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Parametric Optimization of a Single Cylinder Four Stroke Diesel Engine Fuelled with Jatropha and Turpentine Fuel Blends using Taguchi Method

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Abstract: In the present study, the performance of a new combination of biofuels Jatropha biodiesel and turpentine oil for a diesel engine with a view to eliminate dependency on fossil fuel was observed. Jatropha biodiesel and turpentine oil are a high and low viscosity fuel combination with comparable heating values to that of diesel. Diesel engine is examining the combustion performance and emission characteristics using the Jatropha methyl-ester with turpentine oil and pure diesel.

An experimental study has been carried out for Jatropha oil and turpentine was used in single cylinder, 4-stroke diesel engine. Jatropha oil is obtained from Jatropha seeds by Transesterification process.

Transesterification method used to reduce viscosity of Jatropha oil. It method is reaction of fat or oil triglyceride with alcohol to from esters and glycerol. Diesel engine is already optimized for particular fuel i.e. diesel. So, it does not give optimum performance for blend of Jatropha and turpentine blend. In this study, parameters i.e. load, blend proportion and injection pressure were taken as variable for optimization.

As the experiment required simultaneously optimization of three parameters, Taguchi method of optimization is used in this experiment. Three parameters for five levels in single orthogonal array were used in this method. From the analysis of data, selected set of parameters were achieved by Taguchi method from Minitab Software and experiments were done for those experiment.

Keywords: CI engine, Jatropha, Diesel, Turpentine.

I. INTRODUCTION

The world is presently confronted with the twin crises of fossil fuel depletion and environmental degradation. The increasing industrialization and motorization of the world has led to a steep rise for the demand of petroleum-based fuels. Petroleum-based fuels are obtained from limited reserves.

These finite reserves are highly concentrated in certain regions of the world. Therefore, those countries not having these resources are facing energy/foreign exchange crisis, mainly due to the import of crude petroleum. Hence, it is necessary to look for alternative fuels which can be produced from resources available locally within the country such as alcohol, biodiesel, vegetable oils etc.

This experiment touches upon well-to-wheel greenhouse gas emissions, efficiencies, fuel versatility, infrastructure, availability, economics, engine performance and emissions etc. It is well known that the number of diesel engine increasing continuously every year because of having high efficiency, enhanced fuel economy. Diesel engines are preferred over spark ignition engines in almost all heavy-duty application due to their reliability and durability.

Therefore, the world demand for diesel fuel increases every year. Bio-diesel made from agricultural products (oxygenated by nature) reduce the world's dependence on oil imports, support local agricultural industries and enhance farming incomes, while offering serious benefits in terms of sustainability, reduced emissions and increased energy and economic security. The potential of bio-diesel has been found to be a promising fuel for diesel engine in a number of studies.The goal of our experiment is to optimize parameter which gives maximum performance for mechanical efficiency, break thermal efficiency and emission parameters. For achieving desired result, there is required number of experiments which gives results in the form of set of parameters. This set of parameters give different performance with reduction in different fuel consumption. From this sets of parameters, there must be choose set of parameters

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II. PREPARATION OF FUEL BLENDS

A. Jatropha Curcas

Jatropha oil was distinguished as a prominent successor and alternative fuel for commercialization among various non–edible vegetable oils. Jatropha curcas is non-edible oil that can be grown on a huge-scale plantation on all types of land like deserts and wasteland and these plants can withstand adverse weather conditions. It is a perennial plant and drought-resistant, has a life span of fifty years and potential to grow on negligible soils. It needs very low sprinkling and grows in all kinds of soils (hill slopes, coastline areas). The yield of Jatropha seeds is about 0.8 kg per square meter per year. Jatropha seeds contain oil ranges at 30 to 40 % by weight and the kernel itself is ranged from 45% to 60%. The basic restriction of this harvest is that the kernel is harmful and the oil cake cannot be used as mammal food. The oil cake can only be used as organic manure. Some other researchers observed higher smoke, HC, CO and NOx emissions of the engine operating with Jatropha oil.

