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COMBINED EFFECT OF COMPRESSION RATIO & DIFFUSER AT EXHAUST ON PERFORMANCE OF SINGLE CYLINDER CI ENGINE, FUELLED WITH BLENDS OF WASTE PLASTIC OIL AND DIESEL

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Abstract — *The quantity of fossil fuel is reducing day by day as the energy requirement is escalating at an exponential rate and the fossil fuel availability is scarce. Also the use of plastic creates problem of disposing it as it is non bio degradable. The present study deals with overcoming both problems simultaneously by studying the applicability of Waste Plastic Oil as a Diesel oil substitute on a VCR engine fueled with Waste plastic oil and its blends with diesel oil, as most industrial application involves diesel engine. Diffuser shaped exhaust manifold is used for improving engine performance and emission with half cone angles of 10°, 12.5°. Taguchi method of Design of Experiments is used for reducing the number of experiments and getting optimum parameter set. The parameters which has been optimized by using Taguchi method are; BTHE, SFC, CO, HC &* NO_X.

Keywords- *Waste Plastic Oil, Engine performance, compression ratio, Diffuser, Taguchi, Blend.*

I. INTRODUCTION

Waste plastic is a big problem around the globe as the use of plastics has increased enormously in recent years and due to its non-biodegradable nature, waste plastic disposal becomes a major concern. Another big problem is depleting sources of fossil fuel which is the main basis of energy generation. Waste plastic can be transformed to valuable hydrocarbon to be used as alternative to diesel oil by pyrolysis process, in such a manner we can gain fossil fuel and also the waste plastic disposal problem could get solved.

The exhaust gas slows down and expands due to large size of the exhaust manifold. By employing diffuser shaped exhaust manifold, the back pressure of gas can be reduced and this slow moving gas can get faster resulting in good scavenging. Due to this better scavenging effect, the dilution of fresh charge in the suction stroke is reduced resulting in good charging efficiency and hence the performance increases.

Compression ratio is also one of the main parameter affecting the performance of CI engine. The thermal efficiency increase as the compression ratio increases. For optimization Taguchi's method is used.

This study focusses on combined effect of various diffuser angle, blend ratio & compression ratio on performance and emission characteristics of a VCR CI engine.

Abbreviations		
BTHE		Brake Thermal Efficiency
SFC		Specific Fuel Consumption
FC		Fuel Consumption
S/N Ratio		Signal to Noise Ratio
WPO		Waste Plastic Oil
D.O.E		Design of Experiment
0%B		100% Diesel, 0% Biodiesel
50%B		50% Diesel,50% Biodiesel
100%B		0% Diesel, 100% Biodiesel

Table 1 Waste Plastic Oil properties

Parameter	Unit	Result
Density @ 15° C	kg/m^3	890
Kinematic viscosity @ 40° C	CP	14.12
Kinematic viscosity @ 100°C	CP	9.55
Flash point	°C	132
Sulpher content	mg/kg	18
Carbon residue content	%by mass	0.022
Sulpher ash content	Ppm	25
Water content	mg/kg	1167
Total contamination	mg/kg	14
Copper strip corrosion @3hr @50° C	-	Nill
Cetane number	-	61.8
Acid value	mg KOH/gm	22
Methanol content	%by mass	0.19
Sox	%	Nill
Nox	%	Nill
SPM	%	Nill
Shelf life study	In packing month	24

1.1 Experimental Setup

The engine utilized for particular test is a variable compression ratio type single cylinder, naturally aspirated water cooled compression ignition engine. The compression ratio can be changed without stopping the engine.

The engine specifications are publicized in Table 3. The diagrammatic figure of investigational setup is shown in Figure 1. The engine is united with electronically controlled eddy current dynamometer which provide desired load to engine.

The fuel consumption considered by means of single burette, which is connected in such a way that the fuel rate data were delivered through sensors. Setup is equipped with essential instruments for in cylinder pressure, fuel line pressure & crank position. These signals are diagnosed via main PC for various graph and statistical data.

