Scientific Journal of Impact Factor (SJIF): 5.71

e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 5, Issue 03, March -2018

Parametric Optimization of Single Cylinder CI Engine Fuel with Diesel-Waste Plastic Oil Blend

Shaishav B Patel[1], Pragna R Patel[2], Tushar M Patel[3]

[1](ME Scholar, Mechanical Engineering Department, LDRP-ITR, KSV University, Gandhinagar, India)
[2](Associatet professor, Mechanical Engineering Department, LDRP-ITR, KSV University, Gandhinagar, India)
[3](Professor, Mechanical Engineering Department, LDRP-ITR, KSV University, Gandhinagar, India)

Abstract: *In this study, a Taguchi's method is used to determine the optimal combinations of compression ratio, injection pressure, blend ratio and load of a diesel engine fueled with diesel-biodiesel blend. The previous researchers had done research on combined effect of compression ratio and blend ratio but in this research. Experiments has been carried out using various sets of parameters like compression ratio, injection pressure and engine output. The optimum results for selected responses are achieved with optimum sets of parameters. Peak pressure of the cylinder is also measured and optimized within all set of experiments. The optimum set achieved from experiments for SFC is with 16 compression ratio, 100D0B blend, low injection pressure (160 bar) at 12 kg of load. The optimum set achieved from experiment for Brake Thermal Efficiency from experiments is with 16 compression ratio, 100D0B blend, low injection pressure (160 bar) at 12 kg of load. The optimum set achieved from experiment for peak pressure from experiments is with16 compression ratio, 100D0B blend, low injection pressure (160 bar) at 12 kg of load. At the end, the experiments are carried out using optimum set of parameters in order to validate the optimum predicted results. Experiment results shows that predicted values by Taguchi's method are closer to the experiment values. Taguchi's method gives accurate results with less number of experiments.*

Keyword*: Diesel, Waste plastic oil, Taguchi's method, Pyrolysis process, Injection pressure, Compression ratio.*

Nomenclature:

WPO	*: Waste Plastic Oil*
BR	*: Blend Ratio*
100D0B	*: 100%Diesel 0%Biodiesel*
50D50B	*: 50%Diesel 50%Biodiesel*
0D100B	*: 0%Diesel 100%Biodiesel*
SFC	*: Specific Fuel Consumption*
CR	*: Compression Ratio*
IP	*: Injection Pressure*
BTHE	*: Brake Thermal Efficiency*
OA	*: Orthogonal Arrays*

I. INTRODUCTION

Fossil fuel is continuously reduced from the earth due to rapidly growing world population. So, it is important to find other option in place of fossil fuel [1]. Plastic now a day more waste material in whole the world so, it is harmful for peoples and animals [2]. It is essential to utilized plastic and convert in to usable form. In year 2000, approximately 6000 tons of plastic produced every day in India and only 60% of it was recycled. Now a days 129 million tones plastic produced annually all over the world. Plastic is more crucial part today's world. Due to their durability, energy efficiency, lesser weight coupled with a faster rate of production and design flexibility, these plastic materials are hired in integral area of industrial & domestic areas. Plastic are made from different petroleum processes and are composed primarily of hydrocarbons and add some additives such as antioxidants, stabilizers & colorants. Pyrolysis process is used in experiment to collect liquid plastic oil from the solid waste plastic material at the end of process. pyrolysis reactor, char collector, quencher, cyclone reactor is generally in this process. Pyrolysis conflict from other high-temperature processes like combustion & hydrolysis in that it usually does not include reactions with oxygen, water, or any other reagents. In practice, it is not possible to accomplished a completely oxygen-free atmosphere. Because some oxygen is present in any pyrolysis system, a small amount of oxidation occurs. Taguchi method is most relevant method to get optimum result using different parameter.

