Parametric Optimization of Single Cylinder 4 Stroke CI Engine Fueled with Jatropha Biodiesel & Diesel Blend for Mechanical Efficiency using RSM Approach

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Abstract: The present experimental study aims at exploring the effect of Jatropha biodiesel and diesel blends on a single cylinder four stroke water cooled diesel engine. Jatropha biodiesel has been obtained from Jatropha oil by Transesterification process. In this experimentation, the effects of parameters` i.e. injection pressure, blend ratio, inlet water-flow rate and load are taken as adaptable for optimization. RSM optimization has been used with four parameters and three levels of experiments. The proposed Box Behnken design requires 31 runs of experiment for data acquisition and modeling the response surface. Minitab 18 software was used to design the experiment structure. In the end, Taguchi experiment identifies that at JB50, injection pressure 150 bar, engine water flow 300 lph and engine load 11 kg werefound to be the optimum parameter settings for higher mechanical efficiency. Engine performance has been typically influenced by engine loading conditions and least influenced by water inlet flow.

Index Terms: **Jatropha, Transesterification, Mechanical efficiency, CI engine, RSM**

I. INTRODUCTION

Considering the gradual decrease of crude oil reserve and setting impact there's a necessity of establish the varied alternate fuels. In sight of this, vegetable oil may be a promising alternate answer owing to eco-friendly, simply created and renewable characteristics. Therefore, in recent years many researches are studied to use vegetable oils as fuel in engines as biodiesel. Biodiesel is for good cut plant- or animal-based oil. Numerous vegetable oils, as well as vegetable oil, soya bean oil, and sunflower-seed oil, oilseed Energy demand is increasing because of ever increasing variety of vehicles using burning engines. Also, world is presently confronted with the dual crisis of fuel depletion and environmental degradation. Fossil fuels are restricted resources; thus, look for renewable fuels is turning into additional and additional distinguished for guaranteeing energy security and environmental protection. The agriculture sector of Republic of India is totally captivated with diesel for its locomotion and to some extent for stationary power application. Magnified farm mechanization in agriculture additional will increase the need of this depleting fuel supply. Jatropha oil are turn out to be useful as biodiesel fuel and lubricants. Our concern during this article is concerning Jatropha bio-diesel. The Jatropha oil is slow-drying oil that is odorless and colorless once contemporary, however becomes yellow on standing. The oil content of Jatropha seed ranges to fifty fifth by its weight. The carboxylic acid composition of Jatropha classifies it as a linoleic or monounsaturated fatty acid sort, which are unsaturated fatty acids. The carboxylic acid composition of Jatropha oil consists of meristic, palmitic, stearic, arachidic, oleic and linoleic acids. The seeds and oil square measure cyanogenic because of the presence of cursive and curcasive. The potential use of extracted oil from Jatropha curcas or as a mix with diesel has been studied. The calorific value and cetane variety of Jatropha curcas oil are similar to diesel, however the density and viscosity are abundant higher. However, from the properties of this oil it's envisaged that the oil would be appropriate as heating oil. Fuels derived from renewable biological resources to be used in diesel engines square measure called biodiesel. Biodiesel is environmentally friendly liquid fuel like petrol-diesel in combustion properties. Biodiesel is AN ventilated fuel containing 10-15% by weight. additionally it may be aforesaid that biodiesel may be a sulfur-free fuel. These facts lead biodiesel to additional complete combustion.

