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TO Performance Parameter Optimization for CI Engine Fueled with LDPE-PO and Diesel.

Vedansh R Thakur[1], Krunal B Patel[2], Tushar M Patel[3], Maulik A Modi[4]
[1](ME Scholar, Department of Mechanical Engineering, LDRP-ITR, Gandhinagar, India)
[2](Lecturer, Department of Mechanical Engineering, LDRP-ITR, Gandhinagar, India)
[3](Professor, Department of Mechanical Engineering, LDRP-ITR, Gandhinagar, India)
[4](Lecturer, Department of Mechanical Engineering, LDRP-ITR, Gandhinagar, India)

Abstract:
A study is carried out that use of fossil fuels is increasing which directly results into increasing pollution, so to decrease the use of fossil fuels, alternative fuel is the better option. LDPE pyrolysis oil can be used as an alternative fuel as the properties of LDPE and diesel are very close. LDPE oil is obtained from pyrolysis process. In this study the parameters that is % biodiesel, compression ratio, injection pressure and load are considered the variable for optimization. As these four parameters in the experiment needs optimization simultaneously, we have used Taguchi's method of optimization in this experiment. The result obtained from Taguchi experiment shows that 100% - % biodiesel, 17- CR, 220- IP, 100- load are optimum set of parameters for getting highest break thermal heat efficiency, lower specific fuel consumption and lower fuel consumption. Load has maximum effect on BTHE and % biodiesel has minimum effect on BTHE, Load has maximum effect on SFC and % Biodiesel has minimum effect on SFC and load has maximum effect on FC and IP has minimum effect on FC. Experiment was performed and it shows that BTHE found by experiment is closer to the predicted value.

***Key Word**: LDPE pyrolysis oil, Alternative fuel, Taguchi method, BTHE, SFC, FC.*

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I. Introduction

Increases in the cost of petrol and diesel in today's world is the biggest problem and aside the consumption of fossil fuel results directly affects the cost. Use of alternative fuel is the best solution as a approach. There are several processes for biodiesel production such as pyrolysis, transesterification, emulsification etc. Biodiesel production sources used are ecofriendly and emit less emission. Many cooking oil such as (palm, soybean, groundnut), non-cooking oils (Jatropha, neem, Karanja), plastic waste etc. can be converted. There are many optimization techniques that are used for studying engine such as Taguchi's method, RSM method, nonlinear regression method etc. Taguchi method is the best method for engine study as it gives the best outcome. Taguchi method develops orthogonal arrays from theory of DOE to examine a greater number of variables with less number of trials. Number of input parameters were given by Taguchi method which increase BTHE, decreases the Specific Fuel Consumption (SFC) and Fuel Consumption (FC). Effects of % biodiesel, load, CR, IP are considered on brake thermal heat efficiency. In this paper LDPE pyrolysis oil is used as an alternative fuel to obtain the best optimum value for BTHE, SFC and FC.

Wahoo et al. (2012) studied about diesel engine optimization control methods for reduction of exhaust emission and fuel consumption. The research was focused on the minimization of nitrogen oxides (NO_X) emission and soot emission as well as improving BSFC and power in diesel engine. The study gave conclusion that PSO (Particle Swarm Optimization) is an effective method for engine optimization problem [1].**Devaraj et al. (2015)** studied about performance, emission and combustion characteristics of waste plastic pyrolysis oil blended with diethyl ether used as a fuel for diesel engine. The objective of the research was to investigate the relevance of the diesel-DEE to use as fuel in diesel engine. The study gave conclusion that addition of oxygenates had improved the combustion process and reduced the emissions. The blending of DEE with plastic oil increases the cetane rating which is superior to diesel. The CO emissions are lower in the case of DEE blends than that of WPPO. HC emissions were found to increase with the addition of DEE to WPPO. Reduced peak pressure and heat release rate by increasing the percentage of DEE blended with WPPO [2]. **Nilesh Kumar et al. (2015)** studied about effect of blend ratio on plastic pyrolysis oil and diesel fuel on performance of single cylinder CI engine. PPO10, PPO20, PPO30 and PPO50 blends were used as fuel. They concluded that with increase in blend proportion efficiency increases and fuel consumption decreases. At the same time exhaust emissions increases after 30% blend proportion of PPO. Considering performance and exhaust emissions, PPO30 has optimum values compared to other PPO blends [3]. **Sharfuddin et al. (2016)** reviewed on pyrolysis of plastic waste. The study gave conclusion based on the studies on literatures, pyrolysis process was chosen by most researchers because of its potential to convert the most energy from plastic waste valuable to liquid oil, gaseous and char. Therefore, it is the best alternative for plastic waste conversion and also economical in terms of operation [4]. **Kalargaris et al. (2016)** studied about combustion, performance and emission analysis of a DI diesel engine using PPO (Plastic Pyrolysis Oil). The blending ratio with diesel was varied from 25% to 100%. The study gave conclusion that the engine was able to operated steadily on PPO 100 at loads higher than 75%. PPO 90 at loads higher than 50% and on lower PPO blends for all loads. PPO blends have longer ignition delay, higher cylinder peak pressure and higher heat release rate due to lower cetane number. The engine thermal efficiency decreased by 3-4% when PPO blends were used. All emissions increased with higher PPO blending ratio [5]. **Singh et al. (2020)** studied waste plastic to pyrolytic oil and its utilization in CI engine: Performance analysis and combustion characteristics. The study gave conclusion that the higher presence of PPO increases the BTE and reduces the SFC with an increase in load. The presence of crude PPO in diesel blends up to 50% decreases the volume efficiency with increase in the exhaust temperature. The utilization of crude PPO with diesel in different blend ratios shows an increase in exhaust emission [6].