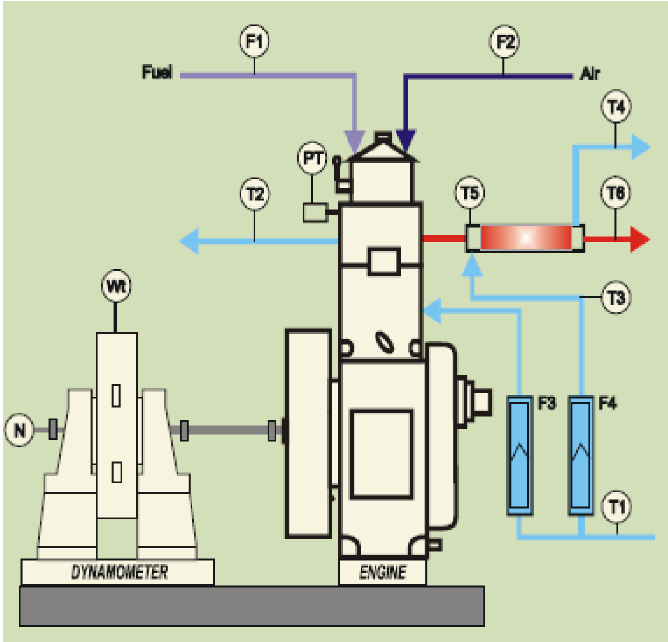

Figure 1 Schematic Diagram of Experimental Setup

Several thermocouples and sensors were used to inspect the engine performance and its combustion characteristics. The pressures within engine were calculated by pressure transducers. Table 2 expresses the directory of sensors employed in an engine for measurement.

Table 2 **Various Sensors Utilized within Engine for Measurement**

Symbol	Sensor Name
F1	Fuel Flow Sensor
F2	Air Flow Sensor
W	Load Sensor
N	Engine Speed Sensor
PT	Cylinder-Injection Pressure Sensor
T1-T6	Temperature Sensor

The experiments were conducted at the estimated engine speed of 1500 rpm & at different load range, which is followed by 2kg, 7kg & 12kg. Three blend ratios of diesel and WPO are as 0%, 50% & 100% (V/V %) were tested at every load. They are designated as 0%B, 50%B & 100%B in subsequent study.

Table 3 reveals the specifications of engine on which the entire test was carried out.

Table 3 Engine Specifications

Engine manufacturer	Apex Innovations (Research Engine test set up)
Software	Engine soft Engine performance analysis software
Engine type	Single cylinder four stroke multi fuel research engine
No. of cylinder	1
Type of cooling	Water cooled
Rated Power	3.5 kW @ 1500 rpm
Cylinder diameter	87.5 mm
Orifice diameter	20 mm
Stroke length	110 mm
Connecting rod length	234 mm
Dynamometer	Type: eddy current, water cooled, with loading unit

II METHODOLOGY

For optimization process, Taguchi's method has been used. In this method, two types of inputs are used: 1. Control variable (design parameter) 2. Noise variable (value is hard to control during the process). Taguchi method is used only when factors are between in 3-50. In the Taguchi, one of the following conditions is considered.

1. Larger is better.
2. Smaller is better.
3. On target minimum variation.

S/N ratio, mean value and variation have been obtained by analyzing experiment data in Minitab. The S/N ratio has been taken instead of standard deviation, because of that, standard deviation has been decreased with decreased in mean value and vice versa.

