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COMPARISON OF VARIOUS DIFFUSERS AT EXHAUST MANIFOLD IN CI ENGINE FUELED WITH WPO BLENDS USING TAGUCHI'S APPROACH

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Abstract-*Fossil fuel is running out of the quantity attributable to the increasing worldwide demand of fossil fuel and quantity of fuel fix. To overcome this situation, Waste plastic oil or a blend of waste plastic oil could be used in place of fossil fuel. Waste plastic oil is produced by pyrolysis process. Another alternate bio-fuel is also available in the market like palm seed oil, Jatropha, Neem etc. Taguchi method is used to reduce the experiment run and it helps to get best result in short time. Experiments have been performed according to L27 orthogonal array were take 27 rows and 4 columns at 3 factors with 4 parameters. In the research effect of the diffuser and waste plastic oil blend study and diffuser attached at the exhaust manifold. Exhaust manifold, variable compression ratio, load and blend have been selected parameters for improving the performance of the engine. Exhaust manifold has been modified by changing its draft angle. 10^0 and 12.5^0 draft angles of exhaust manifold. Range of the parameters are (16, 17, 18) compression ratio, (100D0B, 50D50B, 0D100B) Blend, (2, 7, 12) Load. Combinations of all parameters have been taken to analyze Brake Thermal Efficiency, Specific Fuel Consumption, Fuel Consumption and Mechanical Efficiency.*

Keywords- *Taguchi, CI engine, exhaust manifold, blend, waste plastic oil*

Nomenclatures	
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
DA	Draft Angle
100D0B	100% Diesel, 0% Waste Plastic Oil
50D50B	50% Diesel,50% Waste Plastic Oil
0D100B	0% Diesel, 100% Waste Plastic Oil

I. INTRODUCTION

The world is facing a big problem of the plastic waste, due to the properties of plastic, it can't be biodegradable and recycled easily and also one major problem is fossil fuel quantity. Waste plastic can be utilized by the pyrolysis process to produce WPO. That could replace some amount of fossil fuel and reduce the pollution of the environment [1]. For increasing the demand of power and also need of less pollution, the exhaust emission system has been improved by changing exhaust manifold. Exhaust manifolds are too huge to cause the exhaust gas to expand and slow down, which makes it difficult to release and declining the scavenging effect. Due to the smaller size of exhaust manifold, the opposition of exhaust gas flow will be created which reduces power and dilutes the inward intake charge [2]. One of the main parameters which affect the performance of the CI engine is the compression ratio. By increasing the compression ratio, thermal efficiency is also increasing and due to this internal air temperature is also increasing that's why proper combustion is done. No one has done the study on exhaust manifold and CR on CI engine work with WPO [3]. The main goal is to study the effect of the exhaust manifold and compression ratio on CI engines by using WPO.

II. LITERATURE REVIEW

For optimization of experiment run, the Taguchi method has been used. **Chaudhari** has studied the exhaust system analyze by CFD software and the smallest pressure drop and back pressure [4]. **Basha et al.** have studied on diesel, biodiesel and blend of biodiesel and used in place of diesel. The percentage of NOx increased and other emissions decreased like CO_2, CO and hydrocarbon [5]. **Maharana** has studied on those fuels, which are ecologically friendly and renewable biodiesel. Thermal efficiency was higher in biodiesel compared to the diesel. Specific fuel Consumption was also high compared to diesel due to lower calorific value. So biodiesel can be used in place of diesel [6]. **Viswanath et al.** have studied about waste plastic oil, which was made by the pyrolysis process and the ignition delay was less in diesel as compared to the blend. Blend delay period was high due to lower atomization and improper mixture with air. After comparing all blend, discovered that 75D25B plastic oil, diesel blend was the best option to use in place of diesel [7]. **Saptoadi et al.** have studied about pyrolysis as one of the best processes to recycle the waste plastic oil. More PS can make better oil quality. WPO can be used in kitchen with blend kerosene [8]. **Naima et al.** have studied about waste plastic oil and able to use it in the SI engine. WPO gave higher thermal efficiency in both CI and SI engines. HC emission was lower compared to fossil fuel. CO emission was higher in CI engine. CO_2 had been increased by increasing the load, because of the incomplete combustion [9]. **Mani et al.** have investigated that by using WPO or a blend of WPO they did not find any abnormal change in power. Volumetric efficiency decreased in all WPO blend. Brake thermal efficiency was better in all WPO blend. Mechanical efficiency also increased in all WPO blends [10]. **Patel et al.** have studied Taguchi is one of the best methods for product and process. This has decreased the number of experiment runs and save time [11]. Properties of WPO are shown in Table 1.

Table 1. Properties of waste plastic oil [12].

Parameter	**Unit**	
Density @ 15º C	kg/m^3	890
Kinematic viscosity @ 40º C	CP	14.12
Kinematic viscosity @ 100ºC	CP	9.55
Flash point	ºC	132

III. EXPERIMENT SETUP

Experiment setup is shown in Figure 1. Here, single cylinder and variable load engine are used. Compression ratio and injection pressure also are changeable in this setup. The entire setup is connected to the I.C engine software which gives all data related to the experiment. Here stainless steel diffuser use in place of cast iron conventional manifold. 1Cone angles of Diffuser Vs L/D_{inlet} shown in figure 2

Figure 1. Experiment setup [13]