II. LITERATURE REVIEW

Pyrolysis oil blended with diesel which is used in single cylinder diesel engine conducted by **Patel et al. (2013).** Pyrolysis process carried out in absence of an oxygen. Blend use with diesel fuel which is helps to eliminate consumption of diesel fuel. The IP, injection timing, CR and load are taken in experiment for taking optimum result. The results of the taguchi's experiment identifies that 220-injection timing, injection pressure 200 bar, compression ratio 16 and engine load 20kg are optimum parameter setting for lowest break specific fuel consumption [9].Palm seed oil blended which is used with diesel used in single cylinder diesel engine analyzed by **Modi et al. (2014).** Load, CR, and IP are carried out s variable for optimization. The result from the Taguchi's method established that 16 CR, 180 IP and engine load 10 kg are optimum set of parameters for taking highest BTHE [10]. Engine performance, combustion and emission characteristic of IDI diesel engine to use waste plastic oil conducted by **Rinaldini etal. (2016)**. They tasted engine on full load and partial load.as per result at end of tasting engine performance at full load reduced due to lower volumetric fuel rating, but BSFC and brake fuel conversion efficiency is higher about 8%. Torque and power is also decreased while global efficiency is higher.at a partial load engine performance is same as engine working on full load but BSFC is always lower due to lower density also engine efficiency is still higher. Running engine on WPO the soot emission is always considerably lower in partial load condition [3].Waste plastic such as a polystyrene(PS), polyethylene(PE), polypropylene(PP), Poly Ethylene Terephthalate(PET) and utilized by the pyrolysis process conducted by **Miandad et al. (2017)**. A small reactor used for pyrolysis process. It operated at optimum temperature and retention time of 450º and 75 min respectively. Polystyrene(PS) plastic waste showed maximum production of liquid oil (80.8%) along with least production of gases (13%) and char (6.2%) in comparison of other plastic.PS pyrolysis contained styrene (48.3%), ethylbenzene (21.2%), and toluene (25.6%). Pyrolysis liquid oils found to have ranges of dynamic viscosity (1.77-1.90 Mpa), density (0.91-0.92 g/cm^3), freezing point (-15-(-65º C), flashpoint (28.1-30.2º C) and high heating value (41.4-41.8 MJ/kg). Upgrading of liquid oil using difference post treatment such as distillation, refining & blending with conventional diesel is required to make it suitable as transport fuel.

III. PYROLYSIS PROCESS

Pyrolysis is a thermochemical disintegration of biological material at elevated temperatures in the absence of oxygen. It involves the concurrent change of chemical composition and physical phase and is irretrievable. The word is invented from the Greek-derived elements pyro "fire" and lysis "separating". Pyrolysis contrasts from other high-temperature processes like combustion and hydrolysis in that it usually does not involve reactions with oxygen, water, or any other mixtures. In practice, it is not possible to achieve an entirely oxygen-free atmosphere. Because some oxygen is present in any pyrolysis system, a small amount of oxidation occurs. Bio-oil is produced via pyrolysis, a process in which biomass is hastily heated to 450–500°C in an oxygen-free environment and then quenched, yielding a mix of liquid fuel (pyrolysis oil), gases, and solid char. Several technologies and methodologies can be used for pyrolysis, including circulating fluid beds, entrained flow reactors, multiple hearth reactors, or vortex reactors. The process can be achieved with or without a catalyst or reductant. The original biomass feedstock and processing conditions affect the chemical properties of the pyrolysis oil, but it typically contains a significant amount of water (15%–30% by weight), has a higher density than conventional fuel oils. The heating value of pyrolysis oil is approximately half that of conventional fuel oils. Bio-oil can be hydro-treated to remove the oxygen and produce a liquid feedstock resembling crude oil, which can be further hydro-treated and cracked to create renewable hydrocarbon fuels and chemicals. Bio-oil can be deoxygenated from its high primary oxygen content of 35-45 percent by weight (wt%) on a dehydrated basis all the way down to 0.2 wt%