- Suggestions from Literature Review: **-**
    1. Waste Plastic Pyrolysis is the best alternative for plastic waste conversion and also economical in terms.
    2. Has better performance characteristics but the exhaust parameters show scale up.

- Literature review objectives of this research paper: **-**
    1. To reduce the exhaust emissions.
    2. To get the best optimum parameters for performance and exhaust characteristics.

II. Material and Methods

- Low-density polyethylene (LDPE) is a thermoplastic made from the monomer ethylene. It is a semi-rigid and translucent polymer. LDPE is a soft, flexible, lightweight plastic material.
- LDPE is noted for its low temperature flexibility, toughness, and corrosion resistance. It is not suited for applications where stiffness, high temperature resistance and structural strength are required. It is often used for orthotics and prosthetics.
- LDPE has good chemical and impact resistance and is easy to fabricate and form **[7].**
- Pyrolysis or thermal cracking of plastics, is one of the efficient ways to recover plastic waste.
- Pyrolysis refers to a thermal degradation of long-chain organic molecules into smaller hydrocarbons [8].

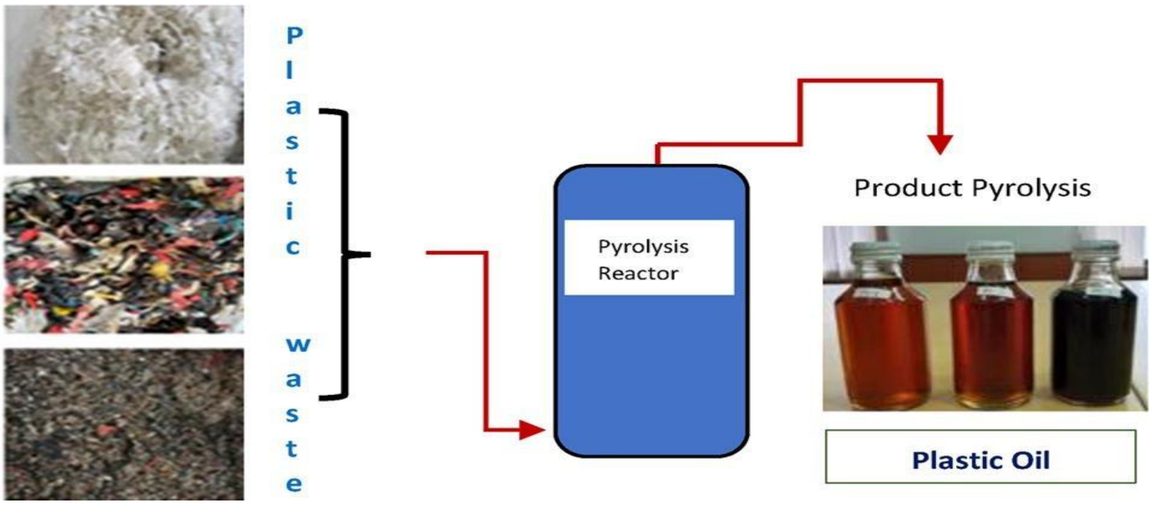


Figure 1: Pyrolysis of plastic waste

III. Methodology

There is a demand of high efficiency in engine which is the biggest problem and with that high BTHE, low specific fuel consumption and fuel consumption. There are several methods/techniques to solve this problem. Some of the methods used for studying engine are Taguchi's method, RSM method, non- linear regression method etc. Taguchi's mother is a collection of mathematical and statistical techniques used for parametric optimization and analysis of problems which examine a greater number of variables with less number of trials.