B. Botanical Feature

It is small tree with smooth grey bark colour. It grows between three to five meters in height, but some time favourable condition height up to ten meters. It has large green to pale green leaves, alternate to sib opposite three to five lobed with a spiral phyllo taxi. Flowers are formed terminally individually with female flowers usually slightly larger and occurs in the hot seasons. Fruits are produced in winter season. The seeds become mature when the capsule changes from green to yellow offer two to four months.

Figure 1 Jatropha Seeds

C. Transesterification Process

The double transesterification process has been used to convert Jatropha oil into Jatropha methyl ester. The first pre-treatment process, Jatropha oil reacts with methanol in the presence of the catalyst (H_2SO_4) to produce glycerol and fatty acid ester. Specified amount 500 ml of Jatropha oil 100 ml methanol and 4 ml catalyst (H_2SO_4) by volume ratio were taken in a round bottom flask. The mixture was heated to 50^0C and stirred (2 h) till ester formation began and then cool about 18 h at a separating flask without stirring. In the separating flask, two layers were formed. The top layer was the ester and bottom layer consisted of glycerol. In second post treatment process pre-treated Jatropha oil react with methanol in the presence of the catalyst (NaOH/KOH) to produce glycerol and fatty acid ester. Specified amount 500 ml of pre-treated Jatropha oil 100 ml methanol and 4 g catalyst (NaOH) by a volume weight ratio were taken in a round bottom flask and apply the same above process till two layers were formed. The top layer was the ester and bottom layer consisted of glycerol.

First Step: - (H_2SO_4, 50^0C)

Jatropha oil + Methanol → Glycerol + Jatropha Methyl ester

Second Step: -(NaOH, 50^0C)

Jatropha oil+ Methanol → Glycerol + Jatropha Methyl ester

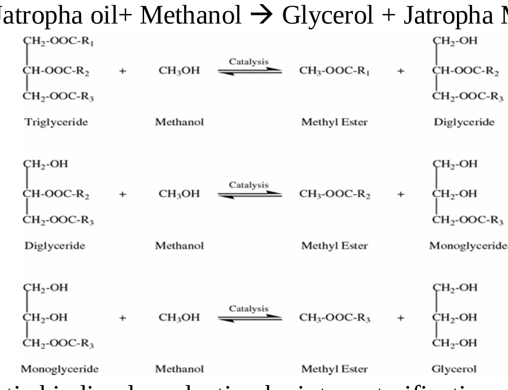

Figure 2 Enzymatic biodiesel production by inter esterification with methyl acetate

D. Turpentine Oil

Turpentine oil was first used in the domestic and industrial applications in the 1700s. Several studies have shown improved performance and emissions of diesel engines using the turpentine-diesel fuel blends. Turpentine oil is basically a biofuel that can easily be obtained from a resin, oleoresin, which in turn can be extracted from pine trees. Physically, it is a yellowish, opaque, colour less, odorous, and water-immiscible liquid. Chemically, the oil of turpentine is flammable, volatile and combustible; and it contains α–pinner 40 % by weight in turpentine. It is made up of 58–65% γ – pinene along with β– pinene and other isometric terpenes. Owing to its prominent properties such as viscosity, calorific value, and low cetane number, it has adequate potential to reduce the dependency on conventional fossil fuels. Furthermore, due to its mixing ability with diesel in any proportion, it can be used as a supplement with diesel. It can prove as a better fuel substitute which can replace diesel due to its high production in the world. However, the higher cost of turpentine oil, as opposed to traditional diesel fuel, can easily be offset in favour of its low emission capability. Turpentine has various advantages over diesel and it is possible to approximately have 60-65% diesel replacement with turpentine in dual fuel mode with minor changes in the engine design. The performance indicators for turpentine oil such as specific fuel consumption, brake thermal efficiency, exhaust gas temperature and emission characteristics such NOx and smoke emission are found better to that of standard diesel fuel.