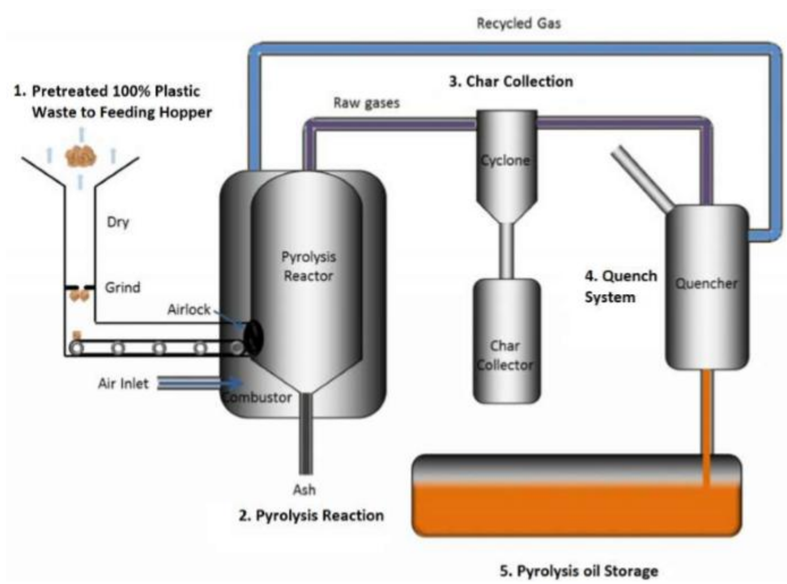

Figure 1. Production of Plastic Pyrolysis Oil

The steps involved in conversion of plastic waste into liquid fuel are shown in fig. 1 & description is given below:

1. Mechanical separation of plastic waste from mixed MSW dump yard/storage.
2. Transportation of separated plastic waste through conveyor belt for optical separation. Optical separation of plastic waste is done. Grinding of plastic waste and displacing dust and impurities.
3. Transportation of separated (100% plastic waste) into feeding hopper (reactor). Feeding of plastic waste into reactor for random depolymerization in presence of additives.
4. Produced raw gases are sent to char collector where solid char particles are separated from gases. Char collector contains a cyclone coil to separate char particles from gases.
5. After that, raw gases are sent to quench system or condenser to separate recycled gases and Pyrolysis oil.

Table 1. Property of WPO [8]

Parameter	**Unit**	**Result**
Density @ 15º C	kg/m^3	890
Kinematic viscocity @ 40º C	CP	14.12
Kinematic viscocity @ 100ºC	CP	9.55
Flash point	ºC	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
Cetane number	-	618
Acid value	mg KOH/gm	22
Methanol content	%by mass	0.19
Ethanol content	%by mass	0.22
Ester content	%by mass	98.30
Free glycerol content	mg/kg	155
Total glycerol content	%by mass	0.18
Oxidation stability @ 110º C	-	11
Iodin value	-	125
CCR(10%Bottem)	%by mass	0.045(100%)

IV. EXPERIMENTAL SETUP AND METHODOLOGY

The setup involves of single cylinder, four strokes, multi-fuel, research engine coupled to eddy type dynamometer for measuring. The procedure mode of the engine can be changed from diesel to Petrol or from Petrol to Diesel with some essential changes. In both modes the compression ratios can be varied without stopping the engine and without altering the combustion chamber geometry by specially designed tilting cylinder block plan. Figure 2 shows the experimental setup.

Table 2. Engine specification

Number of Cylinders	Single cylinder
Number of Srtoke	4
Swept Volume	552.64 cc
Cylinder Diameter	80 mm
Srtoke length	110mm
Connecting Rod Length	234mm
Orific Diameter	20mm
Dynamometer Rotor Radius	141mm
Fuel	Diesel
Power	5.2 kw
Speed	1500rpm
Compression Ratio Range	12 to 18
Injection Point variation	0 to 25 BTDC

Figure 2. Experiment setup [11]

The injection point and spark point can be different for research tests. Setup is provided with compulsory 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. Rotameters are provided for cooling water and calorimeter water flow measurement. A battery, starter and battery charger are provided for engine electric start preparation. The Experimental setup is employed to observe Variable Compression Ratio (VCR) engine performance for brake power, indicated power, frictional power,brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio, heat balance and combustion analysis. The engine specifications used in above stated setup are given in table 2.