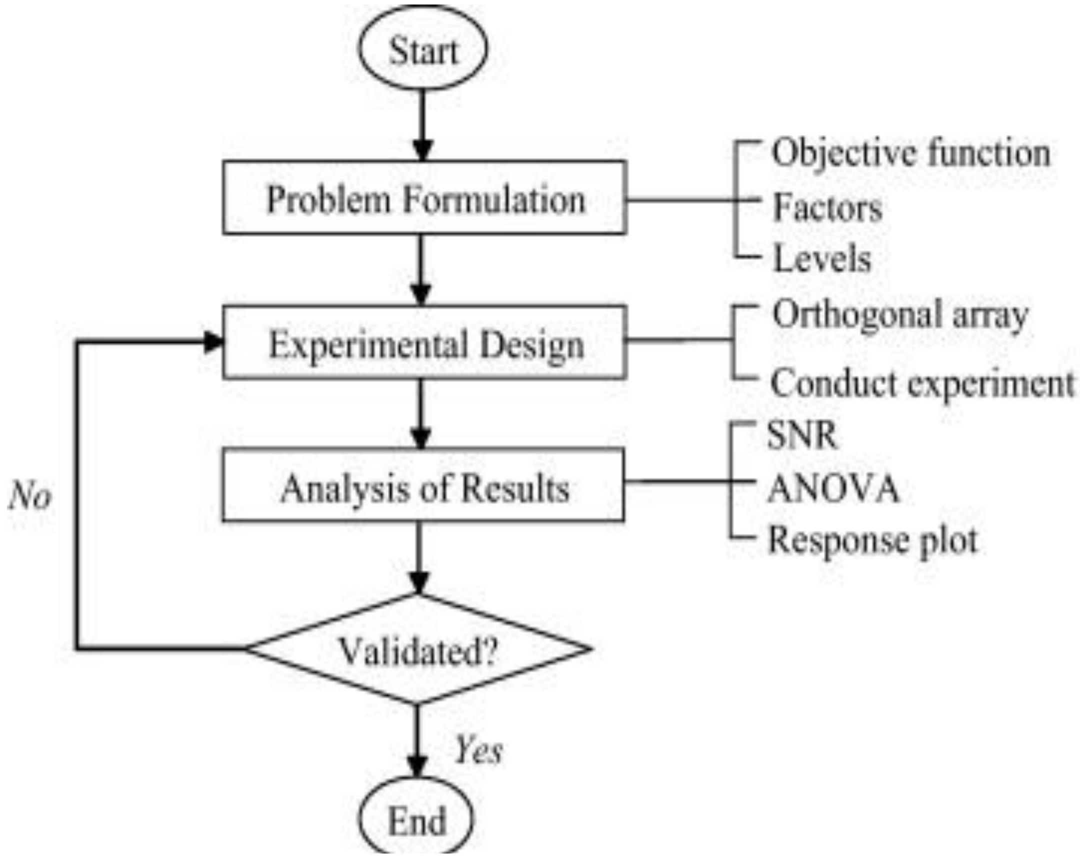

Figure 2 Flow chart of Taguchi approach

2.1 Factors and Levels

L27 orthogonal array was selected for performing experimentation for blend, load, exhaust manifolds & compression ratio. In the experiment table, take 27 rows and 4 columns at 3 levels for L27 orthogonal array. Those 4 factors are shown in Taguchi Table 4.

The experiment is done on the basis of the table and transferring its results into the S/N ratio and means to find the optimum set of parameters. The Taguchi analysis has been used to analyze the optimum set which gave the predictive value.

Table 4 Factors and their levels

Factor	Level 1	Level 2	Level 3
Angle of Diffuser (°)	0 (i.e. no diffuser)	10	12.5
CR	18	17	16
Blend (v/v%)	0%B	50%B	100%B
Load (kg)	2	7	12

III RESULTS

Brake thermal efficiency, specific fuel consumption, CO, HC & NO_X parameters were analyzed to get optimum set of parameter by using Minitab software which offers Taguchi method in DOE. The graphs were plotted using Minitab by following required steps. Based on these graphs, the optimum set was found and predicted value of parameter was found by Minitab.