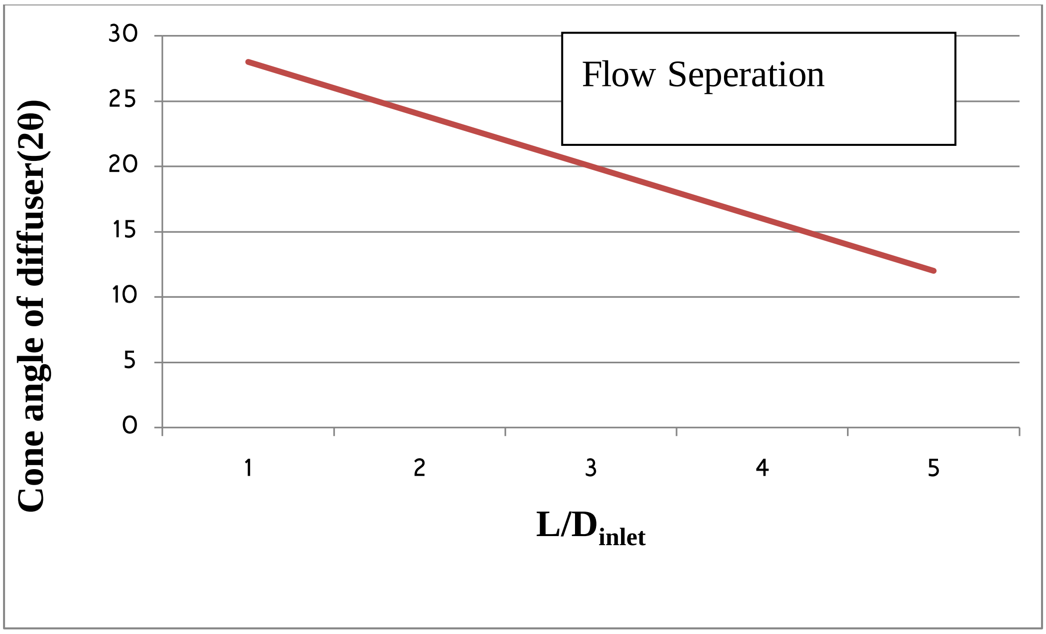

Figure 2. Cone angles of Diffuser Vs L/D$_{inlet}$

Table 2 shows the specification of exhaust manifold and Table 3 shows the engine specification.

Table 2. Specification of exhaust manifold

Exhaust manifold	Conventional manifold	Diffuser shape manifold	
Material	Cast iron	Stainless steel	Stainless steel
Inlet diameter	28 mm	28 mm	28 mm
Outlet diameter	28 mm	57.50 mm	53 mm
Length	62.5 mm	84 mm	56 mm
Thickness	5 mm	5 mm	5 mm
Half cone angle	0°	10°	12.5°

Table 3. Engine specification [13]

Number of Cylinder	Single cylinder
Number of Stroke	4
Swept Volume	552.64 cc
Cylinder Bore	80 mm
Stroke	110mm
Connecting Rod Length	234mm
Oriffice Diameter	20mm
Dynamometer Rotor Radius	141mm
Fuel	Diesel
Power	3.7 kw
Speed	1500rpm
Compression Ratio Range	12 to 18
Inj. Point variation	0° to 25° BTDC

IV. METHODOLOGY

Taguchi method has been used for the optimization of the process. In the Taguchi 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 minitab18. The S/N ratio has been taken instead of standard deviation, because of standard deviation has been decreased with decreased in mean value and vice versa [14].

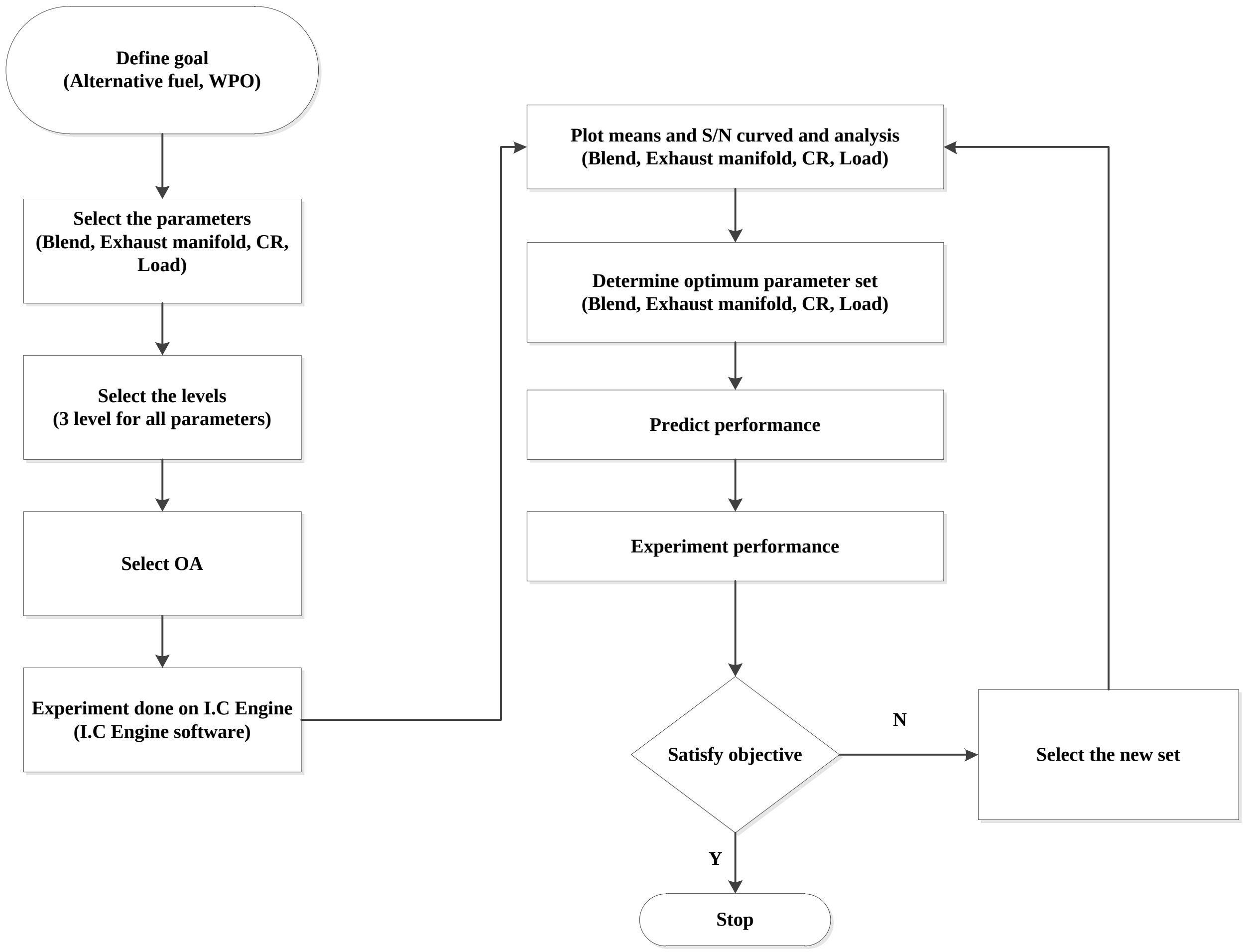

Figure 3. Flow chart of Experiment

V. FACTORS AND LEVELS

Experiments have been performed according to L27 orthogonal array for exhaust manifolds, compression ratio, blend and load. In the experiment table, take 27 rows and 4 columns at 3 factors. Those 4 parameters are shown in Taguchi Table 4.