Taguchi's methodology

Taguchi's method is a simple method for finding effective solutions. It is also called robust method. OA and reliable quality Taguchi's method can decrease the count of experiments runs. For taking basic advantage of the Taguchi's method for development the OA are used for design to simplify the task of arrangement experiment extremely. In Taguchi's method SN ratio is greatly used to illustrate a performance characteristic .SN ratio are three types [5].

1) Lower-the better
2) Higher-the better
3) More nominal-the better

DOF approach is used to describe the key factors that make the superior contributions to the deviation in response parameters of interest. It established the loss function idea which combines cost, target and deviation into one metric.

Flow chart of whole process experiment is shows in figure 3.

First step in experiment is setup the goal what achieve in whole experiment then select parameter as load, indication pressure, compression ratio, blend ratio and peak pressure. After selecting parameters, the OA is to be selected by Taguchi's methodology. After selecting OA by Taguchi's methodology, the analysis of method is carried out then analysis of means and SN ratio curve and plotted. Further the process the optimum set of parameters are established then find out predicted value of parameters. After that predicted value is compared with experiment value which is obtain by experiment [6]. When result is satisfied then stop the procedure if result is not satisfied then set new set of parameters.

Flow chart of the whole process experiment is shown in figure 3.

Steps are involved for SFC are carried out below.

1. First step of experiment process is to define goal for getting optimum result for SFC.
2. After decided goal, Input parameter as load, Injection pressure, compression ratio and blend ratio are included.

3. Then Taguchi's analysis for SFC is carried out.
4. After selecting parameter, the OA is to be selected by Taguchi's methodology.
5. Once selecting OA by Taguchi's methodology, the analysis of the method is carried out, then analysis of means and SN ratio curve and plotted.
6. Further the process the optimum set of parameters are established, then find out the predicted value of parameters.
7. After that predicted value is compared with experimental value which is obtained by experiment.
8. When the result is satisfied, then stop the procedure if result is not satisfied, then set a new set of parameters.

Same procedures are carried out for other output parameters as Brake Thermal Efficiency.

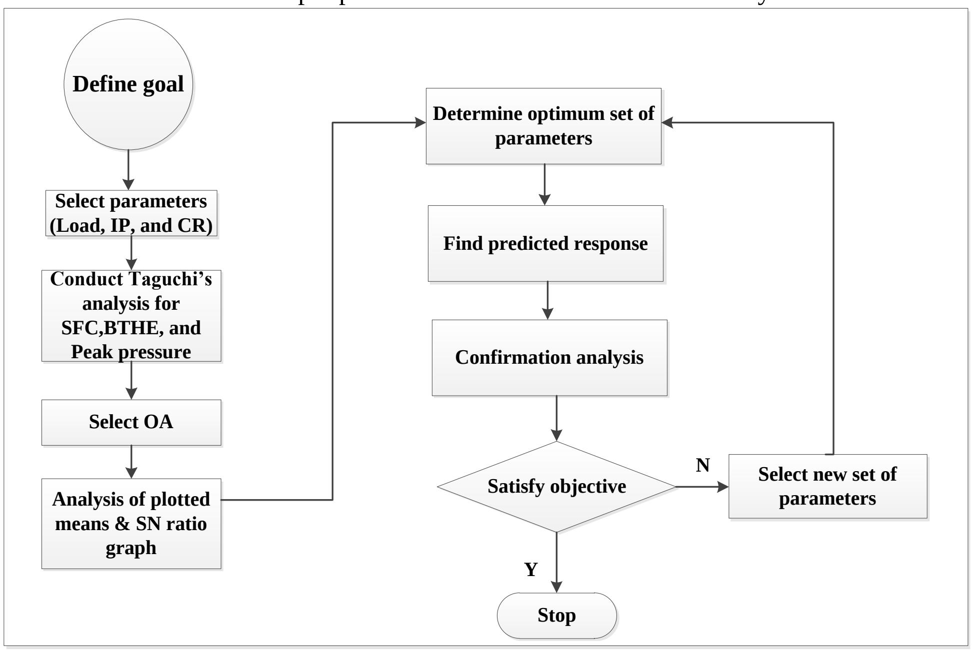

Figure3. Flow chart of experiment process [7]

V. RESULT AND DISCUSSION

Table 3 shows the experiment data. We can obtain different Brake Thermal Efficiency, Mechanical efficiency, SFCusing different blend ratio on different load, IP, CR and load.

