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Optimization of Effective Parmeter of Jatropha Biodiesel Using Taguchi Method and Performance Analysis Using CI Engine

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Abstract—Experiments are carried out by biodiesel blends and compared it's with diesel fuel characteristics. In this study, the optimization of experimental parameters, such as catalyst type, catalyst concentration, molar ratio of alcohol to oil and reaction temperature, on the transesterification for the production of Jatropha methyl ester was performed. Alkali catalyzed method has been used for biodiesel production process by using catalysts such as KOH, NaOH, NaOCH3. The Taguchi method helped to understand the effect of control parameter and to optimize the experimental conditions from a limited number of experiments and contribution of each noise factor calculated by ANOVA. Finally the yield of Jatropha methyl ester could be improved using control parameter which was obtained by Taguchi method. This paper investigated the performance and emission characteristics of various blends of Jatropha biodiesel with diesel on a Single cylinder four stroke diesel engine. The acquired data were analyzed for various parameters such as brake thermal efficiency (BTE), brake mean effective pressure (BMEP), brake specific fuel consumption (BSFC), exhaust gas temperature (EGT).The blends of BJ-10 and BJ-20have superior emission characteristics than other blends and closer to diesel value.

Keywords: ***ANOVA, Basic catalyst, Biodiesel, FAME Jatropha methyl ester, Taguchi method, Transesterification, Engine performance and emission.***

I.INTRODUCTION

Progress of a nation invariably depends on the optimum utilization of its natural resources. India is ranked fourth at the global level on the overall consumption of fossil fuel. Fossil fuel are non renewable in nature and India imports almost 85% of its crude oil consumption by spending billon of dollars and uncontrolled burning of fossil fuel contributes significantly to the environment pollution and global warming. All these lead to us to search for ecofriendly and sustainable alternative. The liquid fuel derived from various oil seeds, starch, molasses and various cellulosic material and any kind of fats from biological sources is defined as biofuel.

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It is possible to produce biodiesel from seeds of vary familiar tree species such as pongamia,neem,mahua,jatropha etc.Jatropha is the one of the oil bearing genuses which can replace diesel oil.Alos jatropha is used for making biodiesel fuel without impact on food consumption .

Many researches reveal that Jatropha is an oil bearing plant, which can be used directly with diesel engine without modifying the engine but has to reduces the viscosity. This can be done by blending the diesel oil. Therefore the oil from Jatropha is one of the alternatives to produce fuel and replace the oil imported from aboard. This is because Jatropha can be planted in almost any regions and give quick yield, which is very beneficial to the farmer for home usage or village usage. Especially agriculturists with low income can grow Jatropha and make diesel oil form Jatropha oil for small engine. This help agriculturist to reduce the fuel cost and become independent. Taguchi has introduced a new method of conducting the design of experiments which are based on well defined guidelines. This method uses a special set of arrays called orthogonal arrays. These standard arrays stipulates the way of conducting the minimal number of experiments which could give the full information of all the factors that affect the performance parameter. The crux of the orthogonal arrays method lies in choosing the level of combinations of the input design variables for each experiment. Ultimatly, the goal is to find the suitable blending ratio for using Jatropha oil with high speed diesel engine with consideration on the engine performance and emission.

II.TRANSESTERIFICATION PROCESS

Transesterification process is the reaction of triglyceride (fat/oil) with an alcohol in the presence of acidic, alkaline or lipase as a catalyst to form monoalkyl ester that is biodiesel and glycerol. The presence of strong acid or base accelerates the reaction. The main purpose of transesterification is to reduce the high viscosity of oil which is suitable for CI engine. In this study, Jatropha methyl ester is obtained by reacting Jatropha oil with methanol in the presence of base catalyst. The Jatropha oil is first filtered to remove solid impurities then it is preheated at100ºC for half an hour to remove moisture. A two stage process is used for transesterification of Jatropha oil. The first stage is esterification to reduce free fatty acid content in Jatropha oil with methanol (99% pure) and acid catalyst (98% pure) heated for one hour at 60-65ºC in magnetic stirrer. After esterification, the esterified oil washed using water. The washing is carried out in a separating funnel.

