0.044680	0.004062	*	*
Pure Error	5	0.000000	0.000000		
Total	19	0.193720			

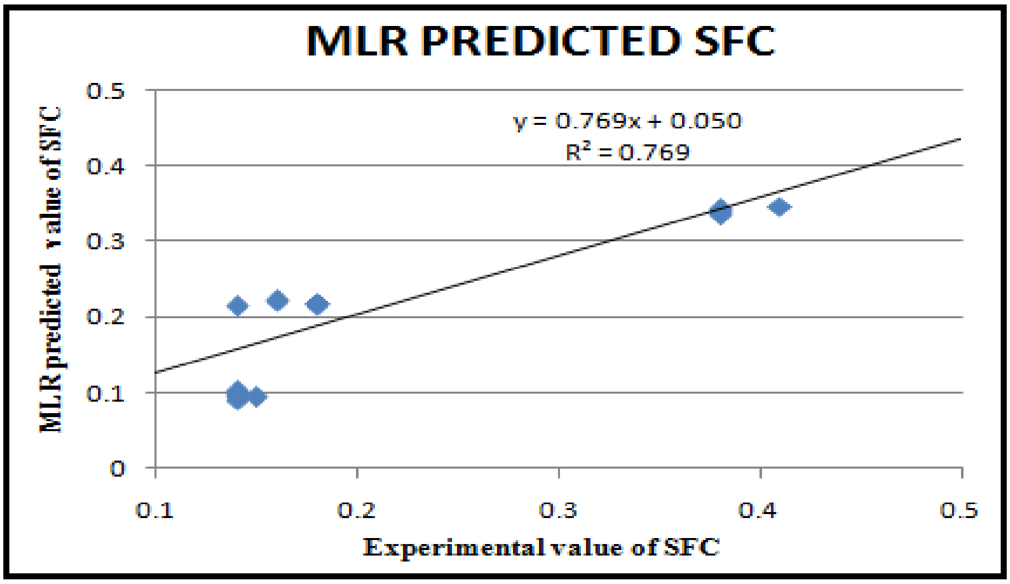

Figure 3. Regression plot for SFC using MLR

5.2. Response surface method analysis

Empirical model for SFC in terms of input parameters CR, BR, and load which all of develop by using RSM using coefficient value as shown in Table 7.the pooled version of ANOVA for SFC indicates that the P values for the quadratic terms CR*CR, BR*BR and interaction terms CR*BR, CR*LOAD, BR*LOAD are above 0.05 which describe its non significant values. In this case LOAD and LOAD*LOAD are significant model terms. The prediction equation for SFC using RSM is as below by eliminating non-significant values. The "Pred R-Squared" of 93.84% is in reasonable agreement with the "Adj R-Squared" of 98.49%.

SFC (coded) = 0.17345+0.00200CR-0.00400BR-0.12200LOAD+0.00636CR*CR-0.01364BR*BR

+0.09636LOAD*LOAD-0.00250CR*BR-0.00250CR*LOAD+0.00500BR*LOAD

Table 7. Estimated regression coefficients for SFC using RSM

Term	Coef	SE Coef	P-Value
Constant	0.17345	0.00427	0.000
CR	0.00200	0.00393	0.622
BR	-0.00400	0.00393	0.333
LOAD	-0.12200	0.00393	0.000
CR*CR	0.00636	0.00749	0.416
BR*BR	-0.01364	0.00749	0.099
LOAD*LOAD	0.09636	0.00749	0.000
CR*BR	-0.00250	0.00439	0.582
CR*LOAD	-0.00250	0.00439	0.582
BR*LOAD	0.00500	0.00439	0.282
R-sq=99.20% R-sq(adj)=98.49%		R-sq(pred)=93.84%	

Table 8. ANOVA for SFC using RSM

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.192176	0.021353	138.33	0.000
Linear	3	0.149040	0.049680	321.84	0.000
CR	1	0.000040	0.000040	0.26	0.622
BR	1	0.000160	0.000160	1.04	0.333
LOAD	1	0.148840	0.148840	964.22	0.000
Square	3	0.042836	0.014279	92.50	0.000
CR*CR	1	0.000111	0.000111	0.72	0.416
BR*BR	1	0.000511	0.000511	3.31	0.099
LOAD*LOAD	1	0.025536	0.025536	165.43	0.000
2-Way Interaction	3	0.000300	0.000100	0.65	0.602
CR*BR	1	0.000050	0.000050	0.32	0.582
CR*LOAD	1	0.000050	0.000050	0.32	0.582
BR*LOAD	1	0.000200	0.000200	1.30	0.282
Error	10	0.001544	0.000154		
Lack-of-Fit	5	0.001544	0.000309	*	*
Pure Error	5	0.000000	0.000000		
Total	19	0.193720			

The model checked by analysis of variance (ANOVA). Table 8 of ANOVA for SFC shows that the p- value for model is less than 0.05, which indicates that model is significant. In quadratic term only load has a significant effect. The model has no significant when interaction of CR, BR, and load. Table 7 shows that load has a significant effect this means that effect on SFC depends on the load.

