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COMPARATIVE ANALYSIS OF MATHEMATICAL MODELS DEVELOPED BY RSM AND MLR METHOD FOR SFC OF SINGLE CYLINDER DIESEL ENGINE FUELED WITH DIESEL AND DIESEL-JATROPHA BLENDS

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Abstract-*The aim of the research is to compare the accuracy of multiple linear regression (MLR) model and response surface method (RSM) model for specific fuel consumption (SFC) of a single cylinder diesel engine using various blends of Jatropha biodiesel. Various researchers did an experiment to compare MLR and RSM method to check better method for a better mathematical model, but no one did experiment related to the SFC comparison of a variable compression ratio (VCR) single cylinder diesel engine. Compression ratio, biodiesel blend, injection pressure and load are the input variables. The single cylinder diesel engine on which experiment performed is equipped with facility to vary compression ratio, injection pressure and load. Three levels are selected for the parameters. Mathematical model was produced using Response Surface Method in 'Minitab 2017' software for predicted SFC calculation. Then Multiple Linear Regression carry out for SFC calculation. Comparison between MLR and RSM results were done. Diesel and jatropha biodiesel blends was used as fuel in single cylinder diesel engine. It is found that the model developed using Response Surface Methodology is more efficient and accurate than Multiple Linear Regression model. So RSM is more appropriate than MLR.*

Keywords-*MLR, SFC, RSM,Blend Ratio, Jatropha biodiesel, Injection pressure, Load, Compression ratio*

Nomenclature

100D0B	*: 100% Diesel 0% Jatropha*
50D50B	*: 50% Diesel 50% Jatropha*
0D100D	*: 0% Diesel 100% Jatropha*
RSM	*: Response Surface Method*
CR	*: Compression Ratio*
MLR	*: Multiple Linear Regression*
BR	*: Blend Ratio*
IP	*: Injection Pressure*
CI engine	*: Compression Ignition Engine*
SI engine	*: Spark Ignition Engine*
SFC	*: Specific Fuel Consumption*
BR	*: Blend Ratio*

I. INTRODUCTION

In recent times there is a major increase in usage of automobile vehicle. This is due to the large population and every person needs a private vehicle for transportation. This causes an increase in demand for a number of vehicles. But it can be seen that all vehicles run on either SI engine or CI engine [1]. And from that, most people prefer a CI engine equipped vehicle as it uses diesel as fuel. Diesel is comparatively cheaper than petrol and diesel fueled vehicle gives more mileage than petrol fueled vehicles [2]. But as it can be seen that there is a limited amount of fossil fuel available in the world. So, the products produce from this fossil fuel is also limited [1]. And these fossil fuels and products are going to be decreased as people are using it for various purposes. So, in the near future there is a probability of the lack of fossil fuel and its products.

Therefore it is needed to find an alternative source for combustion that will reduce the usage of the diesel fuel

[2]. Diesel usage can be reduced by reducing amount of diesel used in engines [1]. For this with diesel there is need of an alternative oil which will mix with diesel and produce same combustion effect inside the engine as diesel produces [4]. Different types of alternative oils and biofuels can be used with diesel to reduce consumption of diesel such as neem oil, karanja oil, palm seed oil, jatropha oil etc [1].

Bio- Diesel is the diesel fuel based on the vegetable oil or animal fuel. Bio-Diesel technically defined as “The mono alkyl esters of long fatty acids derived from renewable lipid feedstock such as vegetable oil, or animal fats, for use in diesel engine” [5]. Bio-Diesel is considered as a renewable fuel because it is manufactured from vegetable oils, animal fats and cooking oil. The main crops that used for producing Bio-Diesel are soybean, palm oil, sun-flower, peanut, castor seed, jojoba, Jatropha, avocado etc [2]. Out of these Jatropha plant is easily available and very useful for manufacturing Bio-Diesel. It is also cheap in nature. That’s why it is appropriate to use Jatropha as Bio-diesel [11].

In this experiment Jatropha biodiesel has been used with diesel oil. Then different parameters has been measured when experiment was performed using different jatropha biodiesel blends at different compression ratio and injection pressure also with varying load conditions. The model for experiment runs was created in ‘Minitab 2017’ software using Response Surface Methodology. Face centered composite design was used for creating model. The experiment was performed as per the model developed and after that for same Model Multiple Linear Regression method was carried out. In this experiment specific fuel consumption (SFC) was taken as response therefore calculations for predicted SFC was done for both MLR and RSM model. And then comparison of both data’s was done.

