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

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Abstract:
All the plastic waste and municipal waste of plastics can be used to produce waste plastic oil (WPO) and it can be used as an alternative fuel because waste plastic oil and diesel have mostly similar carbon chain characteristics and physical properties. LDPE is considered among the most dumped waste plastic. The most favorable way to transform this waste plastic into LDPE Oil is by pyrolysis process. In this study certain parameters such as % biodiesel, compression ratio, Injection Pressure and load are considered as the variables for optimization. Hence continuous optimization is required for these four parameters we have used Taguchi's Method of optimization. The optimum set of parameters which are obtained from Taguchi's method shows that 100 - % Biodiesel, 18- CR, IP – 240, 33- Load which gives the lowest Carbon Mono-oxide (CO), 0 - % Biodiesel, 15-CR, 180 – IP, 0- Load which gives lowest $NO_{x\ and}$ 0- % Biodiesel, 18 – CR, 180 – IP and 0 – Load which gives HC. Load has maximum effect on CO and % Biodiesel has minimum effect; load has maximum effect on NO_x and % Biodiesel has minimum effect on NO_x and load has maximum effect on HC and IP has minimum effect on HC. From the experiment performed the experimental value and predicted value are very closer.
***Key Word**: **Waste** Plastic Oil, LDPE, Plastic, Pyrolysis, Taguchi Method, Carbon Mono-oxide, NO_X, HC*

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I. Introduction

Fossil Fuels are been conventionally used as the primary source for diesel fuel engines. The sectors which who use this kind of fossil fuel are transportation, agriculture etc. As the fossil fuels are at the verge of depletion so scientists and engineers have started working on the alternative fuel which are easily available, cheap and viable in practical use. An alternative fuel which gained the interest of scientist and engineers is waste plastic oil. These wastes are produced from municipal waste like garbage or dustbin that are very difficult to dispose. The quantity of plastic waste has also increased from last years. This plastic waste can be converted into the fuel by many processes that are pyrolysis, gasification, catalytic cracking etc.

The best way for the conversion is pyrolysis process as it can produce small molecules of plastic waste and it also produces very less emissions during the conversion. One of the products from waste plastic or pyrolysis contains 70% carbon chain similar to diesel fuel. We in this experiment are using LDPE oil as an alternative fuel The optimization techniques that are used to study engine are Taguchi's method, RSM method, Nonlinear regression method etc. the best outcome is derived from Taguchi's method as it develops orthogonal arrays to examine large variables with less trials. Some parameters such as % Biodiesel, CR, IP, Load are considered on exhaust parameters such as Carbon Mono-oxide, NO_x, HC. In this paper LDPE pyrolysis oil is used as an alternative fuel to obtain the best optimum value.

Singh et al. (2021) studied about performance and ecological parameters of a diesel engine fueled with diesel and plastic pyrolyzed oil (PPO) at variable working parameters. The objective of the study was to convert LDPE to oil by pyrolysis with the aid of catalyst and use it in a CI engine to evaluate the performance and ecological parameters. Fuel used was D80PO20. The study gave conclusion that increasing engine speeds resulted in higher cylinder pressure and BTE **[1].Rajasekaran et al. (2020)** studied about collective influence of 1-decanol addition, injection pressure and EGR on diesel engine characteristics fueled with diesel/LDPE oil blends. Experiments were conducted to study the effect of substituting 10% volume of 1-decanol in place of waste LDPE oil in D70L30 blend. The study gave conclusion that 1-decanol blend injected at 600 bar pressure and low EGR rate of 10% gave the best possible performance and low emission **[2]. 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 **[3]**.**Vasava et al. (2018)** studied about combine effect of injection pressure and compression ratio on performance of single cylinder CI engine using diesel - WPO blend by Taguchi's design of experiment approach. They concluded that WPO blends represent a fairly good alternative fuel for diesel. They found that for Maximum brake thermal efficiency is compression ratio 18, blend ratio 0B100D, injection pressure L, engine load 12. For maximum mechanical efficiency is compression ratio 16, blend ratio 100B0D, injection pressure M, engine load 12. Engine performance is mostly influenced by engine load and is least influenced by Compression ratio **[4]**. **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 **[5]**.