Table 1 properties of each constituents of fuel blend

No.	Properties	Diesel	Jatropha	Turpentine
1	Chemical Formula	$C_{14}H_{28}$	----	---
2	Density (kg/ m^3)	832	881	920
3	Cetane number	45	48.13	38
4	Lower heating value (kJ/kg)	44000	39500	44400
5	Cloud point (^{0}C)	-12	-4	-15
6	Pour point (^{o}C)	-17	-6	-23
7	Latent heat of Vaporization (kJ/kg)	230	285	320
8	Flash point (^{o}C)	52	165	38
9	Kinematic viscosity (mm^2/s)	3.21	4.12	2.5

III. EXPERIMENTAL SETUP

The setup consists of a single cylinder, four stroke, multi fuel, VCR engine which is connected to eddy Current dynamometer for loading. The operation mode was set to CI engine. The engine is also connected to a computer with 'Enginesoft' engine performance and analysis software. The setup enables study of VCR engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio, heat balance and combustion analysis. The overview of experimental setup is shown in fig-2 below.

Table 2 specifications of engine setup

Engine Type	Four stroke, Water cooled, Diesel
No. of Cylinder	One
Bore	87.5 mm
Stroke	110 mm
Cubic capacity	661 cc
Connecting rod length	234 mm
Compression ratio	18:1
Injector Pressure	180 bar
Operating speed	1500 rpm
Fuel timing	23^o BTDC
Valve timing Inlet valve opens BTDC Inlet valve closes ABDC Exhaust valve opens BBDC Exhaust valve closes ATDC	 4.5^o 35.5^o 35.5^o 4.5^o
Lubricating system	Forced feed type
Lubricating oil pump	Gear type
Dynamometer Arm Length	185 mm

Figure 3 overview of experimental setup

IV. RESULT DATA

The calculated result data of engine performance for each fuel blend are provided in tables below. The performance parameters taken into consideration are BP, FP, IP, BMEP, IMEP, BTHE, ITHE, fuel consumption, SFC and mechanical efficiency.

Table 3 calculated performance data for diesel fuel

No.	%Blends	IP (bar)	Load (kg)	FC (cc/min)	SFC (kg/kWh)	S/N ratio	SFC means	BP (kW)	BTHE (%)
1	0.64	140	2.12	9	0.70	3.11	0.70	0.64	11.84
2	1.23	150	4.05	12	0.49	6.26	0.49	1.23	17.02
3	1.79	160	5.97	13	0.36	8.83	0.36	1.79	22.88
4	2.34	170	7.86	15	0.32	9.90	0.32	2.34	25.86
5	2.94	180	9.89	17	0.29	10.78	0.29	2.94	28.63
6	J100	140	4.33	12	0.47	6.65	0.47	1.36	19.59
7	J100	150	6.08	14	0.40	7.94	0.40	1.85	22.73
8	J100	160	8.08	16	0.35	9.13	0.35	2.42	26.08
9	J100	170	10.03	18	0.32	10.03	0.32	3.02	28.93
10	J100	180	1.97	8	0.73	2.72	0.73	0.58	12.47
11	J50T50	140	6.14	13	0.37	8.59	0.37	1.89	23.08
12	J50T50	150	7.92	15	0.34	9.46	0.34	2.41	25.50
13	J50T50	160	9.95	17	0.30	10.32	0.30	3.01	28.16
14	J50T50	170	1.9	9	0.85	1.37	0.85	0.57	10.04
15	J50T50	180	3.98	11	0.50	5.97	0.50	1.18	17.07
16	J60T40	140	8.09	16	0.35	9.09	0.35	2.43	24.72
17	J60T40	150	9.93	17	0.30	10.34	0.30	2.98	28.56
18	J60T40	160	1.85	9	0.86	1.27	0.86	0.56	10.06
19	J60T40	170	4.07	11	0.49	6.26	0.49	1.21	17.86
20	J60T40	180	6.13	14	0.42	7.62	0.42	1.80	20.88
21	J80T20	140	10.05	19	0.33	9.58	0.33	3.04	26.81
22	J80T20	150	1.86	9	0.85	1.41	0.85	0.56	10.46
23	J80T20	160	3.96	11	0.49	6.20	0.49	1.19	18.16
24	J80T20	170	5.96	14	0.42	7.56	0.42	1.78	21.24
25	J80T20	180	8.04	16	0.36	8.87	0.36	2.36	24.70