II. LITERATURE REVIEW

Agarwal et al. (2007) had studied on performance and emission characteristics using Jatropha biodiesel. The performance and emission test were conducted with diesel, preheated Jatropha oil, unheated Jatropha oil and blend of Jatropha oil at different loads. The conclusion of experiment were made that Jatropha can be used as replacement of diesel fuel and did not require any major modification [1].**Ganapathy et al. (2011)** had investigated the influence of injection timing, engine speed and load torque on the performance and emissions and to optimize these parameters using RSM. There was 27 experimental run designed to perform an experiment. The effect of variation of injection timing, load torque and engine speed on BSFC, BTE, Pmax, CO, HC, NO emissions and smoke were investigated experimentally.the conclusion were made that the optimal values of performance and emission parameters: BSFC, BTE, Pmax, smoke density, CO, HC and NO emissions are 0.2875 kg/kWh, 30.96%, 65.79 bar, 4.26, 0.0076 vol%, 5.27 and 321.69 ppm, respectively, at fuel injection timing, load torque and speed of 342.6 CAD were 11.4 Nm and 1801 rpm, respectively, for the Jatropha biodiesel engine using RSM [2].**Patel et al. (2013)** had compared the accuracy of artificial neural networks (ANN) and multiple linear regression (MLR) model for shear stress of EICHER 11.10 chassis frame. The chassis frame was made of two side members joined with a series of cross members. The number of cross members, their locations, cross-section and the sizes of the side and the cross members was taken as design variables. The chassis frame model had been developed in Solid works and analyzed using Ansys. The weight reduction of the sidebar was achieved by changing the parameters using the orthogonal array. Then FEA was performed on those models. ANN and MLR models were prepared using the results of FEA to predict shear stress on the chassis frame. The results indicate that ANN prediction was more accurate than MLR prediction [3].**Modi et al. (2014)** had experimented for optimization of brake thermal efficiency single cylinder CI engine by use of diesel blend with palm seed oil. The input parameters were taken as IP, load and CR for optimization. Then conclusion of this experiment was made that brake thermal efficiency was highest when the load was 10 kg, IP at 180 bar and compression ratio was 16 [4]. **Uddin et al. (2015)** performed experiment with mustard kerosene blends in diesel engine. Form experiment conclusion was made that m20 had minimum bsfc 257.94 gm/kWh at 12.5 kg load. So, m20 could be considered as suitable blend for mustard blending with kerosene [5]. **Patel et al. (2016)** had experimented foroptimization of weight of chassis frame by developing model of von-Mises stress by use of RSM modelling. The input factors was selected as upper flange thickness, web thickness and lower flange thickness. Conclusion was made that lower flange thickness and web thickness had significant effect on von-Mises stress [6].**Bharadwaj et al. (2016)** had experimented to improve the performance of biodiesel-methanol blends in VCR engine using optimized engine parameters. Compression ratio, fuel blend and load were taken as input parameters whereas brake thermal efficiency and brake specific fuel consumption and emission parameters such as carbon monoxide, unburnt hydrocarbons, nitric oxides and smoke are taken as responses. Derringers Desirability approach was used for optimization of parameters. The result obtained was the VCR engine has maximum performance and minimum emissions at 18 compression ratio, 5% fuel blend and at 9.03 kg of load. At this optimized operating conditions of the engine the responses such as brake thermal efficiency, brake specific fuel consumption, carbon monoxide, unburnt hydrocarbons, nitric oxide, and smoke are found to be 31.95%, 0.37 kg/kW h, 0.036%, 5 ppm, 531.23 ppm and 15.35% respectively [7]. **Patel et al.(2016)** had studied about surface roughness prediction model based on response surface method and artificial neural network (ANN). Five different levels were selected for different input parameters as spindle speed, interference, feed and number of pass. The material selected was aluminum alloy 6061. Mathematical model developed using RSM and developed ANN model was compared for surface roughness. The result from comparison shown that prediction capabilities of ANN model is better than RSM model [8].**Patel et al. (2016)**had studiedabout surface roughness prediction model based on response surface method (RSM) and multiple linear regression (MLR).Five different levels were selected for different input parameters as spindle speed, interference, feed and number of pass. The material selected was aluminum alloy 6061. Mathematical model developed using RSM and developed MLR model was compared for surface roughness. The result from comparison shown that prediction capabilities of RSM model is better than MLR model.The variants of the frame are achieved by topology modification using the orthogonal array. Then Finite Element Analysis (FEA) is performed on those models. RSM model 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 [9].**Patel et al. (2016)** had studied about the prediction accuracy of Response Surface Methodology (RSM) and Multiple Linear Regression (MLR) model for the equivalent stress of the chassis frame. The chassis frame is made of two sidebars connected with a series of crossbar. The web thickness, upper flange thickness and lower flange thickness of sidebar taken as design variables for the optimization. The variants of the frame are achieved by topology modification using the orthogonal array. Then Finite Element Analysis (FEA) is performed on those models. RSM model 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 [10].**Patel et al. (2018)** had experimented with jatropha curcas shell in pilot scale fixed bed reactor at 500°C. In the experiment fuel properties of moisture free bio-oil (MFBO) and diesel were compared. Negligible corrosion effect of MFBO was experienced for SS-316 and anodized Al, whereas significant corrosiveness was observed towards Cu. MFBO was mixed with diesel in proportions of 4%, 8%, 12% and 16% (% v/v) and operating variables of single cylinder VCR engine were optimized using response surface methodology (RSM) with the blends. A central composite design (CCD) was employed to examine the effects of three independent variables - CR, load and blend %, whereas the investigated response variables were brake thermal efficiency (ηBth), brake specific fuel consumption (bsfc), unburnt hydrocarbon (UHC), CO, and CO_2. The optimum conditions were CR 18.00, load 6.665 kg, and blend 12.22%. Under optimum conditions, the experimental values of response variables were fairly comparable with the model predicted values. The designed model achieved overall desirability of 0.786 [11].