Table 3. Experiment data

Sr no.	Compression Ratio	Injection Pressure (bar)	%Bio-Diesel	Load (kg)	SFC (kg/kWh)	BTHE (%)	Peak Pressure (bar)
1	18	160	100D0B	12	0.15	61.83	71.06
2	18	200	50D50B	2	0.32	29.02	52.45
3	18	180	0D100B	7	0.15	61.02	62.4
4	17	180	100D0B	12	0.15	60.32	65.29
5	17	160	50D50B	2	0.32	28.42	47.7
6	17	200	0D100B	7	0.16	59.33	56.74
7	16	160	100D0B	7	0.17	52.93	54.16
8	16	200	50D50B	12	0.14	65.88	65.56
9	16	180	0D100B	2	0.31	29.87	45.96

Taguchi's analysis for SFC with using different parameter IP, CR and load.

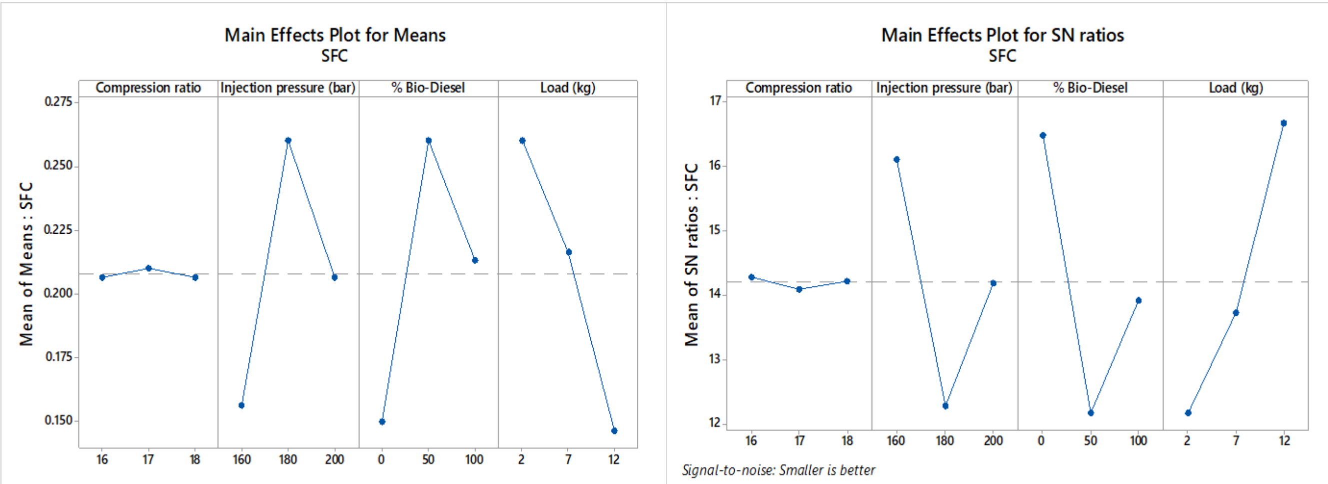

Figure 4. Main effect plot for means and SN ratio: SFC

Figure4 shows the optimum set of parameters of means for SFC is smaller-the better which will give a best result. So, the lower plotted point in this graph shows better performance. SFC is also less using above optimum parameter also,Figure shows that optimum set of parameters of SN ratio for SFC is higher-the better which will give a best result. So, the higher plotted point in this graph shows better performance. SFC is also less using above optimum parameter.