3.1 Taguchi Analysis for Brake Thermal Efficiency

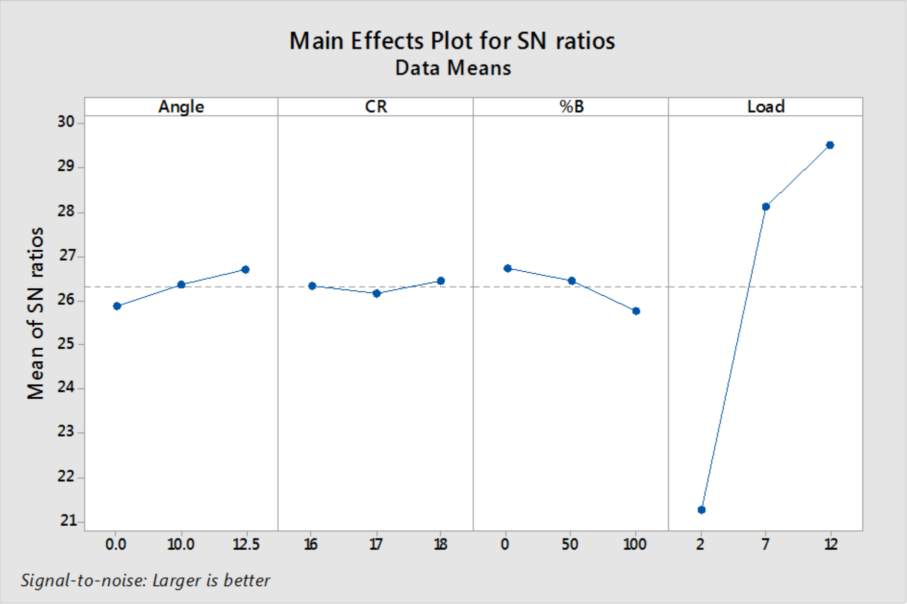

Figure 3 Main Effects Plot for S/N ratios of Brake Thermal Efficiency

Table 5 Response Table for S/N Ratios of Brake Thermal Efficiency

Level	Angle	CR	%B	Load
1	25.9	26.34	26.74	21.29
2	26.36	26.18	26.46	28.14
3	26.7	26.44	25.77	29.53
Delta	0.81	0.26	0.97	8.24
Rank	3	4	2	1

The factor with highest S/N ratio gives optimum level for that particular parameter. Referring
Figure **3** the response curve for S/N ratio, the highest S/N ratio was observed at Engine Load (12 kg), %B (0), Diffuser (12.5°) and CR (18), which are optimum parameter setting for highest Brake Thermal Efficiency. From delta values as mention
Table **5**, maximum (8.24) for engine load and minimum (0.26) for CR. Parameter engine load is most significant parameter for Brake Thermal Efficiency. Optimum parameter set as shown in Table 6

Table 6 Optimum Set of Parameter for Brake Thermal Efficiency

Angle (°)	CR	%B	Load	BTHE (%)	SN Ratio
12.5°	18	0	12	31.8352	30.4581

Experiment has been carried out using optimum set of parameter. Experimental Brake Thermal Efficiency for optimum set of parameter is 32.993 %. This experimental value is nearer to predicted value 31.83 % as shown in Table 7.