III. EXPERIMENTAL DESIGN

Four parameters are to be considered for the study are compression ratio, injection pressure, blend ratio and load. Three levels are chosen for each parameters. The summary of the parameters is shown in Table 1.

Table 1. *Process parameters and levels*

Process parameter	Level		
	-1	**0**	**1**
CR	16	17	18
BR	D100B0	D50B50	D0B100
IP	L	M	H
LOAD	2	7	12

IV. EXPERIMENTAL SETUP

Figure 1 shows the arrangement for the experiment. The setup has four stoke single cylinder multi fuel engine for research purpose. The engine have eddy current dynamometer, which is utilized for operating engine on variable loading conditions. The engine is a variable compression ratio type so there is adjustment provided to change compression ratio of an engine by loosening and tightening of Allen bolts. The injection pressure of the engine also can be changed.

It is single cylinder 4 stroke diesel engine. The compression ratio can be varied in the range of 12 to 18. There is sensors provided at suitable places to measure various parameters. There is also a USB slot provided to connect laptop with control panel and memory circuit of the engine. An experiment was conducted according to Table 3 which was created in Minitab 2017 software using face centered design of RSM approach. The output of results and observations are obtained by use of ICEngineSoft_9_0. The data stored through this software is going to be useful for comparison of RSM and MLR analysis.Specification of the engine is mentioned in Table 2.

Figure 1. *Experiment setup*

Table 2. *Specification of engine*

Number of cylinder	Single Cylinder
Number of Stroke	4
Swept Volume	552.64 cc
Cylinder diameter	80 mm
Stroke length	110 mm
Connecting rod length	234 mm
Orifice Diameter	20 mm
Dynamometer Rotor Radius	141 mm
Fuel	Diesel
Power	5.2 kw
Speed	1500 rpm
Compression ratio range	12 to 18
Injection point variation	0 to 25 Before TDC

Table 3.*Codded values of variables*

Ex No	CR	BR	IP	LOAD
1	0	0	0	0
2	0	0	0	0
3	1	-1	1	-1
4	0	0	0	0
5	0	0	0	0
6	1	1	1	1
7	1	-1	-1	-1
8	-1	0	0	0
9	1	1	1	-1
10	0	0	0	-1
11	0	0	1	0
12	-1	1	1	-1
13	1	-1	1	1
14	-1	1	1	1
15	0	0	0	1
16	1	-1	-1	1
17	-1	-1	1	1
18	0	0	0	0
19	-1	1	-1	-1
20	0	0	0	0
21	0	0	0	0
22	1	1	-1	-1
23	0	1	0	0
24	0	0	-1	0
25	-1	1	-1	1
26	-1	-1	-1	-1
27	1	0	0	0
28	-1	-1	1	-1
29	-1	-1	-1	1
30	0	-1	0	0
31	1	1	-1	1