Steps for Experiments: -

1. Arrange the basic engine setup.
2. Then define the goal that is the performance parameter and exhaust parameters.
3. Now define all the signal factors and level for each factor.
4. Then create an orthogonal array and define custom that which is design. Determine optimum parameter set.
5. No predict the performance unconfirmed analysis if not satisfied with the result, then select new set of optimum parameters.

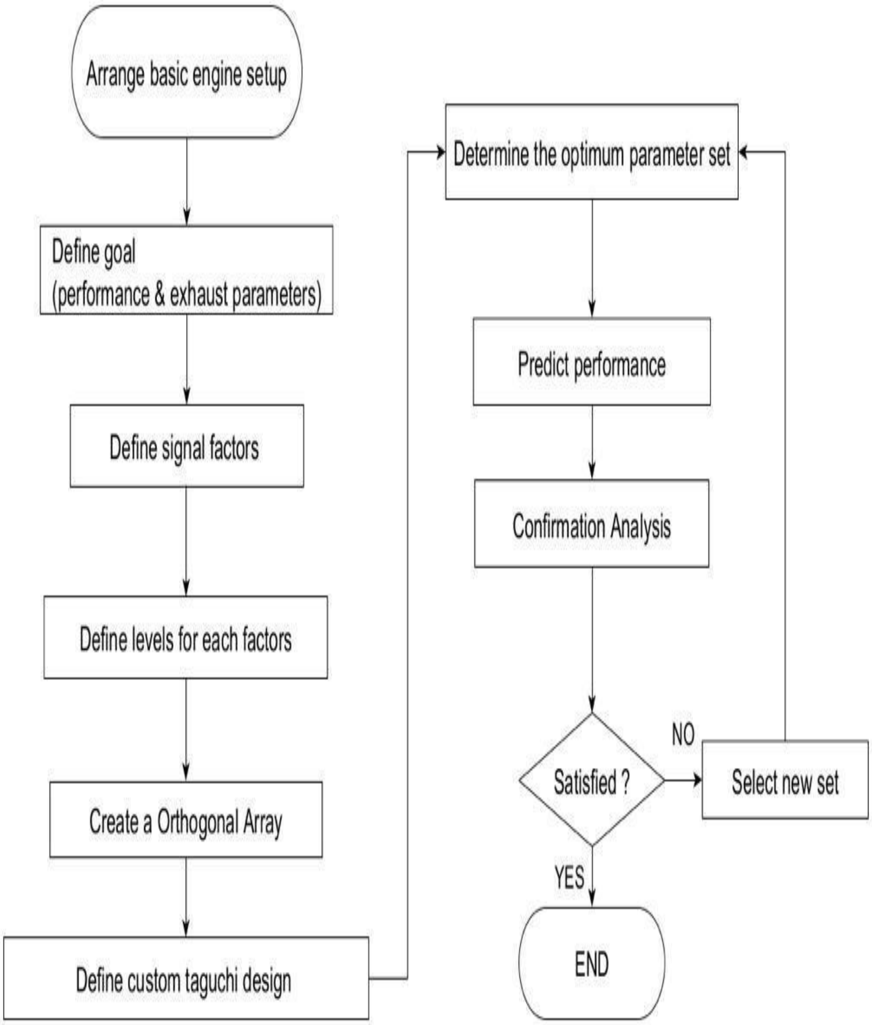


Fig 2: Flow Chart of Experiment

IV. Selection Of Parameters and Levels

Experiments are done with Taguchi's orthogonal array for % biodiesel, CR, IP and load. It has 32 rows and number of tests with 4 columns at 3 level and 4 parameters.

Selected factors and their levels are shown below.

The SN ratio are considered for this selection optimum set of parameters. There are mainly 3 categories such as (1) lower the better, (2) higher the better, (3) nominal the better. The category higher the better is used to calculate S N ratio for BTHE and the category lower is better is used to calculate SN ratio for SFC and FC. Taguchi method is being applied.