V. RESULTS AND DISCUSSION

A. Analysis for Specific Fuel Consumption

Table 5 Response Table for Means of SFC

Level	%blends	IP (bar)	Load (kg)
1	0.4312	0.4438	0.7996
2	0.4523	0.4756	0.4860
3	0.4740	0.4738	0.3938
4	0.4842	0.4789	0.3435
5	0.4901	0.4597	0.3089
Delta	0.0588	0.0351	0.4907
Rank	2	3	1

For above table, mean is average value for reading taken for particular parameters. From graph, mean value is maximum (0.4901) for J80T20 blend and minimum (0.4740) for J50T50 blend. Mean value is maximum (0.4789) for 170 bar and minimum (0.4438) for 140 bar injection pressure. Mean value is maximum (0.7996) for 2 kg and minimum (0.3089) for 8 kg engine load.

Delta is difference of maximum value and minimum value. Delta value is maximum for load (0.4907) and minimum (0.0351) for injection pressure. Delta value for blends ratio is between other two parameters and it is (0.0588). so that effect of load is maximum and effect of injection pressure is minimum on specific fuel consumption.

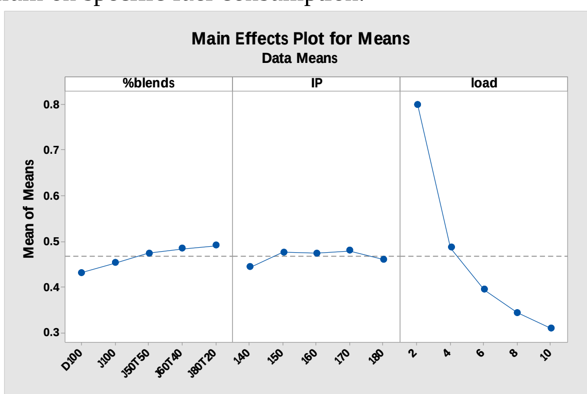

Figure 4 Main Effects Plot for Means of SFC

Table 6 Response Table Plot S/N ratio of SFC

Level	%blends	IP	load
1	7.776	7.405	1.977
2	7.294	7.082	6.270
3	7.144	7.153	8.109
4	6.917	7.024	9.290
5	6.726	7.194	10.212
Delta	1.050	0.381	8.235
Rank	2	3	1

The term optimum setting is reflecting only optimal combination of the parameters defined by this experiment. The optimum setting is determined by choosing the level with the lowest S/N ratio. The response curve for S/N ratio, the smaller S/N ratio was observed at J80T20 blend ratio (6.726), engine load at 2 kg (1.977) and injection pressure at 170 bar (7.024), which are optimum parameter setting for lowest specific fuel consumption. From delta values as mention above, maximum (8.235) for Load and minimum (0.381) for IP. Parameter Load is most significant parameter and injection pressure is least significant for SFC.

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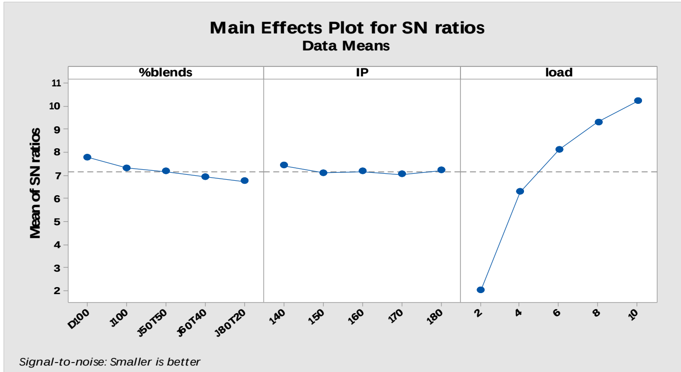

Figure 5 Main Effects Plot for S/N ratio of SFC

Table 7 Optimization Set of Parameter for SFC

Experiment	%blends	IP (bar)	Load (kg)	FC (cc/min)	Torque (Nm)	**SFC (kg/kWh)**	RPM
For SFC	J80T20	170	2	10	3.63	**0.29**	1586

Experiment has done for above set of parameter gives performance given below. Specific fuel consumption is 0.29 lowest for the any other combination. This experimental value is nearer to predicted value 0.3.