II. LITERATURE REVIEW

Rao et al. (2009) evaluated the performance of single cylinder water-cooled diesel engine using Multi-DM-32 diesel additive and methyl-ester of jatropha oil as the fuel.JB-25 and JB-100 blends were considered as the jatropha biodiesel blends for the experimentation.JB-25 mix showed nearer performance to diesel and JB-100 had lower brake thermal efficiency mainly because ofits high viscosity compared to diesel.The brake thermal efficiency for biodiesel and its blends was found to be slightly above that of diesel oil at tested load conditions and there was no distinctionbetween the biodiesel and its blended fuels efficiencies.For jatropha biodiesel and its blended fuels, the exhaust gas temperature was found to be increased with increase in power and amount of biodiesel.However, its diesel blends showed reasonable efficiencies, lower smoke, CO_2 and CO emissions.It was observed that Multi-DM-32, Bio-additive possesses many attributes as Multi-Functional fuel additive.Its ability to cut back the surface tension between two or more interacting incompatible liquidshelped the fuel to flow higher through injector and higher atomization of fuel, which improvedthe combustion and performance of the engine at all variable loads.Multi-DM-32 also improved the pollution control [1]. **Kumar et al. (2013)** investigated the influence of compression ratio (CR) on the performance and emissions of a DI diesel engine using jatropha biodiesel (50%) blended-diesel fuel, known as JB-50.Tests were administered using three totally different CRs (14, 16 and 18:1) at 1500 rpm with varying load from 0 to 100%.The results showed that increasing compression ratio improves the burning characteristics of biodiesel.At higher compression ratio, brake specific fuel consumption (BSFC) increased while brake thermal efficiency decreased.However, slight increase in brake power was found particularly at higher load.Steep decrease was recorded in smoke opacity (OP), carbon monoxide (CO), oxygen (O2) and hydrocarbon (HC) emissions, while increase in CO2 was also observed [2]. **Arakerimath et al. (2012)** used biodiesel from jatropha oil is in a M&M Turbo Charged , four stroke, four cylinders, water cooled, diesel engine in pure and blended form without any modification in engine design or fuel system.The power, torque, and brake thermal efficiency using biodiesel were found higher at numerous load conditions compared to petro-diesel; but specific fuel consumption was found slightly additional.

The biodiesel mix JB-20 showed higher performance than the diesel and different blends.According to the test, it was observed that at low load, mechanical efficiencies of diesel and all consider blends of biodiesel were same but the load increased, the mechanicalefficiency was varied. At full load, JB-40 showed same efficiency as diesel [3]. **Mamilla et al. (2013)** detailed the analysis of the performance and emission characteristics of the jatropha methyl esters and its comparison with petroleum diesel.The tests were administered on a 3.7 kW single cylinder, direct injection water-cooled diesel engine.The fuels used were neat jatropha methyl ester, diesel and totally different blends of the methyl ester with diesel.The experimental result showed that JB-20 mix was higher in performance with reduced pollution.The analysis showed that Jatropha methyl ester amalgamated biodiesel was a decent substitute for pure diesel.It was determined that smoke density accumulated with increasing load for all the blends of Jatropha methylesters.It was found that smoke density decreased at higher blends of jatropha methyl esters [4]. **Sahoo et al.(2009)** made the alkyl radical esters of non-edible Jatropha (Jatrophacurcas), Karanja (Pongamiapinnata) and Polanga (Calophylluminophyllum) oil for experimentation and blended with conventional diesel having sulphur content lessthan 10 mg/kg.Ten fuel blends (Diesel, B-20, B-50 and B-100) were tested for their use as substitute fuel for a water-cooled three cylinder tractor engine.Test information were generated under full/part throttle position for various engine speeds (1200, 1800 and 2200 rev/min).

Change in exhaust emissions (Smoke, CO, HC, NOX, and PM) were also analyzed for determining the optimum test fuel at various operating conditions.The maximum increase in power was ascertained for 50% Jatropha biodiesel and diesel mix at rated speed.Brake specific fuel consumptions for all the biodiesel blends with diesel increases with blends and reduced with speed.There was a reduction in smoke for all the biodiesel and their blends in comparison with diesel.Smoke emission reduced with blends and speeds during full throttle performance test [5]. **Roy et al (2000)** have reported that high pressure injection in a 7799cc, 6 cylinders, and common rail electronic controlled diesel engine produced low hydrocarbon and aldehydes in exhaust. It has been further reported that the ignition delay was reduced and the odor was minimum when injection pressure of 60-80 MPa was maintained. It has been concluded that higher injection pressure only can meet the latest emission requirements [6]. **Pugazhvadivu et al. (2018)** have tested the waste frying oil in a single cylinder, direct injection diesel engine at various injection pressures of 190,210,210,230 and 250 bars and studied the performance and emissions. It has been stated that when the injection pressure was increased the brake specific energy consumption reduced, due to the improvement in the fuel atomization and due to mixing of air and fuel. It has been reported that when injection pressure was increased, there was an improved rate of evaporation and combustion of fuel. It has also been concluded that when the injection pressure was increased, the NOX emission and combustion temperature tend to increase [7].

III. JATROPHA BIODIESEL

Jatropha biodiesel can be acquired from jatropha oil. The conversion of Jatropha oil into its methyl ester can be accomplished by the transesterification process. Transesterification involves reaction of the triglycerides of Jatropha oil with methyl alcohol in the presence of a catalyst Sodium Hydroxide (NaOH) to produce glycerol and fatty acid ester. Biodiesel production process and transesterification process is shown in Figure 1 & Figure 2 respectively.