V. RESULT AND DISCUSSION

Multiple linear regression Analysis

The purpose of the multiple regression model is to study the correlation between several independent variables and dependent variables which have a major effect on SFC. By conducting experiment according to their run with codded values, general equation for SFC can be written as:

SFC = 0.2303-0.0111*CR-0.0156 *BR+0.0039*IP-0.1289*LOAD

Table 4. *Regression coefficient for SFC using MLR*

Term	Coef	SE Coef	T-Value	P-Value
Constant	0.2303	0.0108	21.39	0.000
CR	-0.0111	0.0141	-0.79	0.439
BR	-0.0156	0.0141	-1.10	0.281
IP	0.0039	0.0141	0.28	0.785
LOAD	-0.1289	0.0141	-9.12	0.000

R-sq = 76.60%	**R-sq(pred)** = 67.65%
R-sq(adj) =73.00%	

T-values and P-values achieved by multiple linear regression (MLR) analysis are shown in Table 4.
The significance of the models was checked by employing design of experiment (DOE) as shown in Table 5. The P-value of 0.000 which is less than 0.05 shows statistical significance of the model.

***Table 5.**Analysis of variance for SFC using MLR*

Source	DF	SS	MS	F	P
Regression	4	0.305872	0.076468	21.28	0.000
Residual Error	26	0.093425	0.003593		
Total	30	0.399297			

Figure 2 shows Normal probability plot for experiment design,which represent the closeness of prediction with a regression line. MLR prediction will be compared with the RSM prediction to check the feasibility.

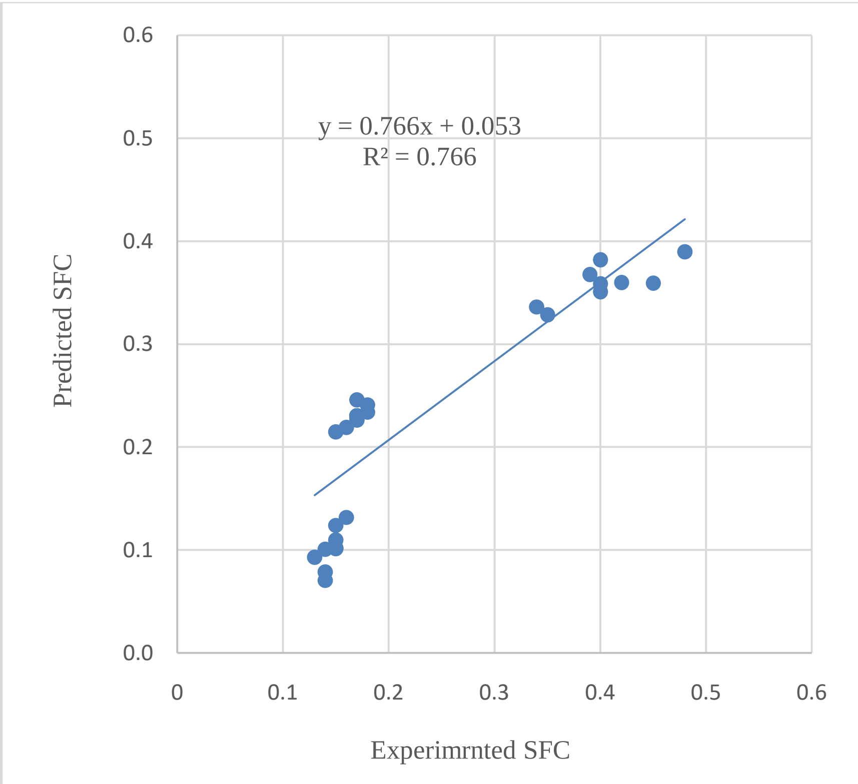

***Figure 2.**Regression plot for SFC using MLR*

Response Surface Methodology

RSM is statistical and mathematical collection for obtaining empirical model building. Empirical model for SFC, regarding with input parameters as CR, IP, BR and LOAD was generated using RSM with coefficients shown in Table 6. Here CR, BR, LOAD, LOAD*LOAD, CR*IP, CR*LOAD, BR*LOAD are significant model terms as their value less than 0.05. And IP, CR*CR, BR*BR, IP*IP, CR*BR, BR*IP, IP*LOAD are not significant as their value increases than 0.05. The value for “R-sq(pred)”=0.9374 and value for “R-sq(adj)”=0.9832 which are close to each other.The equation for predicted SFC developed by RSM is shown below.