Table 8 Validation Results for SFC

Predicated Value	Experimental Value	% Variation
0.30	0.29	3.33

B. Analysis for Brake Thermal Efficiency

Table 1 Response Table for Means of BTHE

Level	%blends	IP	load
1	21.25	21.21	10.97
2	21.96	20.85	17.94
3	20.77	21.07	22.16
4	20.41	20.78	25.37
5	20.27	20.75	28.22
Delta	1.69	0.46	17.24
Rank	2	3	1

From below table, mean is an average value for reading taken for particular parameter. From graph, mean value is maximum (20.77) for J50T50 %blend and minimum (20.27) for J80T20 %blend. Mean value is maximum (21.21) for 140 bar injection pressure and minimum (20.75) for 180 bar injection pressure. Mean value is maximum (28.22) for 10 kg engine load and minimum (10.97) for 2 kg engine load.

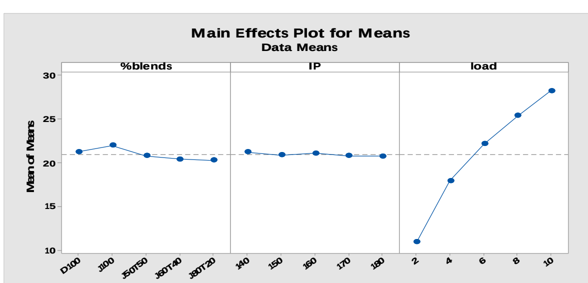

Figure 6 Main Effects Plot for Means of BTHE

Delta is difference of maximum value and minimum value. Delta value is maximum for load (17.24) and minimum (0.46) injection pressure for parameter. Delta value for blends ratio is between other two parameters and it is (1.69). So that effect of load is maximum and effect of injection pressure is minimum on Brake Thermal Efficiency.

Table2 Response Table for S/N ratio for BTHE

Level	%blends	IP	load
1	26.13	26.20	20.77
2	26.49	25.88	25.07
3	25.81	25.95	26.90
4	25.69	25.82	28.08
5	25.71	25.99	29.01
Delta	0.80	0.38	8.24
Rank	2	3	1

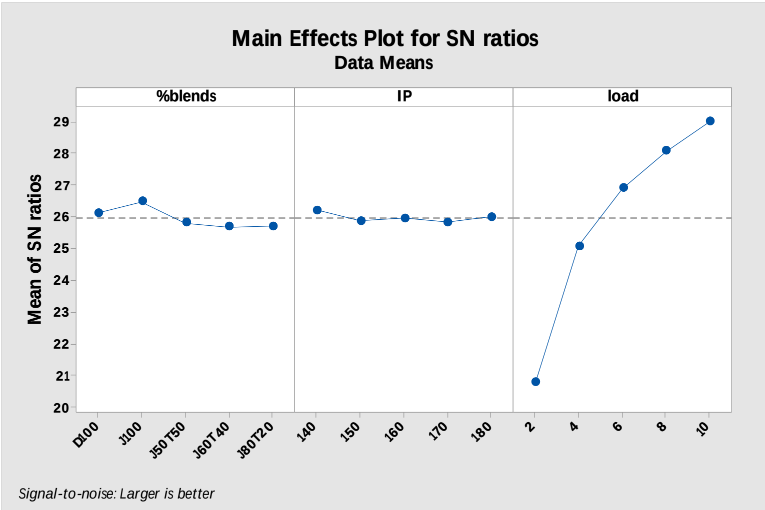

Figure 7 Main Effect Plot for S/N Ratio for BTHE

The term optimum set of parameters is reflecting only optimal combination of the parameters defined by this experiment for highest brake thermal efficiency. The optimum setting is determined by choosing the level with the highest S/N ratio. The response curve for S/N ratio, the highest S/N ratio was observed at J50T50 blend ratio (25.81), engine load 10 kg (29.01) and injection pressure 140 bar (26.20), which are optimum parameter setting for highest brake thermal efficiency. From delta values as mention above, maximum (8.24) for load and minimum (0.38) for injection pressure. Parameter load is most significant parameter and injection pressure is least significant for brake thermal efficiency.