Table no 1: Selection of parameters and levels.

PARAMETERS	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
% Biodiesel	0	100	-	-
CR	15	16	17	18
IP	180	200	220	240
Load (%)	0	33	66	100
FUEL	CV (kj/kg)	Density (kg/m^3)		
Diesel	41990	830		
LDPE	44058	765		

V. Experimental Setup

The set up consists of single cylinder, four stroke, water cooled computerized research engine in which loading has been provided by eddy current dynamometer. Set up is equipped with instruments for measurement of combustion pressure, Diesel line pressure and crank-angle. Pressure crank-angle diagrams were obtained by signals interfaced with computer for. Various instruments for airflow, fuel flow, temperatures and load measurements are also provided.

The set-up consisting of air box, two fuel tanks for dual fuel test, transmitters for air and fuel flow measurements, fuel measuring unit, manometer, process indicator and hardware interface. Rota meter is used for calorimeter water and cooling water flow measurement. A battery, starter and battery charger have been provided for engine electric start arrangement. Various sensors and instruments are integrated with data acquisition system for online measurement of load, air and fuel flow and different temperatures.

The setup enables the evaluation of thermal performance and emission constituents of an engine. Thermal performance parameters include brake power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio, heat balance etc. The constituents of the exhaust gas like CO, HC and NO_x are measured with exhaust gas analyzer. Lab view-based Engine Performance Analysis software package “Engine soft” has been provided for on line performance evaluation.

Table no. 2: - Engine Technical Specifications

Make	Kirloskar Oil Engines
Type	Four stroke, Water cooled, Diesel
No. of cylinder	One
Bore	87.5 mm
Stroke	110 mm
Combustion principle	Compression ignition
Cubic capacity	0.661 liters
Compression ratio 3 port	18:01
Peak pressure	77.5 kg/cm2
Direction of rotation	Clockwise (Looking from flywheel end)
Fuel timing for std. engine	0 to 25 BTDC
Power	3.5 kW @ 1500 rpm
Inlet opens BTDC	4.5
Inlet closes ABDC	35.5
Exhaust opens BBDC	35.5
Exhaust closes ATDC	4.5
Lub. Oil pump delivery	6.50 lit/min.
Break Mean Effective	6.35 kg/cm2
Connecting rod length	234 mm

Figure 3: Front View of Experimental Setup

VI. Results and Discussion

The results of BTHE, SFC and FC are analyzed using Minitab 18. Minitab offers four types of designed experiments: factorial, response surface, mixture, and Taguchi (robust). The steps follow in Minitab to create, analyses, and graph an experimental design are similar for all design types. After conducting the analysis and entering the results, Minitab provides several analytical and graphing tools to help understand the results. The S/N ratio for optimal BTHE are coming under "Higher-is-Better" characteristic, and the S/N ratio for optimal SFC and FC are coming under "Lower-is-Better" characteristics which can be calculated as logarithmic transformation of the loss function. In the experiment, four parameters are considered like as % Biodiesel, CR, Injection pressure, Load. Main Effects Plot for Mean data and S/N ratio data are shown that shows optimal results of BTHE, SFC and FC.

- **Analysis Result for BTHE (%)**

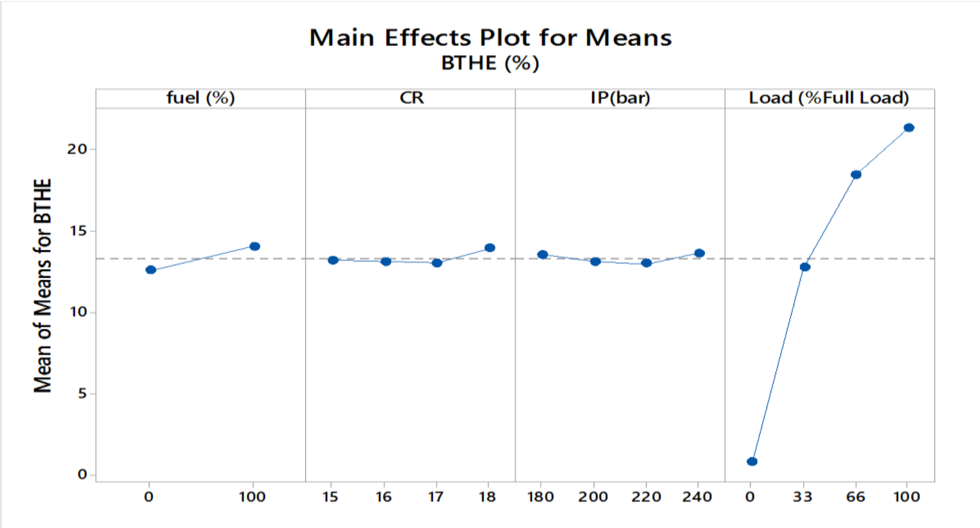


Fig 4: Main Effects Plot for Means Data Means BTHE (%)