Compilation et al. (2014) studied about the effect of diesel-waste plastic oil blends on engine performance characteristics. The objective of the research was to present results of the performance (torque, power, thermal efficiency and specific fuel consumption in a heavy-duty diesel engine when fuelled with diesel-waste plastic pyrolysis oil (WPO) blends in full load condition. Three mixing ratios WPO25, WPO50 and WPO75 were used as fuel at a wide range of engine speeds and the results were compared to those of diesel (WPO0). They concluded that the increase of mixing ratio to WPO 75% greatly decreases engine output torque and power approximately by 23.79%. Consequently, thermal efficiency can be reduced by 5.97%, while specific fuel consumption can be increased by 31.22% **[6]**.

Kalargaris et al. (2017) studied about investigation on the long-term effects of plastic pyrolysis oil usage in a diesel engine. A blend of 75% PPO and 25% diesel was utilized. The study gave conclusion that PPO 75 is not suitable alternative fuel for diesel engine. During the last operational hours, the engine performance deteriorated dramatically, resulting in increased knock and exhaust emissions **[7]**. **Rinaldi et al. (2016)** studied about performance, emission and combustion characteristics of an IDI (Indirect Fuel Injection Diesel engine) engine. The study gave conclusion that the BSFC (Brake specific fuel consumption) is always lower for WPO (Waste Plastic Oil) and the efficiency of WPO is always higher despite of the load **[8]**.

- 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 **[9].**
- Conventional or high-pressure low-density polyethylene is generally the softest and least crystalline of the polyethylene's. LDPE is widely used in applications requiring clarity, inertness, processing ease, seal ability, moisture barriers, and good electrical properties.
- It is not reactive at room temperatures, except by strong oxidizing agents, and some solvents cause swelling. It can withstand temperatures of 80 °C continuously and 95 °C for a short time
- 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 [10].
- Pyrolysis generally consists in heating the material above its decomposition temperature, breaking chemical bonds in its molecules. The fragments usually become smaller molecules, but may combine to produce residues with larger molecular mass, even amorphous covalent solids.

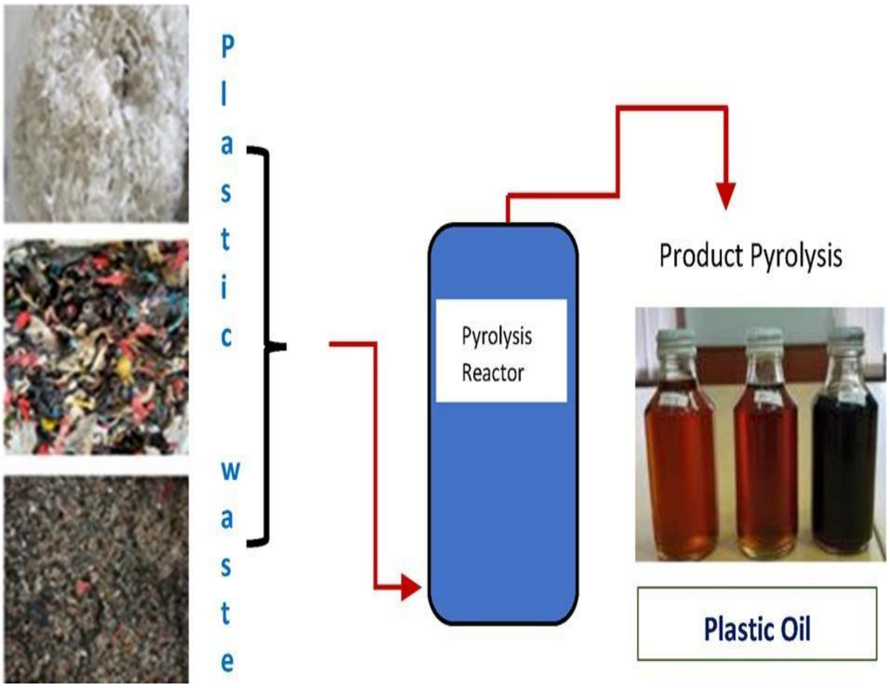

Figure 1: Pyrolysis of plastic waste

III. Methodology

There is a demand of high efficiency in engine which is the biggest problem and with that low CO, HC and NO_X emissions. 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 a smaller 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.
5. Determine optimum parameter set.
6. No predict the performance unconfirmed analysis if not satisfied with the result, then select new set of optimum parameters.