Using optimum set of parameters, which was achieved by Minitab software for Taguchi method of optimization was used for experiment of validation. The result was obtained by experiment is compared with predicated value of software for maximum brake thermal efficiency.

Table 3 Optimization Set of Parameter for Break Thermal Efficiency

Experiment	%blends	IP (bar)	Load (kg)	FC (cc/min)	Torque (Nm)	BTHE (%)	RPM
For BTHE	J50T50	140	10	19	18.15	29.53	1589

Table 4 Validation Results for Break Thermal Efficiency

Predicated Value	Experimental Value	% Variation
30.78	29.53	4.06

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Experiment has done for above set of parameter gives performance as shown in above table. It is Brake Thermal Efficiency is 29.53. This experimental value is nearer to predicted value 30.78.

C. Taguchi Analysis for NO_X Emission

Table 13 Response Table of NO_X Emission

Level	%Blends	IP (bar)	Load (kg)
1	524.8	618.4	156.0
2	716.0	583.6	264.6
3	473.4	581.0	524.0
4	628.8	669.6	840.2
5	690.2	580.6	1248.4
Delta	242.6	89.0	1092.4
Rank	2	3	1

From above table, mean is an average value for reading taken for particular parameter. From graph, mean value is maximum (690.2) for J80T20 %blend and minimum (473.4) for J50T50 %blend. Mean value is maximum (669.6) for 170 bar injection pressure and minimum (580.6) for 180 bar injection pressure. Mean value is maximum (1248.4) for 10 kg engine load and minimum (156.0) for 2 kg engine load.

Delta is difference of maximum value and minimum value. Delta value is maximum for load (1092.4) and minimum (89.0) injection pressure for parameter. Delta value for blends ratio is between other two parameters and it is (242.6). So that effect of load is maximum and effect of injection pressure is minimum on Brake Thermal Efficiency.

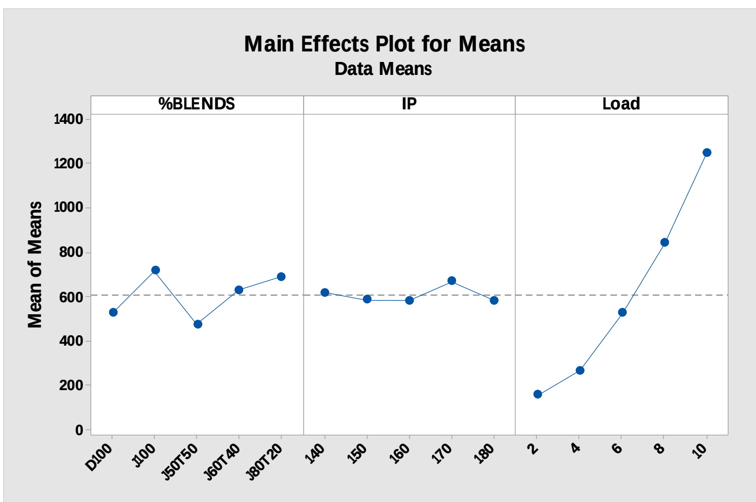

Figure 8 Main Effects Plot for Means of NO_X Emission

Table 14 Response Table for S/N ratio for NO_X Emission

Level	%Blends	IP	Load
1	-51.50	-52.73	-43.48
2	-55.03	-53.06	-47.06
3	-50.26	-53.27	-54.25
4	-53.66	-54.55	-58.41
5	-54.59	-51.44	-61.85
Delta	4.77	3.11	18.37
Rank	2	3	1