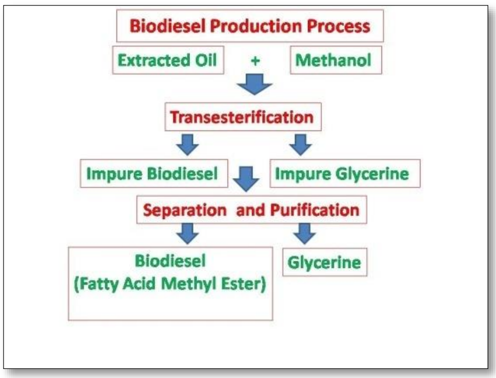

Fig.1 Schematic diagram of biodiesel production [8]

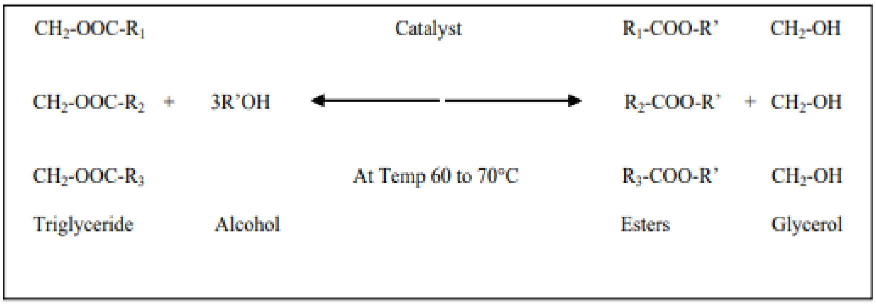

Fig.2 Transesterification Process

IV. METHODOLOGY

Box Behnken design approach was applied to plan the experiments for validating Jatropha oil blends of optimizing the process to find better efficiencies, better fuel consumption rate and lower emissions. Response Surface Methodology (RSM) has been adopted to express the output parameters (responses) that are decided by the input process parameters. RSM also quantifies the relationship between the variable input parameters and the corresponding output parameters. RSM designs allow us to estimate interaction and even the quadratic effects, and hence, give us an idea of the shape of the response surface we are investigating. Box Behnken design is having the maximum efficiency for an experiment involving four factors and three levels; further, the number of experiments conducted for this is much lesser compared to a central composite design. The proposed Box Behnken design requires 31 runs of experiment for data acquisition and modeling the response surface. Minitab 18 software was used to design the experiment structure. The Box Behnken is a good design for response surface methodology because it permits estimation of the parameters of the quadratic model, building of sequential designs, detection of lack of fit of the model and use of blocks. A comparison between the Box-Behnken design and other response surface designs (central composite, Doehlert matrix and three-level full factorial design) has demonstrated that the Box Behnken design and Doehlert matrix are slightly more efficient than the central composite design but much more efficient. Figure 3 shows the flow chart of response surface methology.

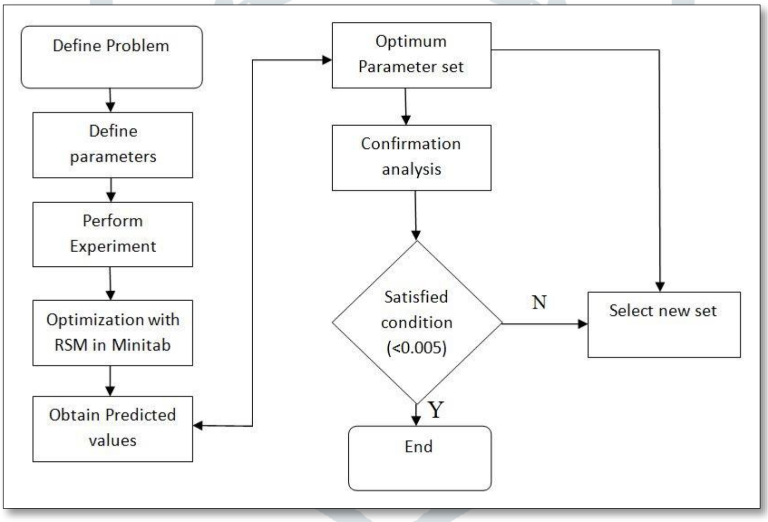

Fig.3 Flow Chart of Response Surface Methodology

V. EXPERIMENT SET UP

The setup was a single cylinder 4- stroke water cooled research engine coupled with eddy current dynamometer for various loading conditions. The mode of operation in this engine can be changed from diesel to Petrol or from Petrol to Diesel with some slight changes. In both operation modes the compression ratio can be changed without stopping the engine and no other changes needed for the geometry of combustion chamber by specially designed tilting cylinder block arrangement. Different other instruments provided to vary airflow, fuel flow, temperatures and load measurement. Rota-meter was provided to measure cooling water flow and calorimeter water flow. A battery, starter and battery charger were provided to start the engine. Analysis software Engine-soft was synced in with engine setup to find performance evaluation and lab view based Engine Performance. The test engine used in the experiment is shown in Figure 4.