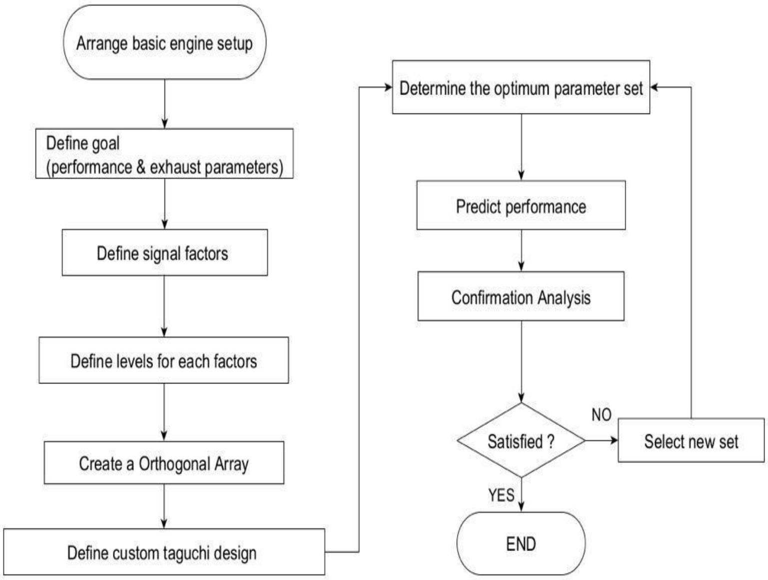

Fig 2: Flow Chart of Experiment

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 lower the better is used to calculate S N ratio for CO, HC and $NO_{X.}$. 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 strokes, 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 emission characteristic such as CO, HC and NO_x 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 emission coming under "Lower-is-Better" characteristic, 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 CO, HC and NO_x. From figure-3, mean is an average measure of reading taken for specific variables.

- **Analysis Result for CO (% vol)**

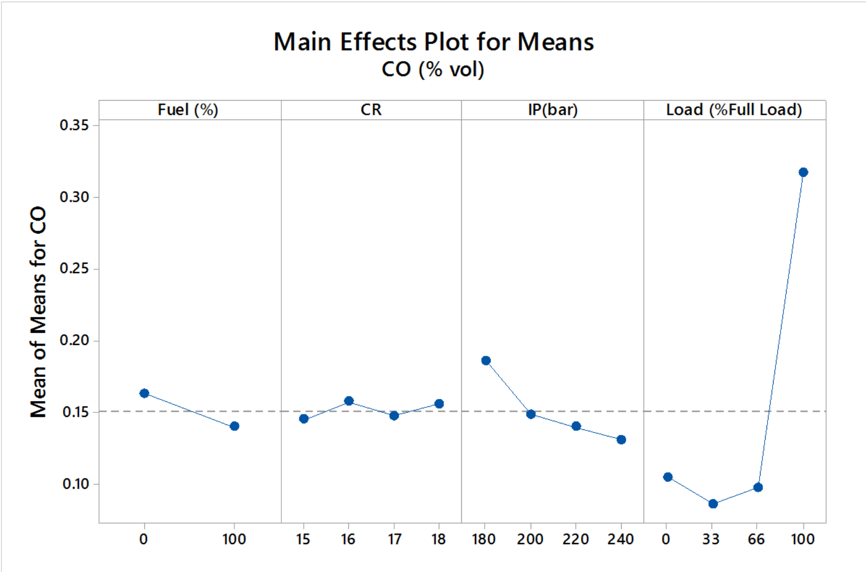

Fig 4: Main Effects Plot for Means Data Means CO (% vol)

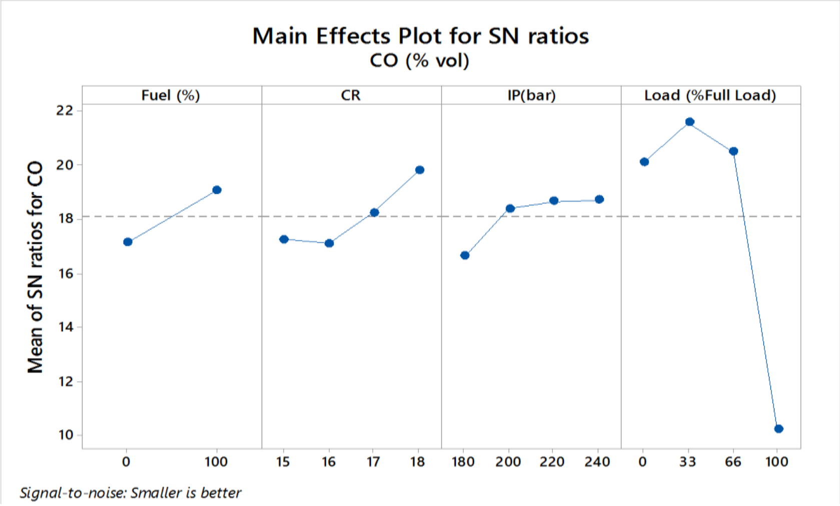

Fig 5: Main Effect for SN Ratios CO (% vol)