Three main ways of S/N ratio:
1. Smaller is better.
2. Larger is better.
3. Normal is better.

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
Draft Angle	0	10	12.5
Compression Ratio	16	17	18
Blend Ratio (%)	100D0B	50D50B	0D100B
Load	2	7	12

VI. RESULT AND DISCUSSION

Table 5. Experimental results table

Sr. No	Draft Angle	Compression Ratio	Blend Ratio (%)	Load (kg)	BTHE (%)	Mechanical Efficiency (%)	FC (kg/h)	SFC (kg/kWh)
1	0	18	100D0B	2	18.62	12.55	0.27	0.43
2	0	18	50D50B	7	45.98	33.49	0.37	0.17
3	0	18	0D100B	12	57.55	48.59	0.48	0.14
4	0	17	100D0B	7	46.37	36.23	0.37	0.17
5	0	17	50D50B	12	57.08	49.79	0.48	0.14
6	0	17	0D100B	2	18.33	10.68	0.21	0.44
7	0	16	100D0B	12	52	47.9	0.53	0.15
8	0	16	50D50B	2	20.9	12.61	0.21	0.38
9	0	16	0D100B	7	44.71	34.8	0.37	0.18
10	10	18	100D0B	2	21.86	11.79	0.21	0.37
11	10	18	50D50B	7	50.31	34.68	0.32	0.16
12	10	18	0D100B	12	55.4	47.05	0.48	0.14
13	10	17	100D0B	7	42.56	35.97	0.37	0.19
14	10	17	50D50B	12	52.8	49.85	0.48	0.15
15	10	17	0D100B	2	22.36	15.77	0.21	0.36
16	10	16	100D0B	12	54.04	51.25	0.48	0.15
17	10	16	50D50B	2	22.43	15.22	0.21	0.36
18	10	16	0D100B	7	50.7	37.94	0.32	0.16
19	12.5	18	100D0B	2	24.42	12.67	0.21	0.33
20	12.5	18	50D50B	7	48.2	36.36	0.32	0.17
21	12.5	18	0D100B	12	60.14	48.83	0.43	0.13
22	12.5	17	100D0B	7	49.1	37.12	0.32	0.16
23	12.5	17	50D50B	12	60.13	50.5	0.43	0.13
24	12.5	17	0D100B	2	21.63	15.29	0.21	0.37
25	12.5	16	100D0B	12	55.21	51.48	0.48	0.14
26	12.5	16	50D50B	2	22.34	15.62	0.21	0.36
27	12.5	16	0D100B	7	49.35	36.48	0.32	0.16

Mechanical efficiency, brake thermal efficiency, fuel consumption and specific fuel consumption have been analyzed for each set of parameter using I.C engine software. Minitab18 offers Taguchi method in DOE. These graphs were created by putting all data in minitab18 and by following the required steps. Based on those graphs, the optimum set is gained. Putting that optimum set in minitab18 and following the steps, the predictive value has been obtained.

Taguchi's analysis for BTHE by using different parameter draft angle, compression ratio, blend and load.