Fig.4 Experimental Setup Test Rig

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 setup 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 Experimental setup is utilized to observe VCR engine performance for Brake Power, Indicated Power, Frictional Power, Brake Mean Effective Pressure, Indicated Mean Effective Pressure, Brake Thermal Efficiency, Indicated Thermal Efficiency, Mechanical Efficiency, Volumetric Efficiency, Specific Fuel Consumption, A/F Ratio and Combustion Analysis. Lab view based engine Performance Analysis software package "Engine soft" is provided for on line performance evaluation. Engine setup specifications are shown in Table 1.The technical specifications of Eddy Current Dynamometer are shown in Table 2. The valve timing and compression ratio were taken as constant parameters, while injection pressure, water injection flow, load and blends were varied during the experimentations.

Table 1 Engine Setup Specifications

Engine manufacturer	Apex Innovations (Research Engine test set up)
Software	Engine soft Engine performance analysis software
Engine	Single cylinder water cooled CI engine
Engine Type	Variable Compression Ratio
Capacity	553 cc
Power Rating & Engine Speed	3.5 kW @ 1500 rpm
Compression Ratio	12:1 to 18:1
Cylinder diameter (B)	87.5 mm
Stroke length (L)	110 mm
Connecting rod length	234 mm
Dynamometer	Eddy current water cooled with loading unit

Table 2 Technical Specification of Eddy Current Dynamometer

Model	AG10
Manufacturer	Saj Test Plant Pvt. Ltd.
End Flanges (on both sides)	Cardon Shaft Model 1260 Type A
Water Inlet (bar)	1.6
Minimum (kPa)	160
Pressure (lbf/in^2)	23
Torque (N-m)	11.5
Hot Coil Voltage max.(volts)	60
Continuous Current (amps)	5.0
Cold Resistance (ohms)	9.8
Speed max.(rpm)	10000
Load (kg)	3.5
Bolt Size	M12 × 1.75
Weight (kg)	130

VI. RESULT DATA TABLE

The result data obtained from the experimentation is shown in Table 3.

Table 3 Result Table for the experiments

Exp. No.	BD (%)	IP (bar)	WIF (lph)	Load (kg)	Density (kg/m^3)	CV (kJ/kg)	FC (kg/hr)	BP (kW)	BTE (%)	η_{mech} (%)
1	0	100	200	1	832	44000	0.40	0.31	6.44	14.16
2	0	100	200	11	832	44000	0.90	3.26	29.65	63.06
3	0	100	400	1	832	44000	0.40	0.30	6.24	13.77
4	0	100	400	11	832	44000	0.90	3.18	28.97	62.51
5	0	150	300	6	832	44000	0.60	1.74	23.75	47.69
6	0	200	200	1	832	44000	0.40	0.23	4.80	10.94
7	0	200	200	11	832	44000	0.90	3.30	30.03	63.35
8	0	200	400	1	832	44000	0.40	0.32	6.50	14.26
9	0	200	400	11	832	44000	0.90	3.22	29.28	62.77
10	50	100	300	6	864	41550	0.78	1.79	19.98	57.99
11	50	150	200	6	864	41550	0.67	1.84	23.72	58.68
12	50	150	300	1	864	41550	0.36	0.39	9.36	23.18
13	50	150	300	6	864	41550	0.67	1.85	23.74	58.71
14	50	150	300	6	864	41550	0.67	1.85	23.74	58.71
15	50	150	300	6	864	41550	0.67	1.85	23.74	58.71
16	50	150	300	6	864	41550	0.67	1.85	23.74	58.71
17	50	150	300	6	864	41550	0.67	1.85	23.74	58.71
18	50	150	300	6	864	41550	0.67	1.85	23.74	58.71
19	50	150	300	6	864	41550	0.67	1.85	23.74	58.71
20	50	150	300	11	864	41550	0.98	3.30	29.02	71.75
21	50	150	400	6	864	41550	0.67	1.84	23.64	58.60
22	50	200	300	6	864	41550	0.67	1.83	23.55	58.50
23	100	100	200	1	896	39100	0.43	0.29	6.14	14.00
24	100	100	200	11	896	39100	1.02	3.28	29.55	65.03
25	100	100	200	1	896	39100	0.43	0.29	6.14	14.00
26	100	100	400	11	896	39100	0.97	3.18	30.24	64.32
27	100	150	300	6	896	39100	0.65	1.72	24.52	49.36
28	100	200	200	1	896	39100	0.43	0.24	5.06	11.82
29	100	200	200	11	896	39100	0.97	3.23	30.77	64.72
30	100	200	400	1	896	39100	0.43	0.23	4.89	11.46
31	100	200	400	11	896	39100	0.97	3.23	30.71	64.68