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

Level	% Biodiesel (%)	CR	IP (bar)	Load (%Full Load)
1	17.13	17.26	16.64	20.11
2	19.06	17.11	18.37	21.58
3		18.23	18.66	20.48
4		19.78	18.7	10.21
Delta	1.94	2.67	2.06	11.37
Rank	4	2	3	1

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

OPTIMUM SET OF PARAMETERS					
% Biodiesel	CR	IP	LOAD	S/N ratio	Predicted Value
100	18	240	33	24.8441	0.059063

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

Basis	Fuel (%)	CR	IP (bar)	Load (% full Load)	Predicated CO (% Vol)	Experimental CO (% Vol)	Error
S/N ratio	100	18	240	33	0.05906	0.05	0.10%

- Validation experiments results are very closer to predicted results. The errors are less than 0.64%.
- 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) CO (% Vol) is achieved when Fuel=100%, CR=18, IP (bar)=240, Load=33%. It is also called optimum set of parameters. The predicted value of CO (% Vol) with optimum set of parameters is 0.0590625.

- **Analysis Result for HC (ppm)**

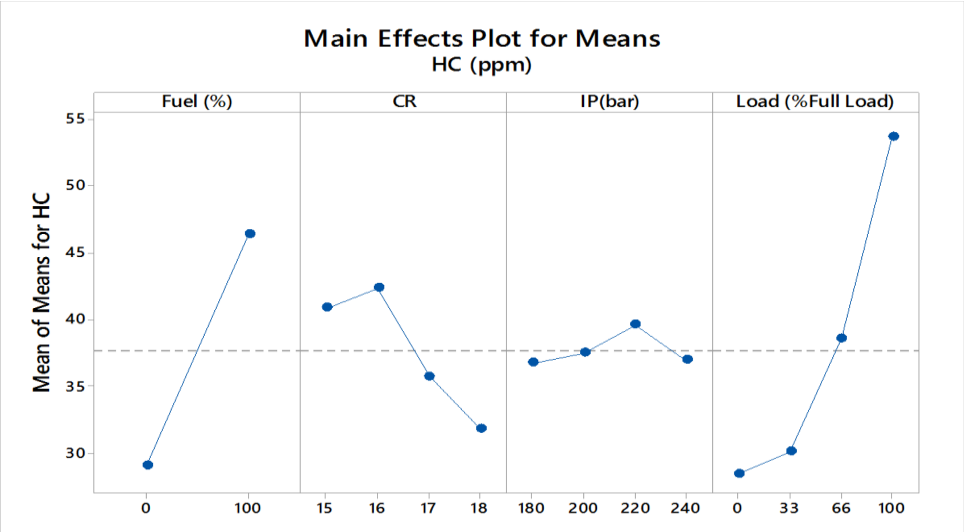

Fig 6: Main Effects Plot for Means Data Means HC (ppm)