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The hot water having temperature as that of esterified oil added in a separating funnel. Impurities like dust, carbon content, sulfur content is washed away with water. After washing, the esterified oil was fed to the transesterification process. The basic catalyst was dissolved in methanol and added into esterified Jatropha oil while heating. This mixture is heated for 60 minutes. Once the reaction is complete, it is allowed for settling for 10-12 hours in a separating funnel. The products formed during transesterification were Jatropha oil methyl ester and glycerin. The bottom layer consists of glycerin, excess alcohol, catalyst impurities and traces of unreacted oil. The upper layer consists of clean amber colored Jatropha oil methyl ester. After settling, the glycerol layer is removed. The separated biodiesel is taken for characterization.

III.DESIGN OF EXPERIMENTS

Design of experiment consists of a set of experiments which is the setting of several products or process parameters to be studied that are changed from one experiment to another. Design of experiments is also called matrix experiment, parameters are also called factors and parameter settings are also called levels. Conducting matrix experiment using orthogonal array is an important technique. It gives more reliable estimates of factor effects with fewer numbers of experiments when compared with the traditional methods such as one factor at a time experiments. The design of experiment via Taguchi method uses a set of orthogonal array for performing of the fewest experiments. Taguchi method involves the determination of large number of experimental situation, described as orthogonal array, to reduce errors and enhance the efficiency and reproducibility of experiments. The columns of an orthogonal array are pair wise orthogonal that is for every pair of column, all combination of factor levels occur at an equal numbers of times.

Table I. Design experiments with four parameters at three level, for the production of Jatropha methyl esters.

Parameters	Levels		
	1	2	3
A Molar ratio (Oil/Methanol)	1:5	1:7	1:9
B Catalyst type	KOH	NaOH	NaOCH3
C Catalyst concentration (wt %)	0.4	0.8	1.2
D Reaction temperature (ºC)	55	60	65

The columns of an orthogonal array represent factors to be studied and the rows represent individual experiments. This study is associated with four factors with each at three levels. The orthogonal array used to find the effects of four parameters namely the molar ratio of oil to methanol, catalyst type, catalyst concentration and reaction temperature on the production of Jatropha oil methyl ester. The four selected parameters at three levels i.e., L-9 (34), experimentally studied are shown in Table I. Table II shows the orthogonal array used to design experiments with four parameters at three levels. [5], [9], [10]

Table II. Orthogonal array used to design experiments with four parameters at three levels,L-9(3^4)

Exp. No.	Column number and parameters assigned			
	1 Molar ratio (A)	2 Catalyst type (B)	3 Catalyst concentration (wt %) (C)	4 Reaction temperature (ºC) (D)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

In this study, Minitab15, which is software for automatic design, was used to analyze the results and optimize the experimental conditions for setting the control variables.

IV.DETERMINATION OF OPTIMAL EXPERIMENTAL CONDITION BY THE DESIGN OF EXPERIMENT.

The yield of Jatropha oil methyl ester, prepared under nine sets of experimental conditions are shown in table. All experiments were performed with three repetitions, under the same experimental conditions(e.g., molar ratio of methanol to oil, catalyst type, catalyst concentration and reaction temperature).

Table III. Yield of Jatropha methyl ester and S/N ratios for the nine sets of experiments.

Exp. No	Yield of Jatropha methyl ester				S/N ratio (η)
	Sample 1	Sample 2	Sample 3	Mean	
1	49.1	58.3	60.3	55.9	34.94
2	65.5	68.8	74.2	69.5	36.83
3	69.3	72.0	73.8	71.7	37.11
4	62.8	63.9	71.3	66.0	36.39
5	67.0	68.2	70.0	68.4	36.70
6	52.4	53.5	62.1	56.0	34.96
7	63.8	66.5	67.4	65.9	36.37
8	58.6	59.8	61.9	60.1	35.57
9	59.0	60.5	64.4	61.3	35.74
			Mean	63.86	36.06

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In Taguchi method, the signal to noise ratio is used to measure the quality characteristics deviating from the desired value. S/N ratio developed by Genichi Taguchi, is a predictor of quality loss after making certain simple adjustments to the product's function. It isolates the sensitivity of the product's function to noise factors. The signal to noise ratios (S/N) are log functions of desired output, serve as the objective functions for optimization, help in data analysis and the prediction of the optimum results.