Table4. Main effect plot for means and SN ratio: SFC

Level	CR	IP (bar)	%Bio-Diesel	Load (kg)
1	0.2067	0.1500	0.1567	0.2600
2	0.2100	0.2600	0.2600	0.2167
3	0.2067	0.2133	0.2067	0.1467
Delta	0.0033	0.100	0.1033	0.1133
Rank	4	2	3	1

Level	CR	IP (bar)	%Bio-Diesel	Load (kg)
1	14.21	16.49	16.12	12.18
2	14.10	12.18	12.29	13.74
3	14.28	13.92	14.19	16.68
Delta	0.19	4.31	3.83	4.50
Rank	4	2	3	1

Table4 shows that maximum value of delta for load is 0.1133 and minimum value of delta for CR is 0.0033. Load is most affected on performance and CR is less affected on performance for means. Also, table shows that maximum value of delta for load is 4.50 and minimum value of delta for CR is 0.19. Load is most affected on performance and CR is less affected on performance for SN ratio.

Table 5. Optimum set of parameters for SFC

CR	IP (bar)	%Bio-Diesel	Load (kg)	Predicted value
16	160	100D0B	12	0.0367

Table5 shows that optimum set of parameters for SFC is obtained with taking blend ratio 100% diesel and 0% biodiesel(WPO), with injection pressure low (160 bar), compression ratio 16 and load on 12kg will give predicted value 0.0367. SFC obtained is less from above parameters and give better result.

Taguchi's analysis for Brake Thermal Efficiency with using different parameter IP, CR and load.

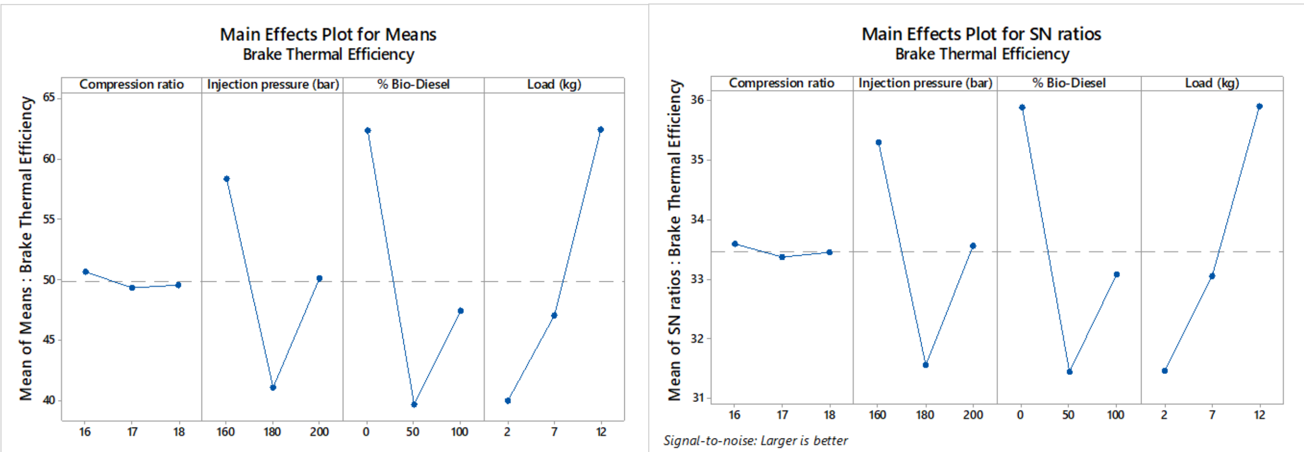

Figure 5.Main effect plot for means and SN ratio: Brake Thermal Efficiency

Figure 5 shows the optimum set of parameters of means for Brake Thermal Efficiency is higher-the better which will give a best result. So, the higher plotted point in this graph shows better performance. Brake Thermal Efficiency is also increase using above optimum parameter.Also, Figureshows that the optimum set of parameters of SN ratio for Brake Thermal Efficiency is higher-the better which will give a best result. So, the higher plotted point in this graph shows better performance. Brake Thermal Efficiency is also increase using above optimum parameter.