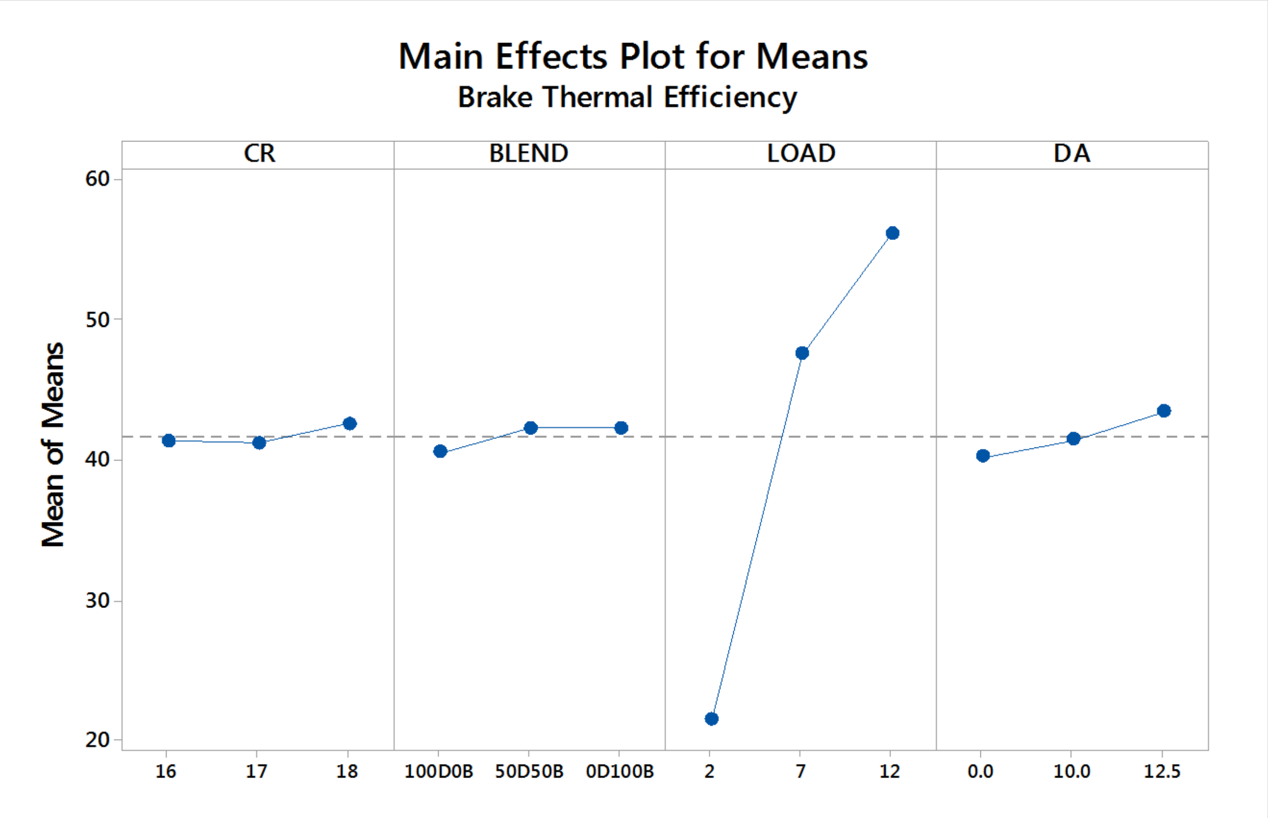

Figure 4. Main effect plot for means: BTHE

Table 6. Main effects plot for means: BTHE

Level	Compression Ratio	Blend	Load	Draft Angle
1	41.30	40.46	21.43	40.17
2	41.15	42.24	47.48	41.38
3	42.50	42.24	56.04	43.39
Delta	1.35	1.78	34.61	3.22
Rank	4	3	1	2

Table 6 show that the maximum value of the delta is 34.61 (LOAD) and the minimum value is 1.35 (CR). BTHE performance more affected by load and less affected by compression ratio, because of load delta value has a maximum and Compression ratio delta value has a minimum on Means result.

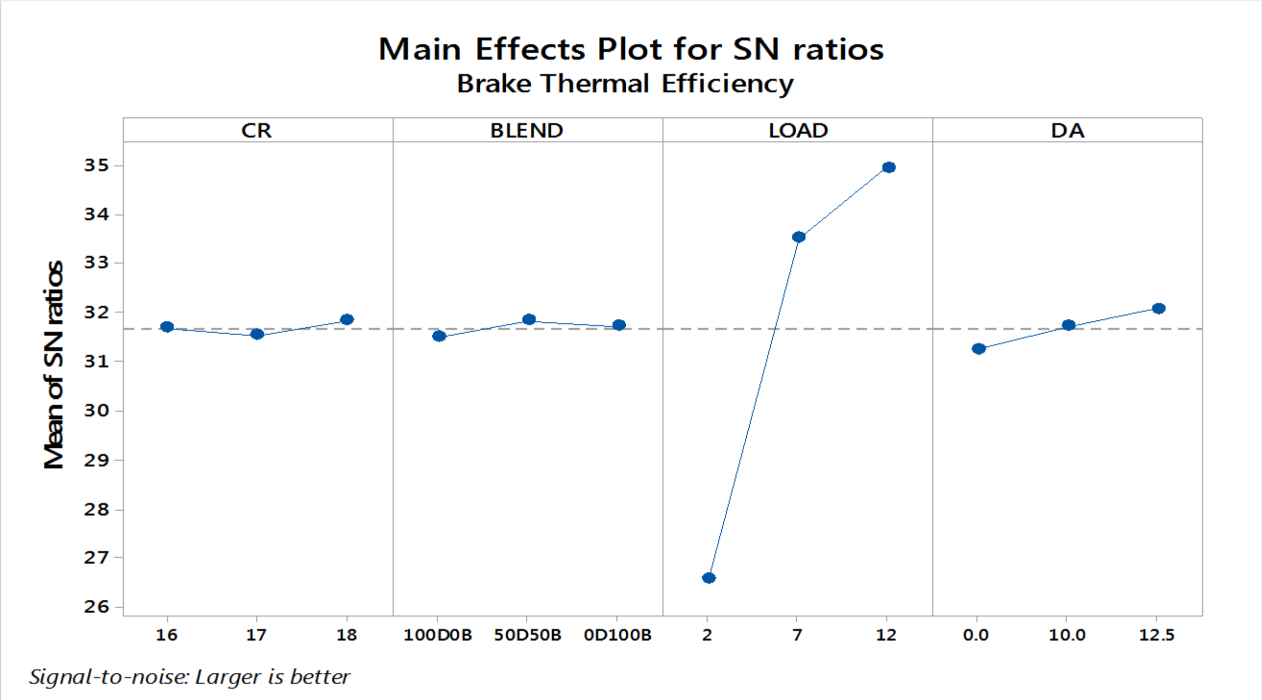

Figure 5. Main effect plot for SN ratio: BTHE

Table 7. Main effects plot for SN ratio: BTHE

Level	Compression Ratio	Blend	Load	Draft Angle
1	31.69	31.50	26.59	31.26
2	31.54	31.83	33.52	31.72
3	31.84	31.73	34.96	32.09
Delta	0.30	0.34	8.37	0.83
Rank	4	3	1	2

Table 7 shows that the maximum value of the delta is 8.37 (LOAD) and the minimum value is 0.30 (CR). BTHE performance more affected by load and less affected by compression ratio, because of the load delta value has a maximum and Compression ratio delta value has minimum on the S/N ratio result.
Figure 4 and 5 shows the minimum and maximum value for all parameters. Take the maximum value from the above graph for the best value of BTHE. The value was DA12.5, CR18, BR50D50B and LOAD12. Predicted value gained by the putting Table value in minitab18, comparing that value to the experiment value.

Table 8. Optimum set of parameters: BTHE

Draft Angle	Compression Ratio	Blend	Load	Predicted	Experiment	Error
12.5	18	50D50B	12	59.2222	55.93	3.292

From the Table 8 Best Brake Thermal Efficiency got at draft angle 12.5, compression ratio18, Blend Ratio50D50B and Load12.

Taguchi's analysis for Mechanical Efficiency by using different parameter draft angle, compression ratio, blend and load.