This study is associated with four parameters with each at three levels. Above table indicates that the best suitable orthogonal array is L9. Table II shows the design matrix for L9. After conducting all the nine experiments and measuring the percentage yields so that there are nine observations in total for each experiment.

According to the analysis for the case of larger the better the mean squared deviations (MSD) of each experiment were evaluated using the following equation

$$MSD = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{y_i}\right)^2$$

Where n is the number of repetitions of each experiment and yi the yield of Jatropha methyl ester. Then the S/N ratio was evaluated using the equation.

$$S/N\ ratio = -10Log(MSD)$$

The effect of parameter level is defined as the deviation it causes from the overall mean. Hence as a first step , calculating the overall mean value of S/N ratio for the experimental region defined bythe factor levels in Table III.

$$Mean = \frac{1}{n}\sum_{i=1}^{n}(\eta_i) = \frac{1}{9}(\eta_1+\eta_2+\ldots\eta_9)$$

The signal to noise ratio nine set of experiments shown in table. The mean yield of Jatropha methyl ester and the S/N ratio were 63.86% and 36.06 respectively. Experiment no. 3 gave the highest mean yield of Jatropha methyl ester and had the largest S/N ratio.

The mean signal to noise ratio, which was calculated from the effect of the parameters and the interaction at assigned levels, was the average of all the S/N ratios of a setoff control parameters at a given level. For example, the effect of parameter at level A1 (at experiment 1, 2 and 3) is calculated as

The effect of parameter at level A1 = (1/3)x (η1+η2+η3)
Similarly
The effect of parameter at level A2 = (1/3)x (η4+η5+η6)
The effect of parameter at level A3 = (1/3)x (η4+η5+η6)

Using the S/N ratio data available in table the average of each level of the four factors is calculated and listed in Table IV and mean effect plot of the control parameter shown in Fig. I.

Table IV. Average S/N for different parameter levels.

Parameters	Levels		
	1	2	3
A Molar ratio	36.29*	36.01	35.89
B Catalyst type	35.90	36.36*	35.93
C Catalyst concentration	35.15	36.32	36.72*
D Reaction temperature	35.79	36.05	36.41*

Our goal in this experiment is to maximize the percentage yield of Jatropha methyl ester. Hence the optimum level for a factor is the level that gives the highest value of η in the experimental region. From table it is observed that the optimum settings of molar ratio, catalyst, catalyst concentration and reaction temperature are A1, B2, C3 and D3. Hence we can conclude that the settings A1B2C3D3 can give the highest η or the highest percentage yield.

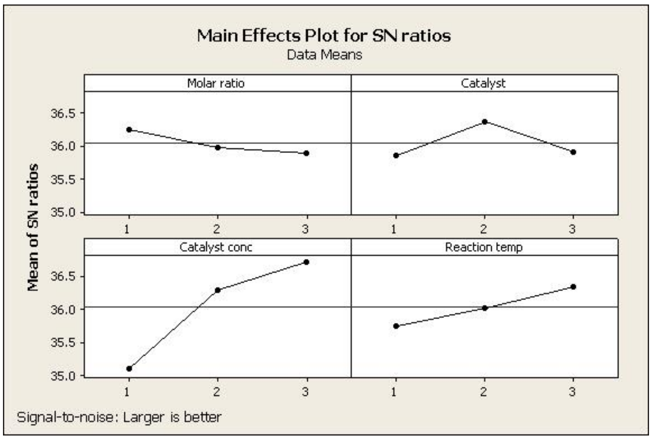

Fig I. Main effects plot of the control parameters

Different parameters affect the yield of methyl ester to a different degree. The relative magnitude of the parameter effects are listed in table. A better feel for the relative effect of the different factors is obtained by the decomposition of variance, which is commonly called as analysis of variance (ANOVA). This is obtained by

Total sum of squares =
Sum of square due to parameter A
[(number of experiments at level A1) x (mA1-m)]+
+[(number of experiments at level A2) x (mA2-m)]
+[(number of experiments at level A3) x (mA3-m)].