The term optimum set of parameters is reflecting only optimal combination of the parameters defined by this experiment for smallest NOX Emission. The optimum setting is determined by choosing the level with the smaller S/N ratio. The response curve for S/N ratio, the smaller S/N ratio was observed at J80T20 blend ratio (-54.59), engine load 10 kg (-61.85) and injection pressure 170 bar (-54.55), which are optimum parameter setting for smaller NOX Emission. From delta values as mention above, maximum (18.37) for load and minimum (3.11) for injection pressure. Parameter load is most significant parameter and injection pressure is least significant for brake thermal efficiency.

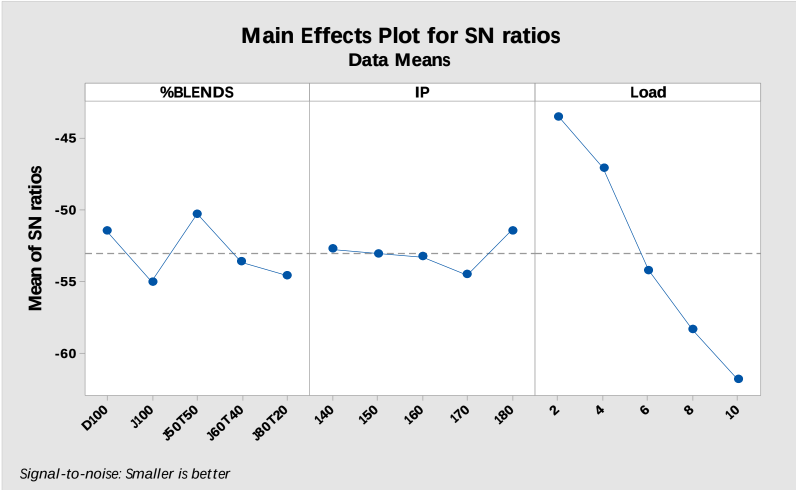

Figure 9 Main Effect Plot for S/N Ratio for NOX Emission

Using optimum set of parameters, which was achieved by Minitab software for Taguchi method of optimization was used for experiment of validation. The result was obtained by experiment is compared with predicated value of software for maximum brake thermal efficiency.

Table 15 Optimization Set of Parameter for NO_X Emission

Experiment	%blends	IP	Load	NO_X
For NO_X	J80T20	170	10	450 ppm

Experiment has done for above set of parameter gives performance as shown in above table. It is NO_X Emission is 180.

VI. CONCLUSIONS

The Taguchi's approach has been carried out for optimizing the performance of diesel engine using Jatropha and Turpentine oil. Three input parameters have been optimized using SNR. The higher-the-better quality characteristic has been used for maximizing the thermal efficiency and the lowest-the-better for the specific fuel consumption of the engine. An L_{25} orthogonal array with three parameters and five levels has been used for predict set of parameters which gives value of specific fuel consumption and brake thermal efficiency. 25 number of experiments were done for those sets of parameters. Experimental values of performance were put in the Minitab software.

A. The specific fuel consumption is 0.29 for set of J80T20 %blend 170 bar injection pressure and 2 kg engine load.
B. Brake thermal efficiency are 29.53% for J50T50 %blends, 140 bar injection pressure and 10 kg engine load. This suggested set of parameters which gives optimum performance of specific fuel consumption and mechanical efficiency.
C. The NO_X Emission is 450 ppm for set of J80T20 blend ratio, 170 bar injection pressure and 10 kg engine load.
D. The Taguchi parameter design concept is more powerful and efficient tool for maximize the break thermal efficiency and minimizing the specific fuel consumption.
E. The Jatropha and Turpentine blends are used to replace the diesel fuel in the diesel engine.
F. J50T50 is best for higher mechanical efficiency and break thermal efficiency compare to the conventional diesel fuel.
G. Jatropha oil and Turpentine oil are mixed with each other easy. In this experiment, blends mixing more than 18 hours before used in the diesel engine.

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