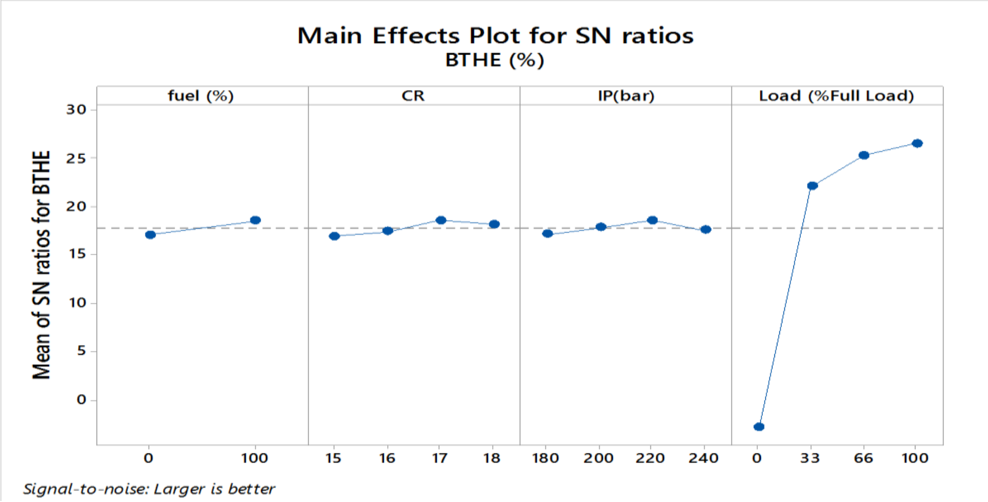


Fig 5: Main Effect for SN Ratios BTHE (%)

Table no. 3: Response Table for Signal to Noise Ratios BTHE (%) (Larger is better)

Level	% Biodiesel (%)	CR	IP (bar)	Load (%Full Load)
1	17.055	16.93	17.109	-2.915
2	18.467	17.38	17.781	22.082
3		18.57	18.593	25.329
4		18.16	17.562	26.548
Delta	1.412	1.638	1.484	29.463
Rank	4	2	3	1

Table no. 4: Predicted Values for S/N Ratio plot BTHE (%)

OPTIMUM SET OF PARAMETERS					
% Biodiesel	CR	IP	LOAD	S/N ratio	Predicted Value
100	17	220	100	28.8969	21.4741

Table no. 5: Validation Experiment Results and Error BTHE (%)

Basis	Fuel (%)	CR	IP (bar)	Load (% full Load)	Predicated BTHE (%)	Experimental BTHE (%)	Error
S/N ratio	100	17	220	100	21.4741	20.81	1.94%

- Validation experimental results are very closer to predicted results. The errors are less than 2.71%.
- As means of means plots are showing combined effects of signal (selected parameters) and noise (unselected parameters), while S/N ratio plot gives effect of signal (selected parameters) only. So, S/N Ratio plot is considered for selection of optimum set of parameters.
- Hence the optimum (maximum) BTHE (%) is achieved when fuel =100%, CR =17, IP (bar)=220, load =200 (%). It is also called optimum set of parameters. The predicted value of BTHE (%) with optimum set of parameters is 20.81.