Similarly the sum of squares due to parameter B,C and D can be computed as 0.03, 0.03 and 0.21 respectively. Now all these sum of squares are tabulated in Table. This is called as the ANOVA table.

Table V. Anova table for S/N ratio.

Symbol	DOF	Parameters	Sum of squares	Mean square	F	Contribution (%)
A.	2	Molar ratio	0.03	0.015	1	10.00
B.	2	Catalyst type	0.03	0.015	1	10.00
C.	2	Catalyst concentration	0.03	0.015	1	10.00
D.	2	Reaction temperature	0.21	0.105	7	70.00
Error	0		0			
Total	8		0.3			
Error	(6)		0.09	0.015		

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In the present study, the degrees of freedom for the error will be zero. Hence an approximate estimate of the error sum of squares is obtained by pooling the sum of squares corresponding to the factors having the lowest mean square. The parameters A,B and C are used to estimate the error sum of squares. They account for six degrees of freedom and their sum of squares is 0.3.

Referring to the sum of squares in table, the parameter D makes the largest contribution to the total sum of squares. The factors A, B and C make 10 % each. The larger the contribution of a particular parameter to the total sum of squares, the larger the ability is of that factor to influence S/N ratio. Moreover , the larger F-value , the larger will be the factor effect in comparison to the error mean square.

V.PERFORMANCE ANALYSIS OF CI ENGINE

A. *Preparation of biodiesel blends:*

The biodiesel from Jatropha oil were blended with diesel in five different portion, 10%, 20%, 30%, 40%, and 50% by volume respectively.

B10 or BJ 10: It contains 10% biodiesel and 90% Diesel by volume.

B20 or BJ 20: It contains 20% biodiesel and 80% Diesel by volume.

B30 or BJ 30: It contains 30% biodiesel and 70% Diesel by volume.

B40 or BJ 40: It contains 40% biodiesel and 60% Diesel by volume.

B50 or BJ 50: It contains 50% biodiesel and 50% Diesel by volume.

B. *Properties of biodiesel blends*

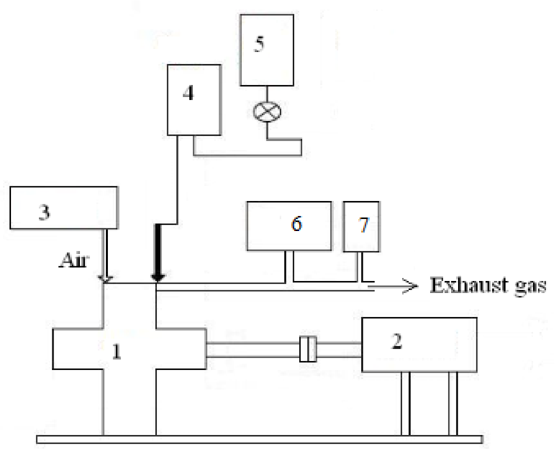
The various properties of prepared blend samples were measured at Nikhil Analytical & Research Laboratory (Approved by Govt. of India) using standard methods at room temperature. The Properties of various Jatropha Blends are as follows.