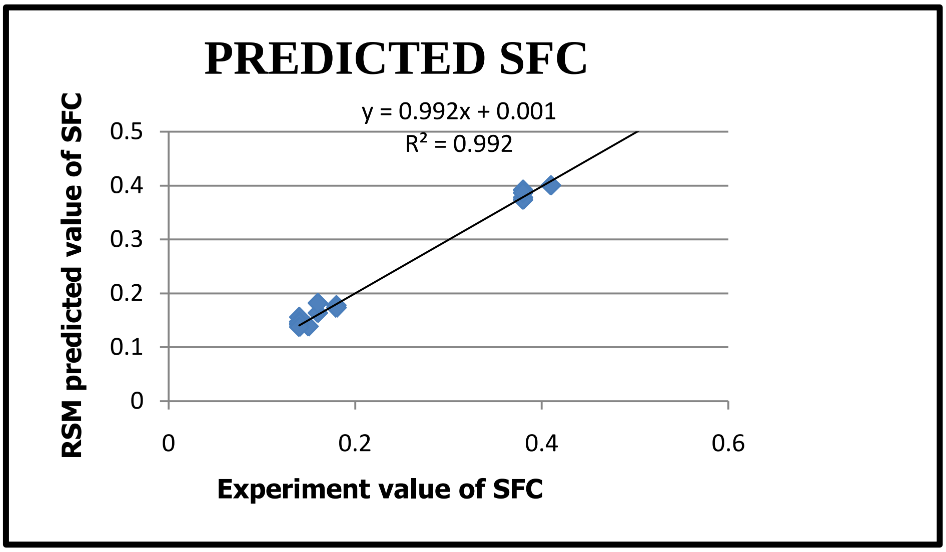

Figure 4. Regression plot for SFC using RSM

5.3. Comparison of MLR and RSM model

Fig.3 and Fig.4 represent Residual plots for MLR and RSM model respectively. It shows RSM technique is more feasible in predicting SFC than MLR technique. In Fig.4 regression plot for SFC using RSM this might due to large amount of data require for developing a regression model, while response surface could recognize relationships with less data for distributed and parallel computing natures. A second reason is effect of predictors on dependent variable, which may not be linear in nature. In other words, RSM model could predict SFC with a better performance to their great flexibility and capability to model nonlinear relationships.

Table 9. Experimental results

EX NO	CR	BR	LOAD (Kg)	Experimental values of SFC (Kg/kW/h)	MLR PREDICTED SFC	RSM PREDICTED SFC	MLR ERROR	RSM ERROR
1	1	1	-1	0.38	0.338	0.37753	0.042	0.00247
2	0	0	0	0.18	0.218	0.17345	-0.038	0.00655
3	0	-1	0	0.16	0.222	0.16381	-0.062	-0.00381
4	1	-1	-1	0.41	0.346	0.40053	0.064	0.00947
5	0	0	0	0.18	0.218	0.17345	-0.038	0.00655
6	0	1	0	0.14	0.214	0.15581	-0.074	-0.01581
7	0	0	0	0.18	0.218	0.17345	-0.038	0.00655
8	0	0	-1	0.38	0.34	0.39181	0.04	-0.01181
9	0	0	1	0.14	0.096	0.14781	0.044	-0.00781
10	0	0	0	0.18	0.218	0.17345	-0.038	0.00655
11	0	0	0	0.18	0.218	0.17345	-0.038	0.00655
12	1	-1	1	0.14	0.102	0.14153	0.038	-0.00153
13	-1	1	-1	0.38	0.334	0.37353	0.046	0.00647
14	1	1	1	0.15	0.094	0.13853	0.056	0.01147
15	-1	1	1	0.14	0.09	0.14453	0.05	-0.00453
16	1	0	0	0.16	0.22	0.18181	-0.06	-0.02181
17	-1	0	0	0.18	0.216	0.17781	-0.036	0.00219
18	-1	-1	1	0.14	0.098	0.13753	0.042	0.00247
19	0	0	0	0.18	0.218	0.17345	-0.038	0.00655
20	-1	-1	-1	0.38	0.342	0.38653	0.038	-0.00653

VI. CONCLUSIONS

- With the help of generated predicted model of SFC optimum set of parameters can be found out for better SFC.
- It is found that model is significant and adequate to represent relationships between the variable and response, the present investigation aimed at comparison of RSM and MLR model for prediction SFC.
- The comparative study of RSM and MLR model for prediction SFC draws conclusions like results obtained during preliminary test suggest that RSM approach is a accurately estimating Predicted SFC compare to MLR model.
- The result shows that RSM technique is far better than MLR method.

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