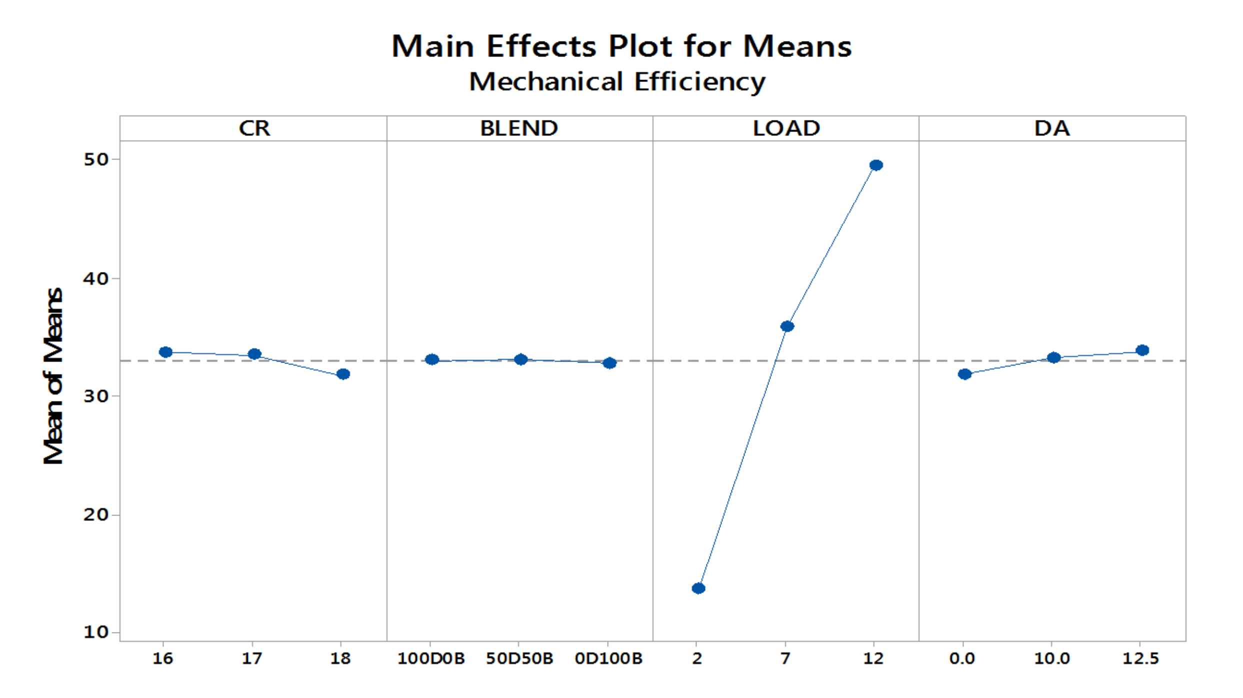

Figure 6. Main effect plot for means: Mechanical Efficiency

Table 9. Main effects plot for means: Mechanical Efficiency

Level	Compression Ratio	Blend	Load	Draft Angle
1	33.70	33.00	13.58	31.85
2	33.47	33.12	35.90	33.28
3	31.78	32.83	49.47	33.82
Delta	1.92	0.30	35.89	1.97
Rank	3	4	1	2

Table 9 shows that the maximum value of the delta is 35.89 (LOAD) and the minimum value is 0.30(BLEND). Mechanical Efficiency performance more affected by load and less affected by blend, because of load delta value has a maximum and blend delta value has a minimum on Means result.