- **Analysis Result for SFC (kg/kWh)**

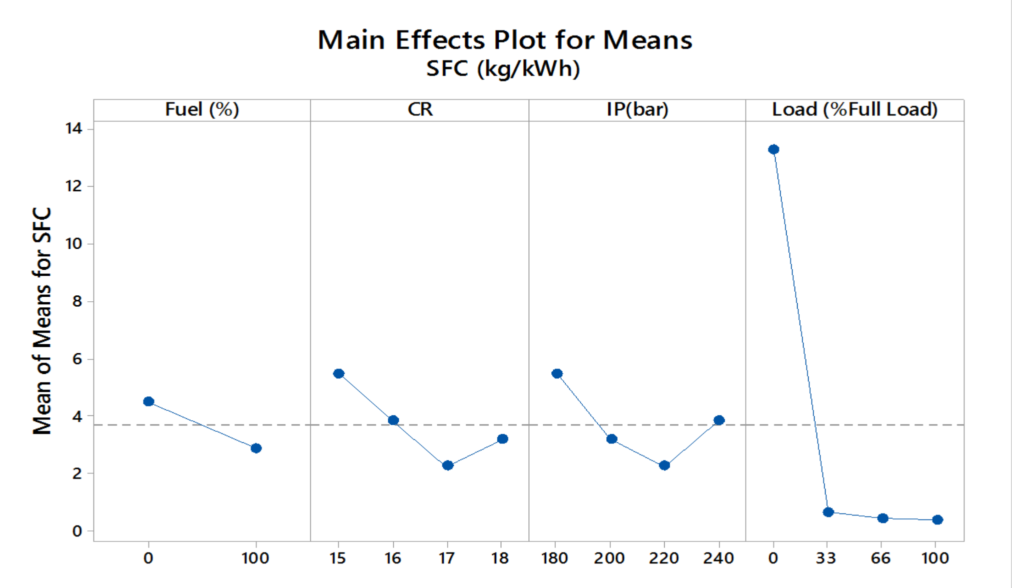
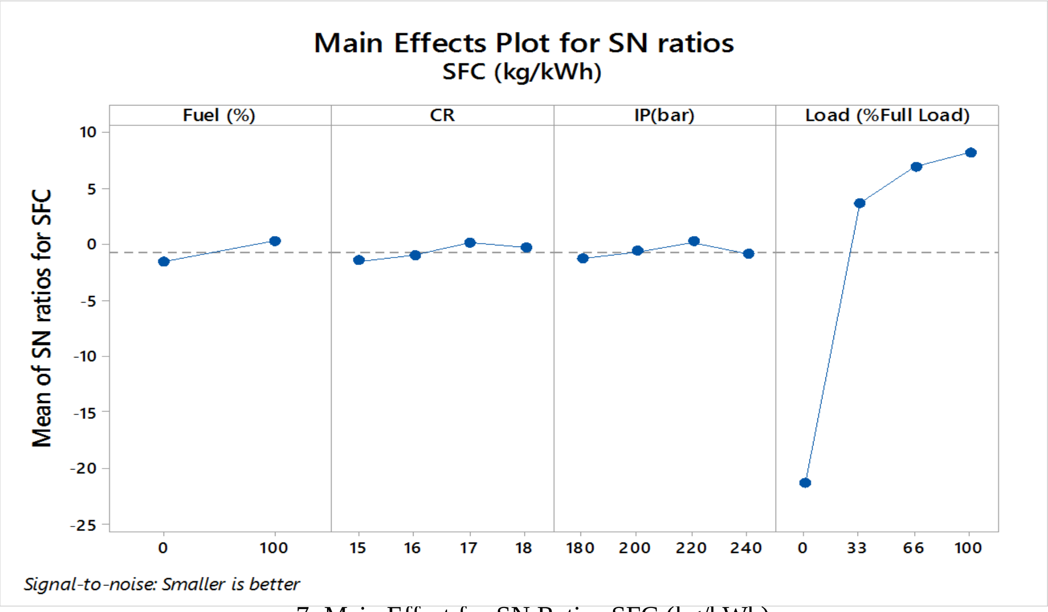


Fig 6: Main Effects Plot for Means Data Means SFC (kg/kWh)



ig 7: Main Effect for SN Ratios SFC (kg/kWh)

Level	Fuel (%)	CR	IP (bar)	Load (%Full Load)
1	-1.6084	-1.521	-1.346	-21.3697
2	0.2216	-1.071	-0.674	3.6275
3		0.1172	0.1385	6.8747
4		-0.299	-0.893	8.094
Delta	1.83	1.6382	1.4844	29.4636
Rank	2	3	4	1

Table no. 6: Response Table for Signal to Noise Ratios SFC (kg/kWh) (Smaller is better)

Table no. 7: Predicted Values for S/N Ratio plot SFC (kg/kWh)