Table 7 Validation Results for Brake Thermal Efficiency

Predicted Value	Experimental Value	% Variation
31.8352%	32.993%	3.6

3.2 Taguchi Analysis for Specific Fuel Consumption

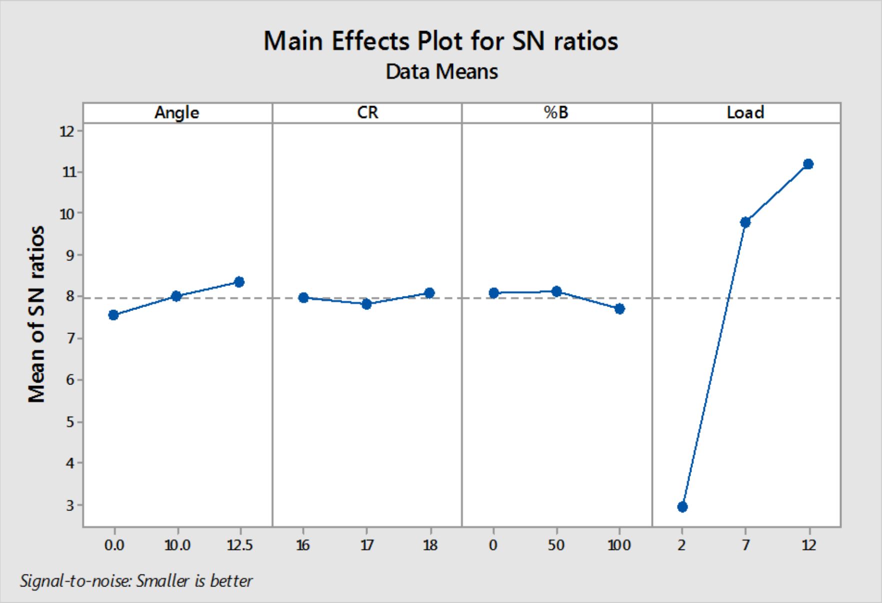

Figure 4 Main Effects Plot for S/N ratios of Specific Fuel Consumption

Table 8 Response Table for S/N Ratios of Specific Fuel Consumption

Level	Angle	CR	%B	Load
1	7.55	7.99	8.077	2.944
2	8.018	7.836	8.12	9.791
3	8.356	8.099	7.727	11.189
Delta	0.807	0.263	0.393	8.245
Rank	2	4	3	1

The factor with highest S/N ratio gives optimum level for that particular parameter. Referring Figure 4 the response curve for S/N ratio, the highest S/N ratio was observed at Engine Load (12 kg), %B (50), Diffuser (12.5°) and CR (18), which are optimum parameter setting for Specific Fuel Consumption. From delta values as mention Table 8, maximum (8.245) for engine load and (0.263) for CR. Parameter engine load is most significant parameter for Specific Fuel Consumption. Optimum parameter set as shown in Table 9

Table 9 Optimize Set of Parameter for Specific Fuel Consumption

Angle (°)	CR	%B	Load	SFC(kg/kWh)	SN Ratio
12.5°	18	50	12	0.235407	11.8404

Experiment has been carried out using optimum set of parameter. Experimental Specific Fuel Consumption for optimum set of parameter is 0.247631kg/kWh. This experimental value is nearer to predicted value 0.235407 as shown in Table 10.

Table 10 Validation Results for Specific Fuel Consumption (kg/kWh)

Predicted Value	Experimental Value	% Variation
0.235407	0.247631	4.7

3.3 Taguchi Analysis for CO (%)

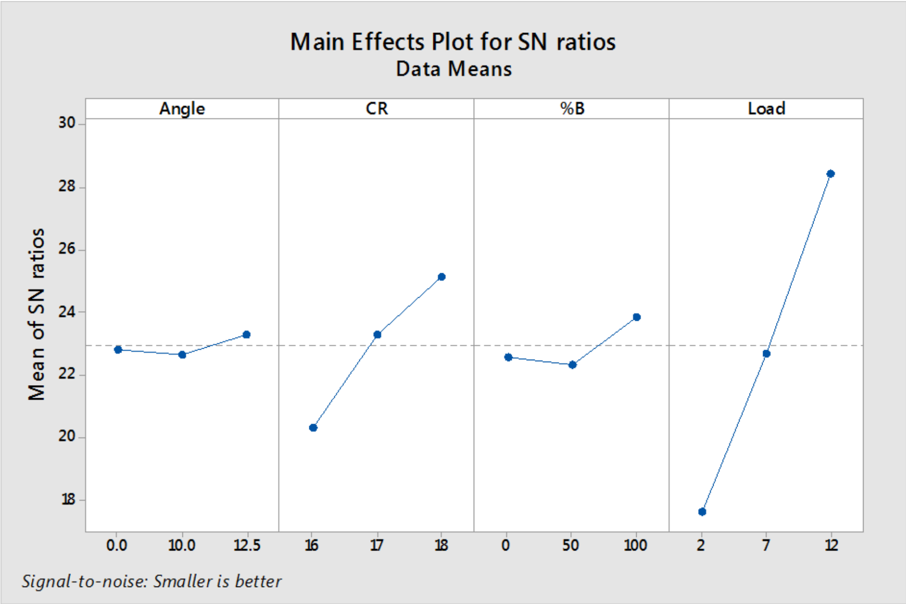

Figure 5 Main Effects Plot for S/N ratios of CO

Table 11 Response Table for S/N Ratios of CO

Level	Angle	CR	%B	Load
1	22.84	20.33	22.57	17.63
2	22.65	23.31	22.36	22.72
3	23.32	25.17	23.89	28.46
Delta	0.67	4.84	1.53	10.83
Rank	4	2	3	1