VII. RSM ANALYSIS FOR MECHANICAL EFFICIENCY

The results of mechanical efficiency were analyzed using Minitab 18. Minitab software can be helpful for DOEs like factorial, response surface, mixture, and Taguchi (robust). Minitab can be utilized to create, define and analyze the DOE to generate graphs of an experimental design which are similar for all design types.

Percentage of blend, water inlet flow, load and IP are taken as A, B, C and D respectively to better understand the analysis but mechanical efficiency is output parameter which is directly affected by the input parameters. Table 4 shows the normalized data for RSM analysis on Mechanical Efficiency. Table 6 displays analysis of variance data.

Table 4 Normalized Data for Mechanical Efficiency

Exp. No.	A (%)	B (bar)	C (lph)	D (kg)	η_{mech} (%)
1	0	100	200	1	14.16
2	0	100	200	11	63.06
3	0	100	400	1	13.77
4	0	100	400	11	62.51
5	0	150	300	6	47.69
6	0	200	200	1	10.94
7	0	200	200	11	63.35
8	0	200	400	1	14.26
9	0	200	400	11	62.77
10	50	100	300	6	57.99
11	50	150	200	6	58.68
12	50	150	300	1	23.18
13	50	150	300	6	58.71
14	50	150	300	6	58.71
15	50	150	300	6	58.71
16	50	150	300	6	58.71
17	50	150	300	6	58.71
18	50	150	300	6	58.71
19	50	150	300	6	58.71
20	50	150	300	11	71.75
21	50	150	400	6	58.60
22	50	200	300	6	58.50
23	100	100	200	1	14.00
24	100	100	200	11	65.03
25	100	100	200	1	14.00
26	100	100	400	11	64.32
27	100	150	300	6	49.36
28	100	200	200	1	11.82
29	100	200	200	11	64.72
30	100	200	400	1	11.46
31	100	200	400	11	64.68

Table 6 Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	14	14160.5	1011.5	2081.26	0.000
Linear	4	10951.6	2737.9	5633.72	0.000
% BD	1	2.1	2.1	4.38	0.053
IP (bar)	1	1.8	1.8	3.65	0.074
WIF (lph)	1	0.0	0.0	0.00	0.047
Load (kg)	1	10547.8	10547.8	21703.97	0.000
Square	4	2558.0	639.5	1315.89	0.000
% BD×% BD	1	245.1	245.1	504.30	0.000

IP (bar)×IP (bar)	1	0.0	0.0	0.00	0.996
WIF (lit/hr)×WIF (lit/hr)	1	0.4	0.4	0.80	0.385
Load (kg)×Load (kg)	1	301.4	301.4	620.24	0.000
2-Way Interaction	6	12.2	2.0	4.19	0.010
% BD×IP (bar)	1	0.2	0.2	0.49	0.493
% BD×WIF (lit/hr)	1	0.6	0.6	1.21	0.287
% BD×Load (kg)	1	4.9	4.9	10.17	0.006
IP (bar)×WIF (lit/hr)	1	1.0	1.0	2.11	0.166
IP (bar)×Load (kg)	1	3.3	3.3	6.74	0.019
WIF (lit/hr)×Load (kg)	1	0.9	0.9	1.80	0.198
Error	16	7.8	0.5		
Lack-of-Fit	9	7.8	0.9	*	*
Pure Error	7	0.0	0.0		
Total	30	14168.2			

From above Table 6 values of 'P' is less than 0.0500 for blend and IP which indicate that model is significant for design.The p-value for the Box Behnken based design is less than 0.05. From the model summary the values are shown as below in Table 7.