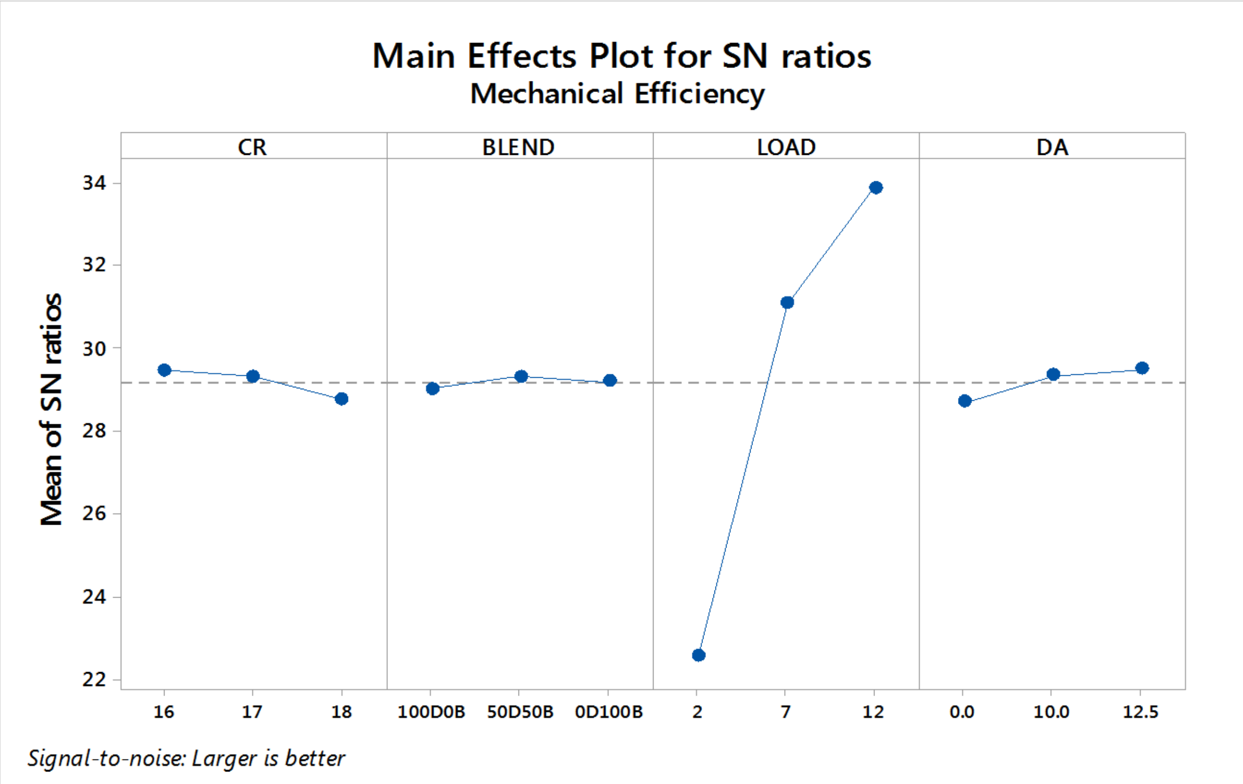

Figure 7. Main effect plot for SN ratio: Mechanical Efficiency

Table 10. Main effects plot for SN ratio: Mechanical Efficiency

Level	Compression Ratio	Blend	Load	Draft Angle
1	29.47	29.02	22.58	28.71
2	29.32	29.33	31.10	29.35
3	28.77	29.20	33.88	29.50
Delta	0.70	0.31	11.30	0.80
Rank	3	4	1	2

Table 10 shows that the maximum value of the delta is 11.30 (LOAD) and the minimum value is 0.31 (BLEND). Mechanical Efficiency performance more affected by load and less affected by blend, because of load delta value has a maximum and blend delta value has a minimum on the S/N ratio result.
Figure 6 and 7 shows the minimum and maximum value for all parameters. Take the maximum value from the above graph for the best value of Mechanical Efficiency. The value was DA12.5, CR16, BR50D50B and LOAD12. Predicted value gained by the putting Table value in minitab18, compare that value to the experiment value.

Table 11. Optimum set of parameters: Mechanical Efficiency

Draft Angle	Compression Ratio	Blend	Load	Predicted	Experiment	Error
12.5	16	50D50B	12	51.1667	50.1217	1.045

From table 11 Best Mechanical Efficiency got at draft angle 12.5, compression ratio16, Blend Ratio50D50B and Load12.

Taguchi's analysis of Fuel Consumption by using different parameter draft angle,compression ratio, blend and load.

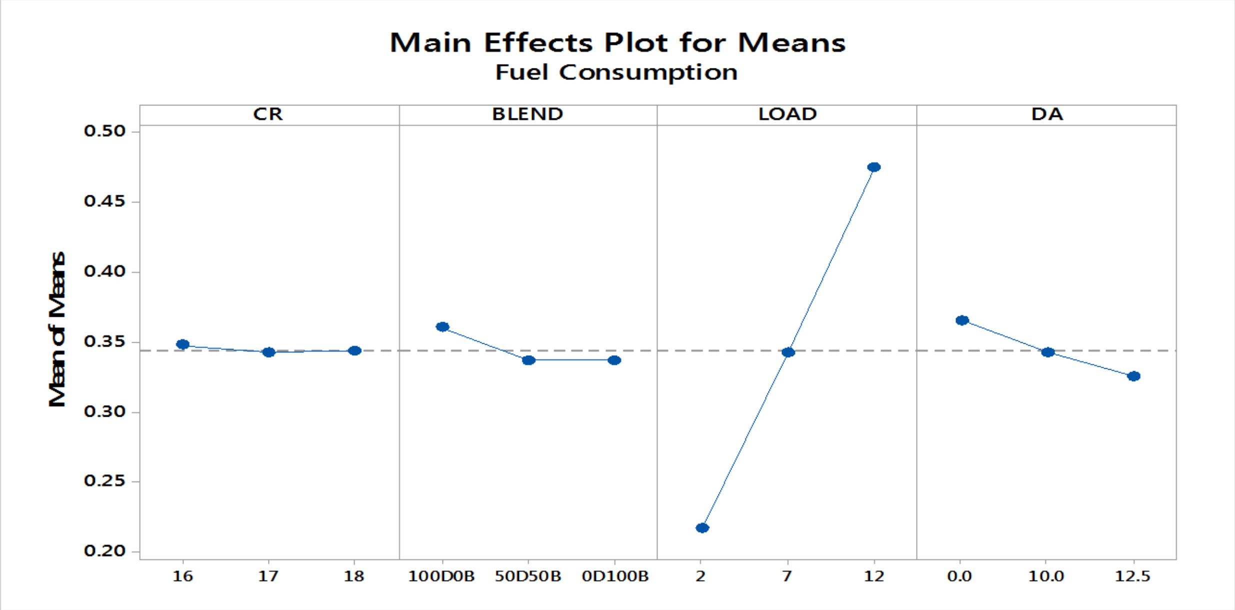

Figure 8. Main effect plot for means: Fuel Consumption

Table 12. Main effects plot for means: Fuel Consumption

Level	Compression Ratio	Blend	Load	Draft Angle
1	0.3478	0.3600	0.2167	0.3656
2	0.3422	0.3367	0.3422	0.3422
3	0.3433	0.3367	0.4744	0.3256
Delta	0.0056	0.0233	0.2578	0.0400
Rank	4	3	1	2

Table 12 show that maximum value of delta is 0.2578 (LOAD) and the minimum value is 0.0056 (CR). Fuel consumption performance more affected by load and less affected by compression ratio, because of load delta value has a maximum and compression ratio delta value has a minimum on Means result.