SFC (CODDED) = 0.17304 – 0.01111 CR – 0.01556 BR + 0.00389 IP – 0.12889 LOAD – 0.00659 CR*CR – 0.01659 BR*BR – 0.00159 IP*IP + 0.12341 LOAD* LOAD – 0.00125 CR*BR – 0.00875 CR*IP + 0.01125 CR*LOAD – 0.00375 BR*IP + 0.00875 BR*LOAD – 0.00125 IP* LOAD

Table 6. *Regression coefficients for SFCusing RSM*

Terms	Coef	SE Coef	T-Value	P-Value
Constant	0.17304	0.00443	39.04	0.000
CR	-0.01111	0.00352	-3.16	0.006
BR	-0.01556	0.00352	-4.42	0.000
IP	0.00389	0.00352	1.10	0.286
LOAD	-0.12889	0.00352	-36.60	0.000
CR*CR	-0.00659	0.00927	-0.71	0.488
BR*BR	-0.01659	0.00927	-1.79	0.093
IP*IP	-0.00159	0.00927	-0.17	0.866
LOAD*LOAD	0.12341	0.00927	13.31	0.000
CR*BR	-0.00125	0.00373	-0.33	0.742
CR*IP	-0.00875	0.00373	-2.34	0.032
CR*LOAD	0.01125	0.00373	3.01	0.008
BR*IP	-0.00375	0.00373	-1.00	0.330
BR*LOAD	0.00875	0.00373	2.34	0.032
IP*LOAD	-0.00125	0.00373	-0.33	0.742
R-sq = 99.11%				**R-sq(pred)** = 93.74%
R-sq(adj)= 98.32%				

Table 7.*Analysis of variance for SFC using RSM*

Source	DF	SS	MS	F	P
Regression	14	0.395726	0.028266	126.64	0.000
Linear	4	0.305872	0.028266	342.59	0.000
Square	4	0.085103	0.021276	95.32	0.000
Interaction	6	0.00475	0.00792	3.55	0.020
Residual error	16	0.003571	0.000223		
Lack of fit	10	0.003571	0.000357		
Pure error	6	0.000000	0.000000		
Total	30	0.399297			

Suitability of the model was tested by analysis of variance. From Table 7 it can be seen that the P-value is less than 0.05, which signifies the model. In quadratic term CR, BR and load have a significant effect.

Figure 3 shows the regression line plot for SFC using RSM data. It also shows the equation and the value of R^2. The value of R^2 is 0.9911 which is near to unity. It means the model is accurate.

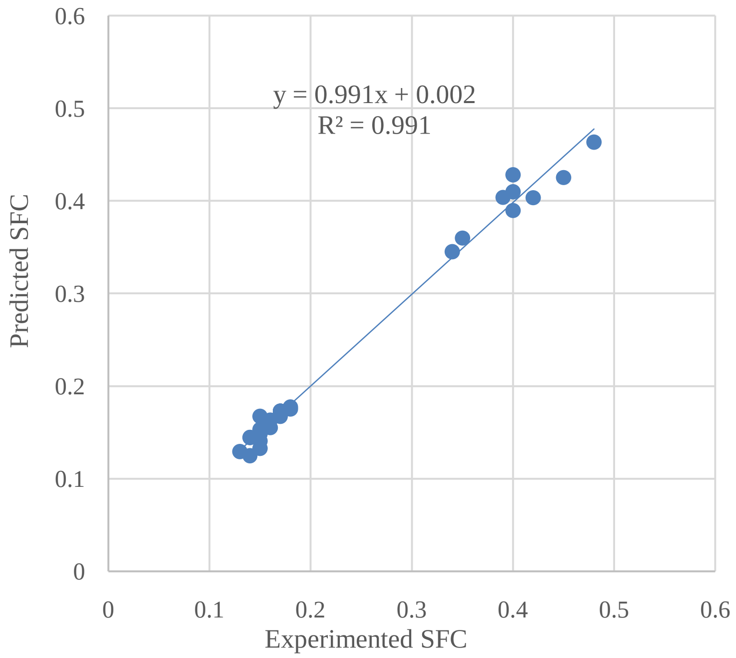

***Figure 3.** Regression plot for SFC using RSM*

Comparison of MLR and RSM model

Regression plot for SFC generated by MLR method and RSM approach are shown in Fig. 2 and Fig. 3. It can be seen that MLR method is not feasible as RSM. Table 8 shows experimental results obtained by performing experiments. Form table it can be seen that error in RSM calculation is lower than MLR. It means RSM is better method for prediction of SFC of an engine than MLR method.