Table 7 Model Summary

S = 0.697126	R^2 = 99.95 %	R^2(adj) =99.90 %	R^2(predicted) = 99.58 %

A surface plot displays the three-dimensional relationship in two dimensions, with the variables on the x- axes and y-axes, and the response variable (z) represented by a smooth surface. Figure 5 shows the surface plot IP and blend ration are on the X & Y axis where Mechanical Efficiency is on Z axis.

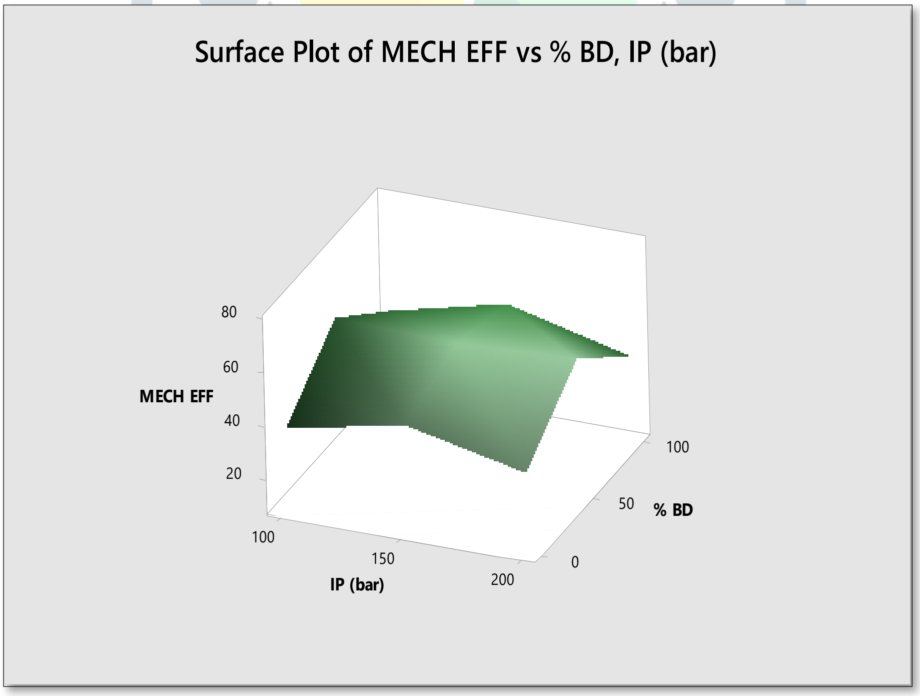

Fig.5 Surface Plot of Mechanical Efficiency

In Figure 6, darker regions indicate higher z-values. These higher Mechanical efficiency values seem to form a ridge running from the upper left of the graph to the middle right. The valleys in the lower part of the graph and the upper right represent time-temperature combinations that result in under-cooked or over-cooked entrees respectively.