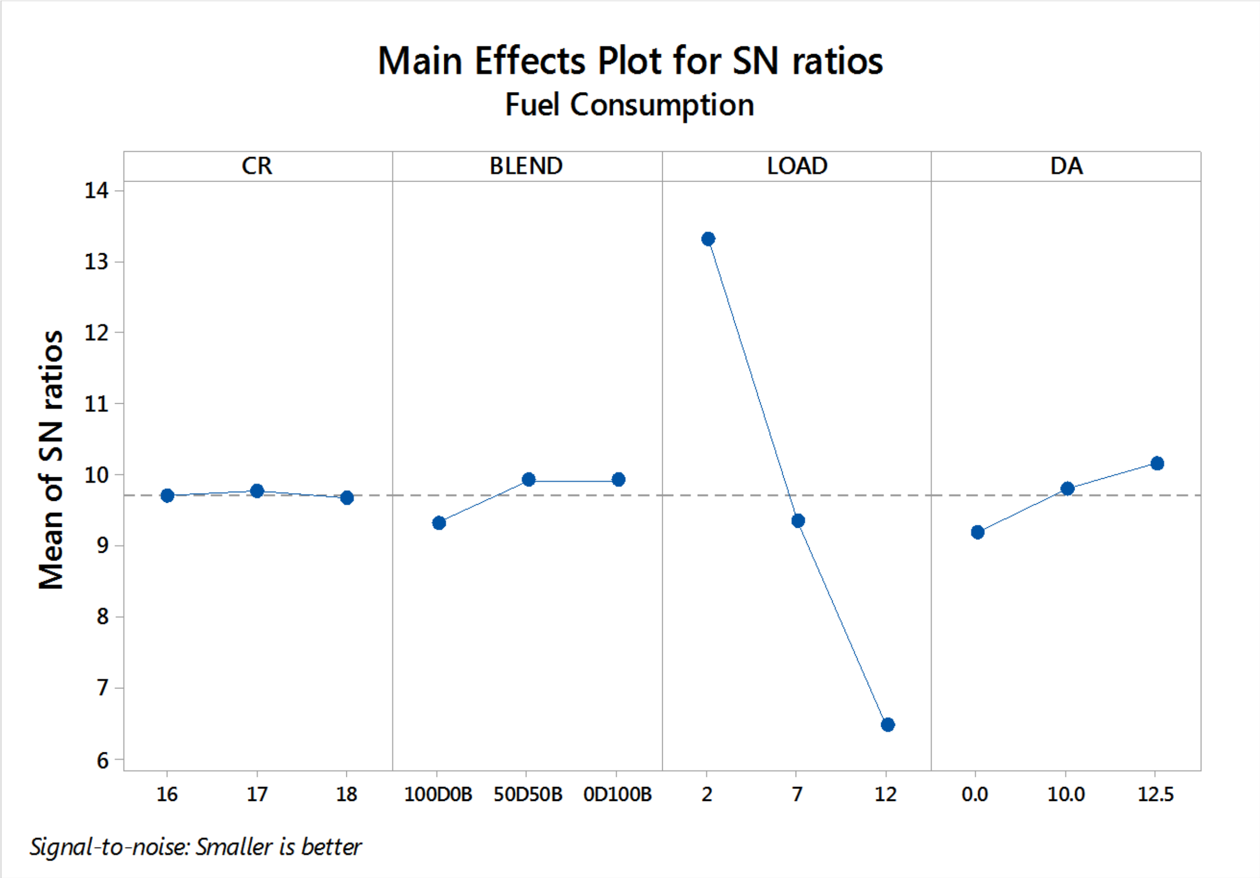

Figure 9. Main effect plot for SN ratio: Fuel Consumption

Table 13. Main effects plot for SN ratio: Fuel Consumption

Level	Compression Ratio	Blend	Load	Draft Angle
1	9.707	9.324	13.313	9.184
2	9.769	9.909	9.337	9.802
3	9.666	9.909	6.492	10.155
Delta	0.102	0.584	6.821	0.971
Rank	4	3	1	2

Table 13 show that the maximum value of delta is 6.821 (LOAD) and the minimum value is 0.102 (CR). FC performance more affected by load and less affected by compression ratio, because of load delta value has a maximum and Compression ratio delta value has minimum on the S/N ratio result.
Figure 8 and 9 shows the minimum and maximum value for all parameters. Take the maximum value from the above graph for the best value of Fuel Consumption. The value was DA12.5, CR17, BR50D50B and LOAD2. Predicted value gained by the putting Table value in minitab18, compare that value to the experiment value.

Table 14. Optimum set of parameters: Fuel Consumption

Draft Angle	Compression Ratio	Blend	Load	Predicted	Experiment	Error
12.5	17	50D50B	2	0.18777	0.20666	0.01889

From the table 14 Minimum Fuel Consumption got at draft angle 12.5, compression ratio17, Blend Ratio50D50B and Load2.

Taguchi's analysis of Specific Fuel Consumption by using different parameter draft angle,compression ratio, blend and load.

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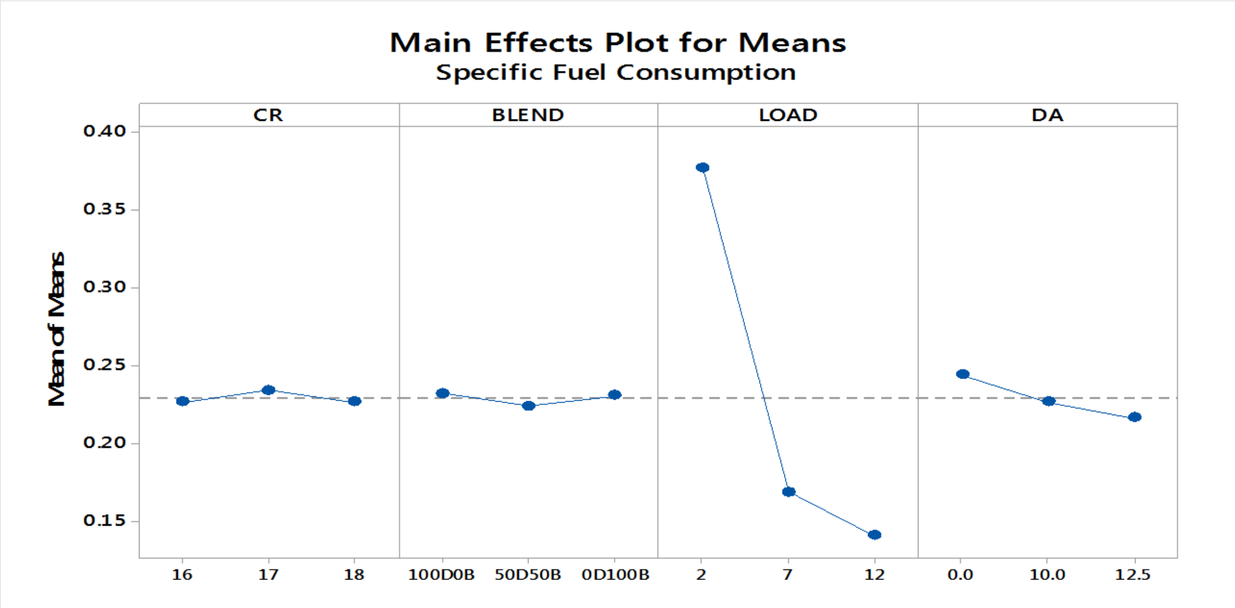