Table VI: Properties of various Jatropha Blends

Sr no.	Parameters	Unit	BJ-10	BJ-20	BJ-30	BJ-40	BJ-50
1	Density	Kg/m^3	885	860	876	880	891
2	Total ash	%	0.10	0.058	0.033	0.17	0.20
3	Flash point	^{0}C	33	55	60	62	65
4	Fire point	^{0}C	34	60	68	70	74
5	Kinematic viscosity	cst	1.1883	1.2115	1.2553	1.297	1.3045
6	Calorific value	Kcal/kg	9464	9231	9051	8752	8322

C. *Experimental set up*

The schematic diagram of experimental set up as shown in figure 2. The engine set up shown is single cylinder water cooled diesel engine. The engine has rated output 5.2kw at speed 1500rpm with compression ratio 17.5, injection pressure 180kg/cm^3 and coupled with rope break dynamometer. The detailed specification of engine is given in Table VII. Performance test are carried out on compression ignition engine using various blends of biodiesel and diesel as fuel.



1. Engine 2. Dynamometer 3.Air plenum 4.U-tube manometer 5. Dual biodiesel tank 6.Exhaust gas analyzer 7. Smoke meter

Fig II: Experimental setup

D. *Engine technical specifications*

Table VII: Engine specification

Engine speed	1500 rpm
BHP	5
Bore	80mm
Stroke	95mm
No. of Cylinder	1
Dynamometer	Mechanical loading
Drum diameter	28cm
Do	24mm
Cd (Coefficient of Discharge)	0.6

The engine was coupled to a dynamometer to provide load to the engine. A tachometer was used to measure the speed. A burette was used to measure fuel flow to the engine via fuel pump. A thermocouple with a temperature difference indicator measures the exhaust gas temperature. The ambient temperature is measured by thermometer. The cooling water temperature is measured by thermometer by taking outlet cooling water in the flask. Emission such as nitrous oxide (NO_x), carbon monoxide (CO) and unburned hydrocarbon (HC) were measured by an Exhaust gas analyzer. First, the tank was filled with conventional diesel and cooling water was supplied. Engine was started and run at no load condition for four to five minutes.

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Then the burette connected with fuel tank and was filled up to 20cc. Subsequently the time to consume 20cc was noted. Simultaneously the time taken for 1000ml discharge of cooling water was noted and its temperature was measured. The pressure head was calculated from the difference between the level in the U-shaped manometric tube. Finally the temperature of the exhaust gas was noted. The same procedure was followed with successive increase in load maintaining the speed constant. For different blends of biodiesel the engine was allowed to run continuously until the entire earlier diesel was consumed. Then the engine was allowed to run for five minutes for obtaining reliable results. The same procedure for conventional diesel was followed for different blends at different loads.

VI.RESULTS AND DISCUSSIONS

A. Engine load V/S BSFC

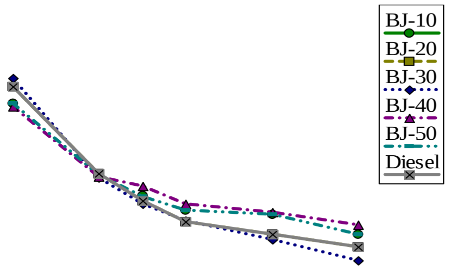


Fig III : Variation of brake specific fuel consumption at different engine load condition.

Fig III. shows the variation of brake specific fuel consumption at different engine load condition. It can be observed from the figure that the BSFC for B-10 is nearer to that of diesel fuel. The possible reason may be that at higher load, the cylinder wall temperature is increased which reduces ignition delay leading to the improvement in combustion and reduction in fuel consumption. The availability of the oxygen in the biodiesel blend may be the reason for the lower BSFC. At lower loads, significant properties of the fuel inducted through the intake does not burn completely due to lower quantity of pilot fuel, low cylinder gas mixture and lean air fuel mixture. When two different fuels of different heating values are blended together, the fuel consumption may not reliable, since the heating value and density of the two fuels are different. In such cases the BSFC will give more reliable result.