OPTIMUM SET OF PARAMETERS					
% Biodiesel	CR	IP	LOAD	S/N ratio	Predicted Value
100	17	220	100	10.6514	-3.2779

Table no. 8: Validation Experiment Results and Error SFC (kg/kWh)

Basis	Fuel (%)	CR	IP (bar)	Load (% full Load)	Predicated SFC (kg/kWh)	Experimental SFC (kg/kWh)	Error
S/N ratio	100	17	220	100	-3.2779	0.39	2.96%

- Validation experiments results are very closer to predicted results. The errors are less than 2.96%.
- As means of means plots are showing combine effects of signal (selected parameter) and noise (unselected parameters), while S/N ratio plot gives effects of signal (selected parameters) only. So, S/N ratio plot is considered for the selection of optimum set of parameters.
- Hence, the optimum (minimum) SFC (kg/kWh) is achieved when Fuel=100%, CR=17, IP (bar) =220, Load=100%. It is also called optimum set of parameters. The predicted value of SFC with optimum set of parameters is 0.39.

- **Analysis Result for FC (kg/hr)**

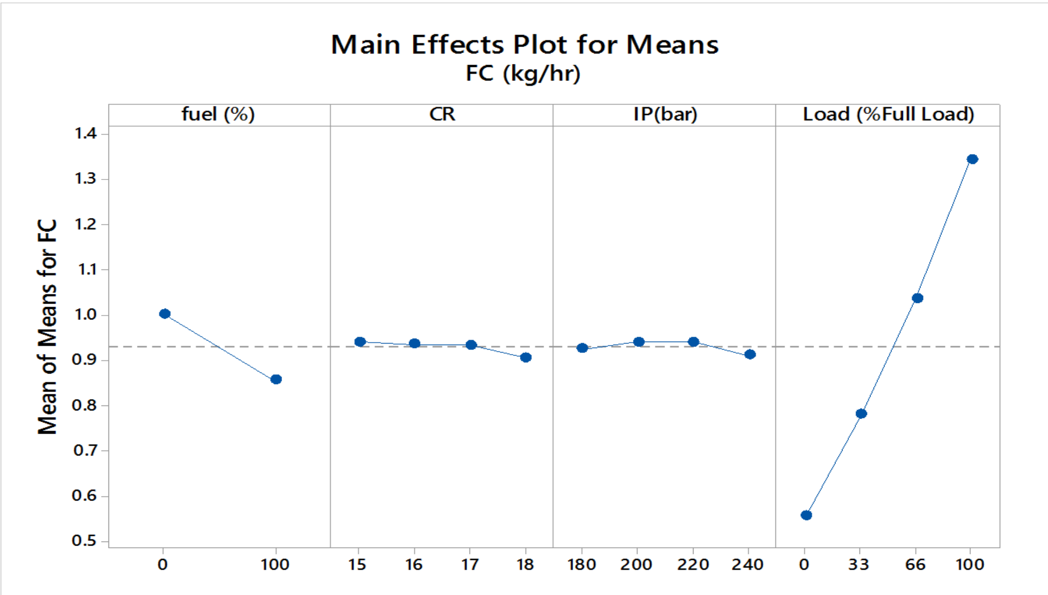


Fig 8: Main Effects Plot for Means Data Means FC (kg/hr)