Table6.Main effect plot for means and SN ratio: Brake Thermal Efficiency

Level	**CR**	**IP (bar)**	**%Bio-Diesel**	**Load (kg)**
1	49.56	62.35	58.39	40.04
2	49.36	39.74	41.11	47.09
3	50.62	47.46	50.07	62.41
Delta	1.27	22.61	17.25	22.37
Rank	4	1	3	2

Level	**CR**	**IP (bar)**	**%Bio-Diesel**	**Load (kg)**
1	33.45	35.89	35.30	31.47
2	33.38	31.46	31.57	33.06
3	33.60	33.09	33.56	35.90
Delta	0.21	4.43	3.74	4.43
Rank	4	1	3	2

Table 6 shows that maximum value of delta for IP is 22.61 and minimum value of delta for CR 1.27. IP is most affected on performance and CR is less affected on performance for means. Also, Table shows that maximum value of delta for IP is 4.43 and minimum value of delta for CR 0.21. IP is most affected on performance and CR is less affected on performance for SN ratio.

Table7. Optimum set of parameters for Brake Thermal Efficiency

CR	**IP (bar)**	**%Bio-Diesel**	**Load (kg)**	**Predicted value**
16	160	100D0B	12	84.1967

Table7 shows that optimum set of parameters for Brake Thermal Efficiency is obtained with taking blend ratio 100% diesel and 0% biodiesel(WPO), with injection pressure low (160bar), compression ratio 18 and load on 12kg will give predicted value 84.1967. Brake Thermal Efficiency obtained is more from above parameters and give better result.

Taguchi's analysis for Peak Pressure with using different parameter IP, CR and load.

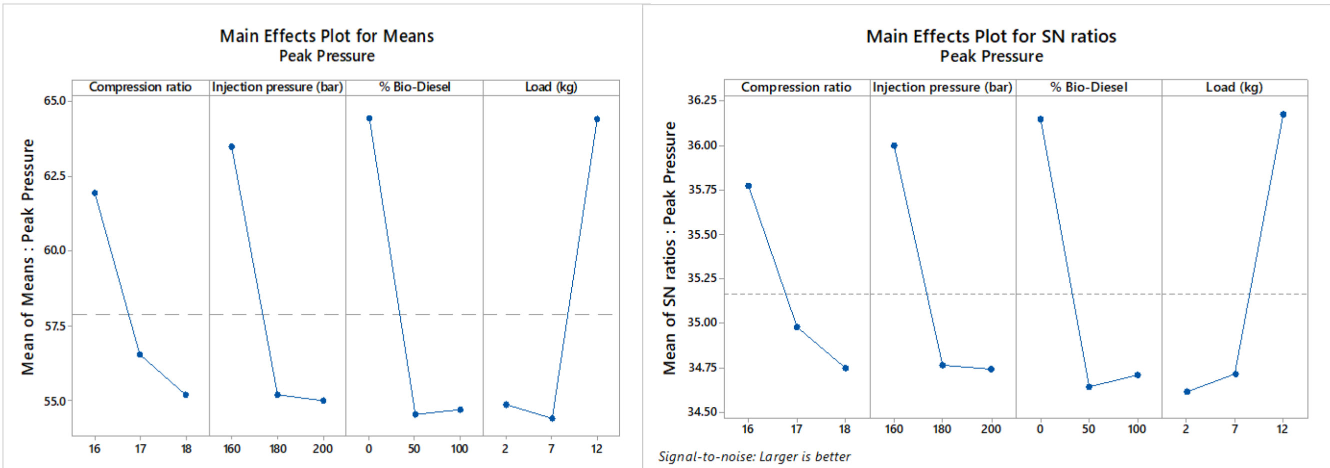

Figure 6. Main effect plot for means and SN ratio: Peak Pressure

Figure 6 shows the optimum set of parameters of means for peak pressure is higher -the better which will give a best result. So, the higher plotted point in this graph shows better performance. Peak pressure is high using above optimum parameter. Also, Figure shows the optimum set of parameters of SN ratio for peak pressure is higher-the better which will give a best result. So, the higher plotted point in this graph shows better performance. Peak pressure is achieved high using above optimum parameter.