B. Engine load V/S BTE

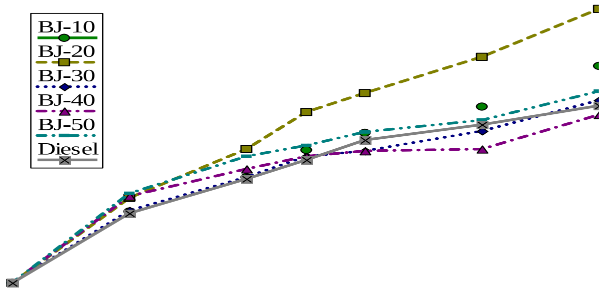
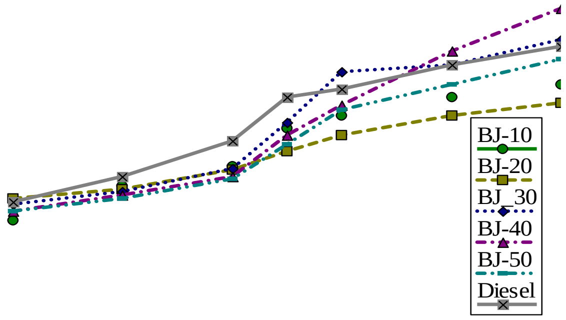


Fig IV: Variation of brake thermal efficiency at different engine load condition.

Fig 4 shows the variation of brake thermal efficiency with respect to the load for diesel fuel and Jatropha methyl ester diesel fuel blends. It can be observed that all the blends show slightly better thermal efficiency at higher load conditions. The higher thermal efficiencies due to the additional lubricity provided by the fuel blends.

C. Engine load V/S Exhaust gas temperature(EGT)



FigV : Variation of exhaust gas temperature at different engine load conditions.

Fig V. shows the variation of the exhaust gas temperature at different engine load conditions for the fuel blends. Exhaust gas temperature was found to increase in both concentration of biodiesel in blends and engine load. The exhaust gas temperature rises from 120ºC at no load to 200ºC for various blends. The increase in EGT with engine load is due to the fact that a higher amount of fuel is required in the engine to generate extra power needed to take up conditional loading.

D. Engine load V/S NOx.

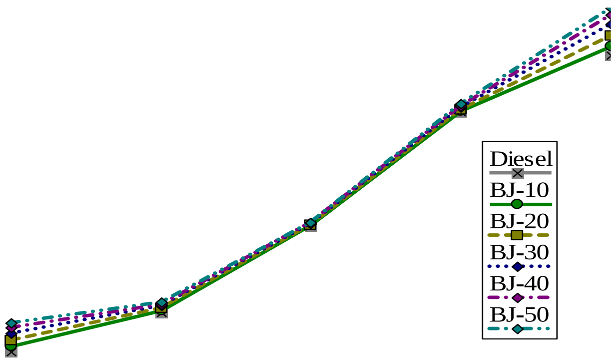


Fig VI : Variation of NOx at different engine load conditions.

Fig VI. shows that the variation of NOx emission at different engine load conditions. The exhaust gas temperature with blends having high percentage of Jatropha oil is high as compared to diesel at higher loads.

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The slower burning character of the fuel causes a slight delay in the energy release, which results in higher temperature in later part of power stroke and exhaust stroke. Increased exhaust gas temperature is due lower heat transfer and the fact that biodiesel has some oxygen content in it which facilitate NOx formation.

E. Engine load V/S CO

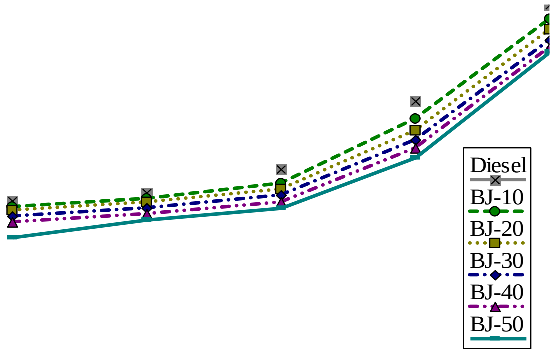

Fig VII : Variation of CO at different engine load conditions.

Fig. VII shows the variation of CO at different engine load conditions for various blends. It has been observed that CO emission was found to decrease with the increase in proportion of biodiesel in the blends. CO emissions are increased with increase in engine load. The lower CO emission of biodiesel compared to diesel is due to the presence of biodiesel which helps in complete oxidation of fuel. Further it can be seen that CO increased on further loading, the excess fuel required led to the formation of more smoke, which might prevented the oxidation of CO into CO_2, which results increased emission.