The factor with highest S/N ratio gives optimum level for that particular parameter. Referring **Figure 5** the response curve for S/N ratio, the highest S/N ratio was observed at Engine Load (12 kg), %B (100), Diffuser (12.5°) and CR (18), which are optimum parameter setting for CO. From delta values as mention Table 11, maximum (10.83) for engine load and (0.67) for Diffuser angle. Parameter engine load is most significant parameter & parameter angle is least significant for CO. Optimum parameter set as shown in Table 12

Table 12 Optimize Set of Parameter for CO

Angle (°)	CR	%B	Load	CO (%)	SN Ratio
12.5	18	100	12	0.019	32.0301

Experiment has been carried out using optimum set of parameter. Experimental CO for optimum set of parameter is 0.021. This experimental value is nearer to predicted value 0.019 as shown in Table 13.

Table 13 Validation Results for CO (%)

Predicted Value	Experimental Value	% Variation
0.019	0.02	5

3.4 Taguchi Analysis for HC (ppm)

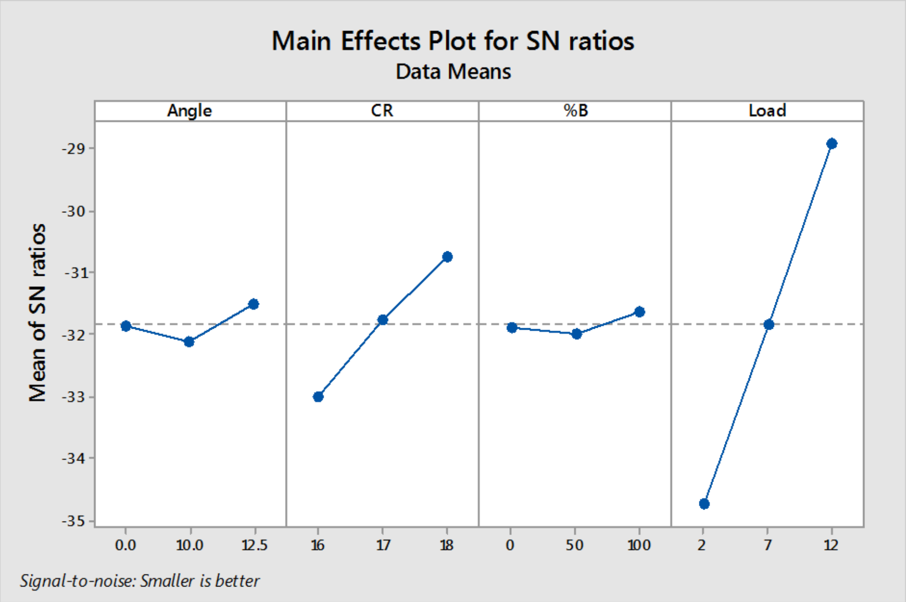

Figure 6 Main Effects Plot for S/N ratios of HC (ppm)

Table 14 Response Table for S/N Ratios of HC (ppm)

Level	Angle	CR	%B	Load
1	-31.85	-33	-31.88	-34.75
2	-32.12	-31.75	-31.98	-31.83
3	-31.52	-30.74	-31.63	-28.91
Delta	0.6	2.26	0.35	5.84
Rank	3	2	4	1

The factor with highest S/N ratio gives optimum level for that particular parameter. Referring Figure **6** the response curve for S/N ratio, the highest S/N ratio was observed at Engine Load (12 kg), %B (100), Diffuser (12.5°) and CR (18), which are optimum parameter setting for HC (ppm). From delta values as mention Table 14, maximum (5.84) for engine load and (0.35) for %B. Parameter engine load is most significant parameter for HC (ppm). Optimum parameter set as shown in Table 15

Table 15 Optimize Set of Parameter for HC (ppm)

Angle (°)	CR	%B	Load	HC (ppm)	SN Ratio
12.5°	18	100	12	21.2222	-27.3079

Experiment has been carried out using optimum set of parameter. Experimental HC (ppm) for optimum set of parameter is 22. This experimental value is nearer to predicted value 21.2222 as shown in Table 16

Table 16 Validation Results for HC (ppm)