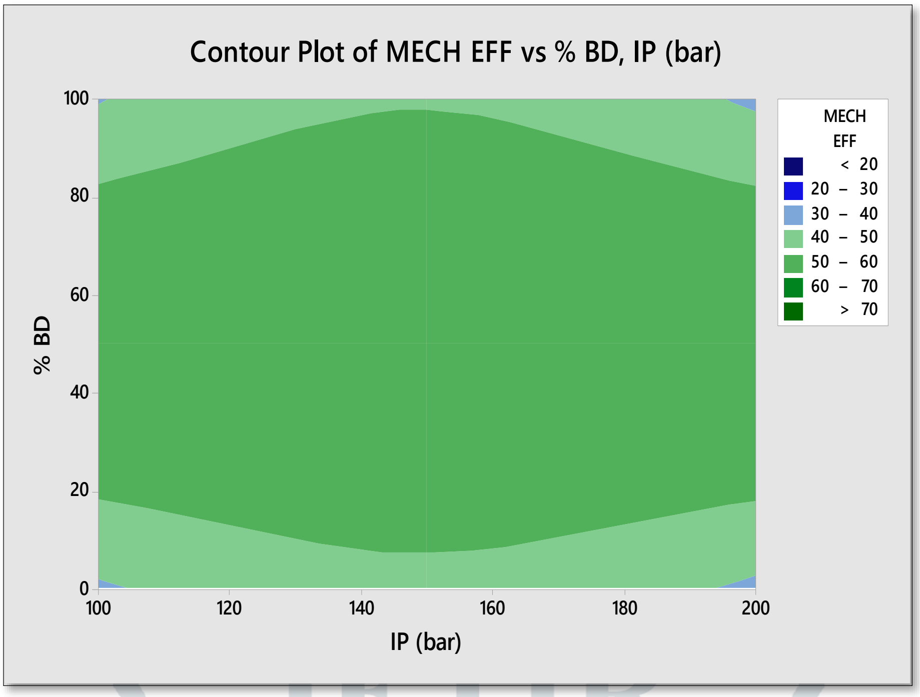

Fig.6 Contour Plot of Mechanical Efficiency

Figure 7 indicates residual plots for mechanical efficiency to check the data for the non-random variation, non-constant variance and outliners. On the Normal Probability plot the straight line indicate residual are normally distributed. Versus fits, Histogram and versus graph represent there is no undesirable effect and for the prediction Values of mechanical efficiency can be calculated from the Regression Equation in un-coded units.

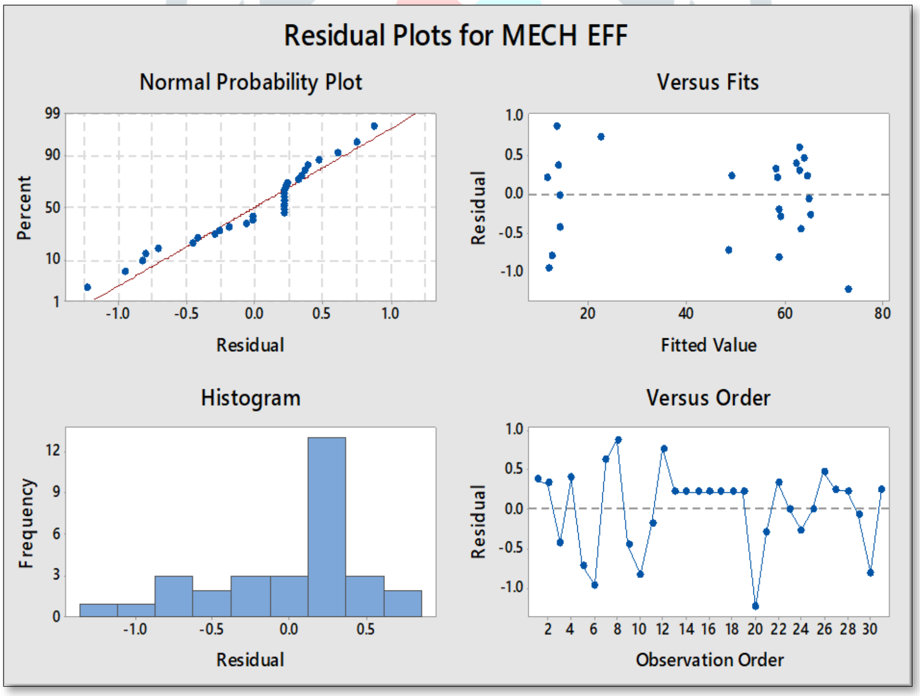

Fig.7 Residual Plots for Mechanical Efficiency

The residual equation in un-coded units for mechanical efficiency is given below as well as experimental and predicted values of mechanical efficiency is displayed in Table 8, while the comparison graph for the same is displayed in Figure 8.

Mechanical Efficiency = 9.91+0.4023 % BD-0.0315 IP(bar)-0.0262 WIF (lit/hr)
+9.983 Load (kg)0.003890 % BD×% BD0.000001IP(bar)×IP (bar)+0.000039 WIF (lit/hr)×WIF (lit/hr)-
0.4314 Load (kg)×Load (kg)- 0.000051 % BD×IP (bar)
0.000042%BD×WIF (lit/hr)+ 0.002334 % BD×Load (kg)+0.000055 IP (bar)×WIF (lit/hr) +0.001900 IP (bar)×Load (kg)-
0.000507 WIF (lit/hr)×Load (kg)

This equation is used to predict the equivalent stress for set of independent variable. The comparison of experimental equivalent stress and predicted equivalent stress is given in terms of standard error and R squared error.