F. Engine load V/S HC

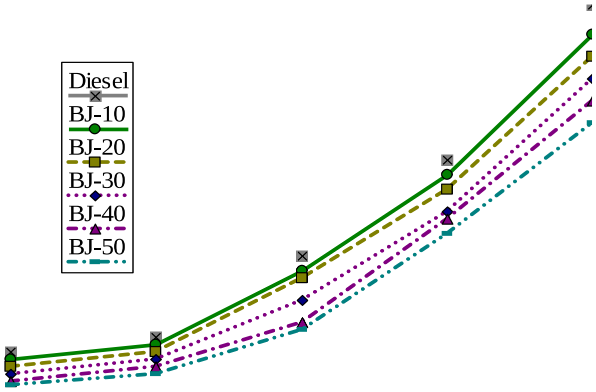

Fig VIII : Variation of HC at different engine load conditions.

Fig. VIII shows the variation of HC at different load conditions for various blends. Hydrocarbons in exhaust are due to incomplete combustion of carbon compounds in the blends. The values of HC emission decrease with increase in proportion of biodiesel in the fuel blends. The emissions of unburnt hydrocarbon for biodiesel exhaust are lower than that of diesel fuel. The possible reason for decrease in unburnt HC may be higher cetane number and increased gas temperature. The higher cetane number of biodiesel results decrease in HC emission due to shorter ignition delay. Increased temperature of burnt gases in biodiesel fuel helps in preventing condensation of higher hydrocarbon thus reducing unburnt HC emissions.

G. Engine load V/S Smoke

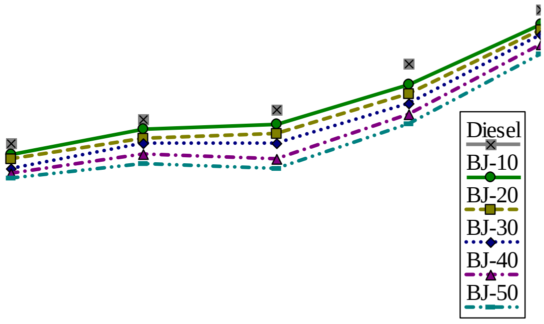

Fig IX **:** Variation of smoke at different engine load conditions.

Fig IX shows the variation of smoke opacity at different engine load conditions. The smoke opacity increases with increase in Jatropha methyl ester blends in diesel fuel at higher load conditions. The higher smoke opacity may be due to poor atomization of the Jatropha oil. Higher viscosity of Jatropha result in poor atomization of fuel blends.

VII.CONCLUSION

The calculated S/N ratio corresponding to nine set of experiments given in Table. The average S/N ratios of parameter at each level for Jatropha methyl ester are shown in Table 4. Also the main effect plot for S/N ratio is shown in Fig 1. The average S/N ratio for maximum percentage yield of Jatropha oil methyl ester is obtained at level 1 (Molar ratio of oil to methanol 1:5), level 2 (catalyst NaOH), level 3 (Catalyst conc. 1.2%by wt) and level 3 (reaction temperature 65^o). i.e., the optimum parameter setting for high percentage yield of Jatropha methyl ester is $A_1B_2C_3D_3$. The results of ANOVA for S/N ratios are given in Table 5. The percentage of yield of Jatropha methyl ester has been significantly improved using Taguchi Method. These investigation leads to conclude that Jatropha biodiesel blended with diesel fuel can be use as an alternative fuel which has low smoke emission that diesel.

1. BJ-20 has less brake specific fuel consumption and more brake thermal efficiency.
2. BJ-20 and BJ-30 has nearer volumetric efficiency.
3. If engine load increases brake thermal efficiency slightly increases in BJ-20 as compared to other. Inexhaust parameter NOx is increases with increase in blend proportion and CO, HC, smoke decreases withblend proportion.

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