Predicted Value	Experimental Value	% Variation
21.2222	22	3.6

3.5 Taguchi Analysis for NO_X (ppm)

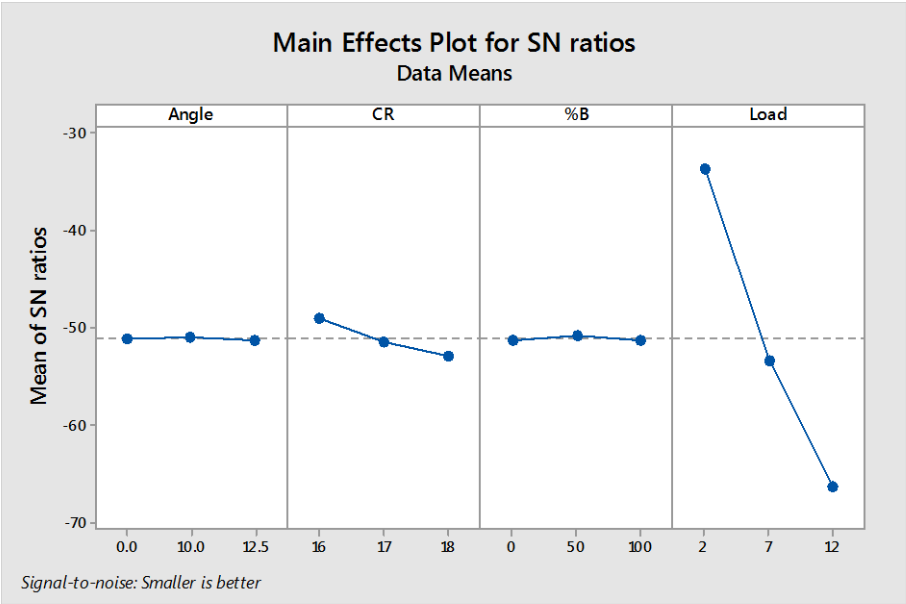

Figure 7 Main Effects Plot for S/N ratios of NO_X (ppm)

Table 17 Response Table for S/N Ratios of NO_X (ppm)

Level	Angle	CR	%B	Load
1	-51.12	-49.11	-51.38	-33.86
2	-51.04	-51.43	-50.9	-53.47
3	-51.41	-53.03	-51.29	-66.24
Delta	0.36	3.92	0.48	32.38
Rank	4	2	3	1

The factor with highest S/N ratio gives optimum level for that particular parameter. Referring Figure 7 the response curve for S/N ratio, the highest S/N ratio was observed at Engine Load (2 kg), %B (50), Diffuser (10°) and CR (16), which are optimum parameter setting for NO_X (ppm). From delta values as mention Table 17, maximum (32.38) for engine load and (0.36) for diffuser angle. Parameter engine load is most significant parameter and parameter angle is least significant parameter for NO_X (ppm). Optimum parameter set as shown in Table 18

Table 18 Optimize Set of Parameter for NO_X (ppm)

Angle (°)	CR	%B	Load	NO_X (ppm)	SN Ratio
10°	16	50	2	32.5624	-31.3414

Experiment has been carried out using optimum set of parameter. Experimental NO_X (ppm) for optimum set of parameter is 31. This experimental value is nearer to predicted value 32.5624 as shown in Table 19.

Table 19 Validation Results for NO_X (ppm)

Predicted Value	Experimental Value	% Variation
32.5624	31	7.6

Conclusions

- It can be concluded that WPO and its blends can be used in CI engine without engine modification.
- For the parameter BTHE, SFC, HC & CO the variable 12.5° angle of diffuser, CR18 gives optimum performance. However, while changing the blend ratio, the optimum blend is 100%B for HC and CO, 50%B for SFC and 0%B for BTHE.
- The value of BTHE is higher and value of SFC is lower at higher CR.
- The diffuser shape helps in scavenging process by reducing back pressure, due to which the charging efficiency (mass of fresh air contained in cylinder/total mass of air contained in cylinder) increases which is seen from improvement in brake thermal efficiency in case of a diffuser.
- Diffuser with half cone angle 12.5° gives better performance and emission characteristics.

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