Table 8 Experimental and predicted values of Mechanical efficiency

Sr.No.	Experimental Value	Predicted Value	Error	R^2
1	14.15604408	14.04933717	0.106707	0.9995
2	63.05925243	62.77964746	0.279605	
3	13.76884927	14.16679846	-0.39795	
4	62.51486537	62.04495089	0.469914	
5	47.69282713	47.42185492	0.270972	
6	10.93778607	9.697259062	1.240527	
7	63.35222187	62.82075211	0.53147	
8	14.2618505	13.86705041	0.3948	
9	62.77021326	63.28402489	-0.51381	
10	57.99323982	59.14629496	-1.15306	
11	58.67696059	59.6456685	-0.96871	
12	23.18363586	25.14716126	-1.96353	
13	58.70523121	59.18016334	-0.47493	
14	58.70523121	59.18016334	-0.47493	
15	58.70523121	59.18016334	-0.47493	
16	58.70523121	59.18016334	-0.47493	
17	58.70523121	59.18016334	-0.47493	
18	58.70523121	59.18016334	-0.47493	
19	58.70523121	59.18016334	-0.47493	
20	71.74931008	73.07401214	-1.3247	
21	58.59795747	59.59437234	-0.99641	
22	58.50327276	58.76656806	-0.2633	
23	14.00008423	13.45551496	0.544569	
24	65.03352264	65.39709184	-0.36357	
25	14.00008423	13.45551496	0.544569	
26	64.32315727	63.62777446	0.695383	
27	49.36023055	47.8378125	1.522418	
28	11.82232337	9.48363624	2.338687	
29	64.72406423	64.77508574	-0.05102	
30	11.46442241	10.00995936	1.454463	
31	64.67987488	64.46272774	0.217147	

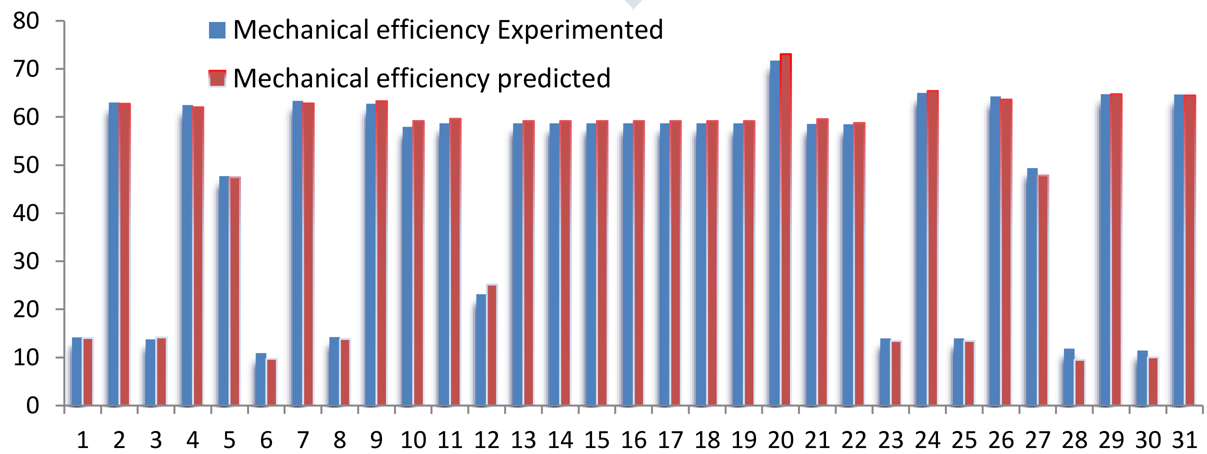

Fig.8 Predicted and Experimental Value Comparison Diagram of Mechanical Efficiency

VIII. CONCLUSIONS

The RSM method was found to be an efficient technique for quantifying the effect of control parameters. From the results of the experiment it's been concluded that;

1) The p-value for the Box Behnken based design is less than 0.05. This result indicates that the mean differences between the blend and injection pressure is statistically significant.
2) The value of R^2obtained was 0.995, which suggests that the experiments were performed successfully.
3) The maximum mechanical efficiency was obtained at JB50, injection pressure 150 bars, water inlet flow 300 lph and 11 kg of engine load.

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APPENDIX

Table9 Nomenclatures

L	engine stroke, mm	η_{mech}	mechanical efficiency, %
B	bore diameter, mm	$\eta_{Vol.}$	volumetric efficiency,%
IP	injection pressure, bar	EGT	exhaust gas temperature, °C
WIF	water inlet flow, lph	JB50	jatropha biodiesel (50% diesel+50% jatropha)
lph	litre per hour	JB100	jatropha biodiesel (100% jatropha)
SFC	specific fuel consumption, kg/kWh	VCR	variable compression ratio
B.P.	brake power, kW	HC	hydrocarbon, ppm
I.P.	indicated power, kW	CO_2	carbon dioxide, ppm
F.P.	friction power, kW	CO	carbon monoxide, ppm
BTE	brake thermal efficiency,%	NO_X	nitrogen oxides, ppm
ITE	induced thermal efficiency,%	RSM	response surface method