Figure 10. Main effect plot for means: Specific Fuel Consumption

Table 15. Main effects plot for means: Specific Fuel Consumption

Level	Compression Ratio	Blend	Load	Draft Angle
1	0.2267	0.2322	0.3778	0.2444
2	0.2344	0.2244	0.1689	0.2267
3	0.2267	0.2311	0.1411	0.2167
Delta	0.0078	0.0078	0.2367	0.0278
Rank	4	3	1	2

Table 15 show that the maximum value of the delta is 0.2367 (LOAD) and the minimum value is 0.0078 (CR). Specific Fuel Consumption performance more affected by load and less affected by compression ratio, because of load delta value has a maximum and compression ratio delta value has a minimum on Means result.

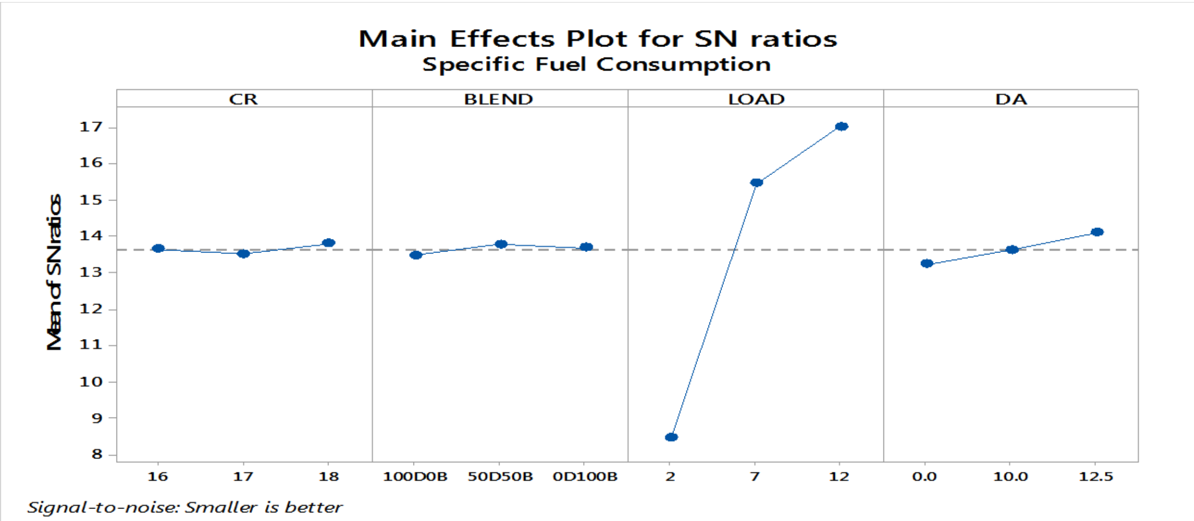

Figure 11. Main effect plot for SN ratio: Specific Fuel Consumption

Table 16. Main effects plot for SN ratio: Specific Fuel Consumption

Level	Compression Ratio	Blend	Load	Draft Angle
1	13.657	13.485	8.488	13.242
2	13.517	13.792	15.463	13.631
3	13.797	13.694	17.021	14.098
Delta	0.280	0.307	8.533	0.857
Rank	4	3	1	2

Table 16 show that the maximum value of the delta is 8.533 (LOAD) and the minimum value is 0.280 (CR). Specific Fuel Consumption performance more affected by load and less affected by compression ratio, because of the load delta value has a maximum and compression ratio delta value has a minimum on the S/N ratio result.
Figure 10 and 11 shows the minimum and maximum value for all parameters. Take the maximum value from the above graph for the best value of Specific Fuel Consumption. The value was DA12.5, CR17, BR50D50B and LOAD2. Predicted value gained by the putting Table value in minitab18, compare that value to the experiment value.

Table 17. Optimum set of parameters: Specific Fuel Consumption

Draft Angle	Compression Ratio	Blend	Load	Predicted	Experiment	Error
12.5	18	50D50B	12	0.1211	0.1181	0.00401

From the table 17 Minimum Specific Fuel Consumption got at draft angle 12.5, compression ratio18, Blend Ratio50D50B and Load12.

VII. CONCLUSIONS

From the experiment, it concluded that WPO can be used in CI engine as a fuel. Optimum set for Break Thermal Efficiency and Specific Fuel Consumption is 12.5 Draft Angle, 18 Compression Ratio, 50D50B Blend and 12 Load. These sets give the highest value of BTHE and SFC. Optimum set for Fuel Consumption is 12.5 Draft Angle, 17 Compression Ratio, 50D50B Blend and 2 Load. These sets give the highest value of Fuel Consumption. Optimum set for Mechanical Efficiency is 12.5 Draft Angle, 16 Compression Ratio, 50D50B Blend and 12 Load. These sets give the highest value of Mechanical Efficiency. As result analyze 12.5 draft angle and 50%diesel50%WPO blend are give the best result for SFC, FC, BTHE, Mechanical Efficiency. SFC, BTHE and Mechanical Efficiency are give batter value at higher load and FC is give batter value at lower load. SFC and BTHE are performing well at higher compression ratio and FC is performing well at lower load. Analyze the result and found that among the 4 parameter load is more affect to the BTHE, SFC, FC and Mechanical Efficiency, on the side compression ratio is less affect to the BTHE, SFC and FC. Mechanical Efficiency less affected by blend. From the experiment, it is deduced that WPO and WPO blend have little less brake thermal efficiency, specific fuel consumption, fuel consumption and mechanical efficiency. Taguchi method save time by reducing experiment run and gives best optimum value for all parameter.

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