This might be due to the large amount of data required for developing a sustainable regression model, while the response surface could recognize the relationships with less data for distributed and parallel computing natures. A second reason is the effect of the predictors on the dependent variable, which may not be linear in nature. In other words, the RSM model could probably predict surface roughness with a better performance owing to their greater flexibility and capability to model nonlinear relationships.

Therefore, in the case of data sets with a limited number of observations in which regression models fail to capture reliably, advanced soft computing approaches like RSM has to be preferred.

***Table 8.**Experimental results table*

Ex. No.	CR	BR	IP	LOAD	SFC (kg/kWh)	MLR PREDICTED SFC	RSM PREDICTED SFC	ERROR MLR	ERROR RSM
1	0	0	0	0	0.17	0.23	0.17304	-0.06	-0.00304
2	0	0	0	0	0.17	0.23	0.17304	-0.06	-0.00304
3	1	-1	1	-1	0.39	0.37	0.40391	0.02	-0.01391
4	0	0	0	0	0.17	0.23	0.17304	-0.06	-0.00304
5	0	0	0	0	0.17	0.23	0.17304	-0.06	-0.00304
6	1	1	1	1	0.14	0.08	0.12501	0.06	0.01499
7	1	-1	-1	-1	0.42	0.36	0.40363	0.06	0.01637
8	-1	0	0	0	0.18	0.24	0.17756	-0.06	0.00244
9	1	1	1	-1	0.34	0.34	0.34529	0.00	-0.00529
10	0	0	0	-1	0.45	0.36	0.42534	0.09	0.02466
11	0	0	1	0	0.18	0.23	0.17534	-0.05	0.00466

12	-1	1	1	-1	0.4	0.36	0.41001	0.04	-0.01001
13	1	-1	1	1	0.15	0.11	0.14863	0.04	0.00137
14	-1	1	1	1	0.14	0.10	0.14473	0.04	-0.00473
15	0	0	0	1	0.15	0.10	0.16756	0.05	-0.01756
16	1	-1	-1	1	0.15	0.10	0.15335	0.05	-0.00335
17	-1	-1	1	1	0.16	0.13	0.16335	0.03	-0.00335
18	0	0	0	0	0.17	0.23	0.17304	-0.06	-0.00304
19	-1	1	-1	-1	0.4	0.35	0.38973	0.05	0.01027
20	0	0	0	0	0.17	0.23	0.17304	-0.06	-0.00304
21	0	0	0	0	0.17	0.23	0.17304	-0.06	-0.00304
22	1	1	-1	-1	0.35	0.33	0.36001	0.02	-0.01001
23	0	1	0	0	0.15	0.21	0.14089	-0.06	0.00911
24	0	0	-1	0	0.17	0.23	0.16756	-0.06	0.00244
25	-1	1	-1	1	0.13	0.09	0.12945	0.04	0.00055
26	-1	-1	-1	-1	0.4	0.38	0.42835	0.02	-0.02835
27	1	0	0	0	0.16	0.22	0.15534	-0.06	0.00466
28	-1	-1	1	-1	0.48	0.39	0.46363	0.09	0.01637
29	-1	-1	-1	1	0.15	0.12	0.13307	0.03	0.01693
30	0	-1	0	0	0.17	0.25	0.17201	-0.08	-0.00201
31	1	1	-1	1	0.14	0.07	0.14473	0.07	-0.00473

VI. CONCLUSION

Present study shows the comparison between response surface model and multiple regression model for estimation of SFC of single cylinder diesel engine. The experimental run table was created using RSM and data obtained for SFC through that was used for comparison with data MLR data. The conclusion that are made from this research study are:

- It is found that the model is significant and adequate to represent the relationship between the variables and response.
- The value of R^2 obtained through RSM model was 0.9911 which is near to unity and that obtained through MLR was 0.7660. This shows RSM model is more accurate than MLR model.
- Error found by calculation shows that value of error is much lower in case of RSM model than MLR model. This shows closeness of predicted to experimented value.
- So, the performance of RMS model for predicting SFC was found to be better compared to MLR model in terms of the prediction accuracy.

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