Table 8. Main effect plot for means and SN ratio: Brake Thermal Efficiency

Level	CR	IP (bar)	%Bio-Diesel	Load (kg)
1	55.22	64.45	63.50	54.91
2	56.48	54.57	55.24	54.45
3	61.96	54.74	55.02	64.40
Delta	6.73	9.89	8.48	9.96
Rank	4	2	3	1

Level	CR	IP (bar)	%Bio-Diesel	Load (kg)
1	34.75	36.15	36.00	34.62
2	34.98	34.65	34.77	34.71
3	35.78	34.71	34.74	36.18
Delta	1.02	1.50	1.26	1.56
Rank	4	2	3	1

Table 8 shows that maximum value of delta for load is 9.96 and minimum value of delta for CR is 6.73. Load is most affected on performance and CR is less affected on performance. Also, table shows that maximum value of delta for load is 1.56 and minimum value of delta for CR is 1.02. Load is most affected on performance and CR is less affected on performance.

Table 9. Optimum set of parameters for Peak Pressure

CR	IP (bar)	%Bio-Diesel	Load (kg)	Predicted value
16	160	100D0B	12	80.5567

Table 9 shows that optimum set of parameters for peak pressure is obtained with taking blend ratio 100% diesel and 0% biodiesel(WPO), with injection pressure low (160 bar), compression ratio 18 and load on 12kg will give predicted value 80.5567. Peak pressure is high using above parameters and give better result.

Figure 7 shows Pressure v/s Crank angle diagram.

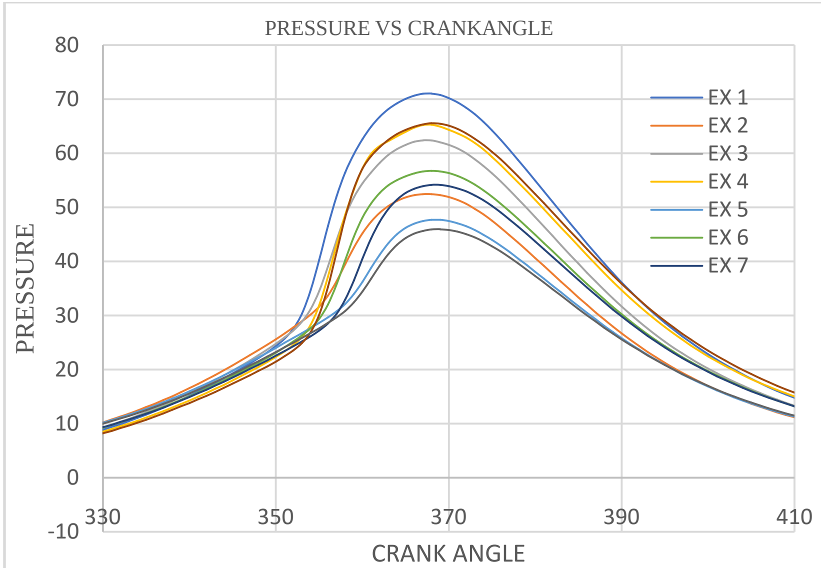

Figure 7.Pressure v/s Crank angle diagram

VI. CONCLUSIONS

- The optimal operation factors of high brake thermal efficiency and low SFC have been obtained for a diesel engine with diesel and biodiesel blends usingwith Taguchi's method. The Optimization performance of different parameters have also been compared with optimized engine and diesel engine.
- The Taguchi method was a good method to find out the optimumcombinations. The predictions using Taguchi's parameter designtechnique is in adequate agreement with the confirmationresults, with a confidence interval of 90%, and this technique saves75% of the time taken to perform the experiment in this research.
- From result and discussions, the optimum sets for different values of SFC,Brake Thermal Efficiency and peak pressure of engine is measured for differentparameters as three compression ratios (16,17,18),three blend ratios (100D0B, 50D50B, 0D100B), three injection pressures Low (160 bar),Medium (180 bar), High (200 bar) at three different loads as 2 kg, 7kg and 12 kg.
- The optimum set achieved from experiment for SFC iswith 16 compression ratio, 100D0B blend, low injection pressure (160 bar) at 12 kg of load.
- The optimum set achieved from experiment for Brake Thermal Efficiency is with16 compression ratios, 100D0B blend, low injection pressure (160 bar) at 12 kg of load.

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