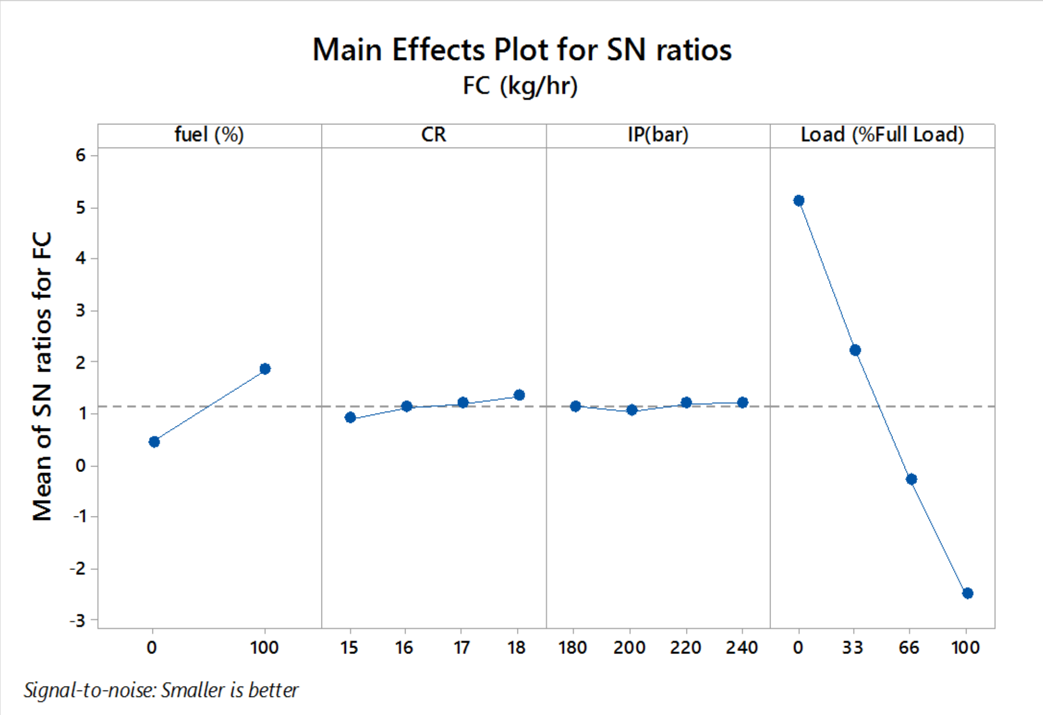


Fig 9: Main Effect for SN Ratios FC (kg/hr)

Table no. 9: Response Table for Signal to Noise Ratios FC (Kg/hr) (Smaller is better)

Level	% Biodiesel (%)	CR	IP (bar)	Load (%Full Load)
1	0.4382	0.905	1.1299	5.1259
2	1.8395	1.115	1.039	2.2169
3		1.196	1.1806	-0.2802
4		1.34	1.2059	-2.5073
Delta	1.4014	0.435	0.1668	7.6332
Rank	2	3	4	1

Table no. 10: Predicted Values for S/N Ratio plot FC (kg/hr)

OPTIMUM SET OF PARAMETERS					
% Biodiesel	CR	IP	LOAD	S/N ratio	Predicted Value
100	18	240	0	6.09465	0.44267

Table no. 11: Validation Experiment Results and Error FC (kg/hr)

Basis	Fuel (%)	CR	IP (bar)	Load (% full Load)	Predicated FC (kg/hr)	Experimental FC (kg/hr)	Error
S/N ratio	100	18	240	0	0.44267	0.69	1.25%

- Validation experiments results are very closer to predicted results. The errors are less than 1.25%.
- As means of means plots are showing combine effects of signal (selected parameter) and noise (unselected parameters), while S/N ratio plot gives effects of signal (selected parameters) only. So, S/N ratio plot is considered for the selection of optimum set of parameters.
- Hence, the optimum (minimum) FC (kg/hr) is achieved when Fuel=100%, CR=18, IP (bar) =240, Load=0%. It is also called optimum set of parameters. The predicted value of SFC with optimum set of parameters is 0.69.

VII. Conclusion

The best and efficient technique was founded by Taguchi Method for getting the effect of control parameters. Result discusses below,

- As means of means plots are showing combined effects of signal (selected parameters) and noise (unselected parameters), while S/N ratio plot gives effect of signal (selected parameters) only. So, S/N Ratio plot is considered for selection of optimum set of parameters.
- For BTHE, Validation experimental results are very closer to predicted results for BTHE. The errors are less than 1.94%.
- Hence the optimum (maximum) BTHE (%) is achieved when fuel =100%, CR =17, IP (bar)=220, load =200 (%). It is also called optimum set of parameters. The predicted value of BTHE (%) with optimum set of parameters is 20.81.
- For SFC, Validation experiments results are very closer to predicted results for SFC. The errors are less than 2.96%.
- Hence, the optimum (minimum) SFC (kg/kWh) is achieved when Fuel=100%, CR=17, IP (bar) =220, Load=100%. It is also called optimum set of parameters. The predicted value of SFC with optimum set of parameters is 0.39.
- For FC, Validation experiments results are very closer to predicted results for FC. The errors are less than 1.25%.
- Hence, the optimum (minimum) FC (kg/hr) is achieved when Fuel=100%, CR=18, IP (bar) =240, Load=0%. It is also called optimum set of parameters. The predicted value of SFC with optimum set of parameters is 0.69.

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