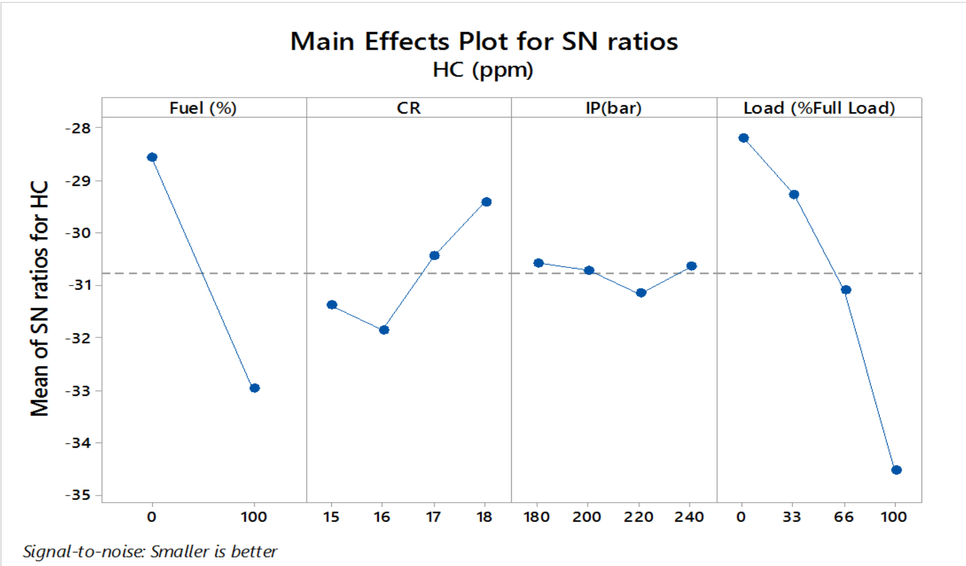

Fig 7: Main Effect for SN Ratios HC (ppm)

Table no. 6: Response Table for Signal to Noise Ratios HC (ppm) (Smaller is better)

Level	% Biodiesel (%)	CR	IP (bar)	Load (%Full Load)
1	-28.56	-31.4	-30.57	-28.18
2	-32.97	-31.9	-30.71	-29.26
3		-30.4	-31.15	-31.1
4		-29.4	-30.64	-34.53
Delta	4.42	2.44	0.58	6.35
Rank	2	3	4	1

Table no. 7: Predicted Values for S/N Ratio plot HC (ppm)

OPTIMUM SET OF PARAMETERS					
% Biodiesel	CR	IP	LOAD	S/N ratio	Predicted Value
0	18	180	0	-24.413	13.0313

Table no. 8: Validation Experiment Results and Error HC (ppm)

Basis	Fuel (%)	CR	IP (bar)	Load (% full Load)	Predicated HC (ppm)	Experimental HC (ppm)	Error
S/N ratio	0	18	180	0	13.0313	15	2.03%

- Validation experiments results are very closer to predicted results. The errors are less than 2.03%.
- 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) HC (ppm) is achieved when Fuel=0%, CR=18, IP (bar)=180, Load=0%. It is also called optimum set of parameters. The predicted value of HC (ppm) with optimum set of parameters is 15.

- **Analysis Result for NO_x (ppm)**

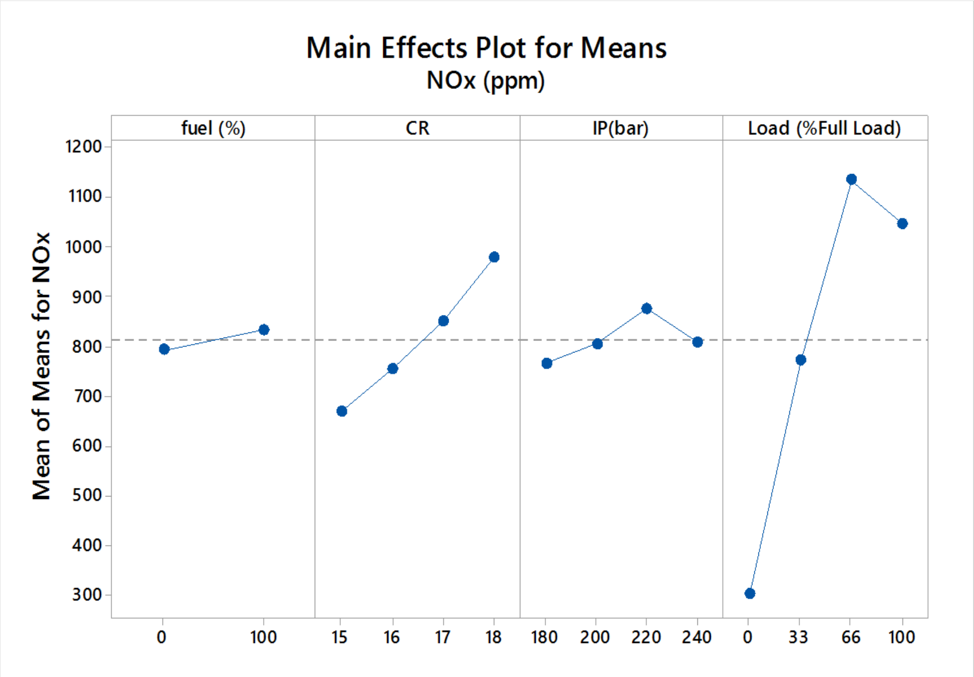

Fig 8: Main Effects Plot for Means Data Means NO_x (ppm)

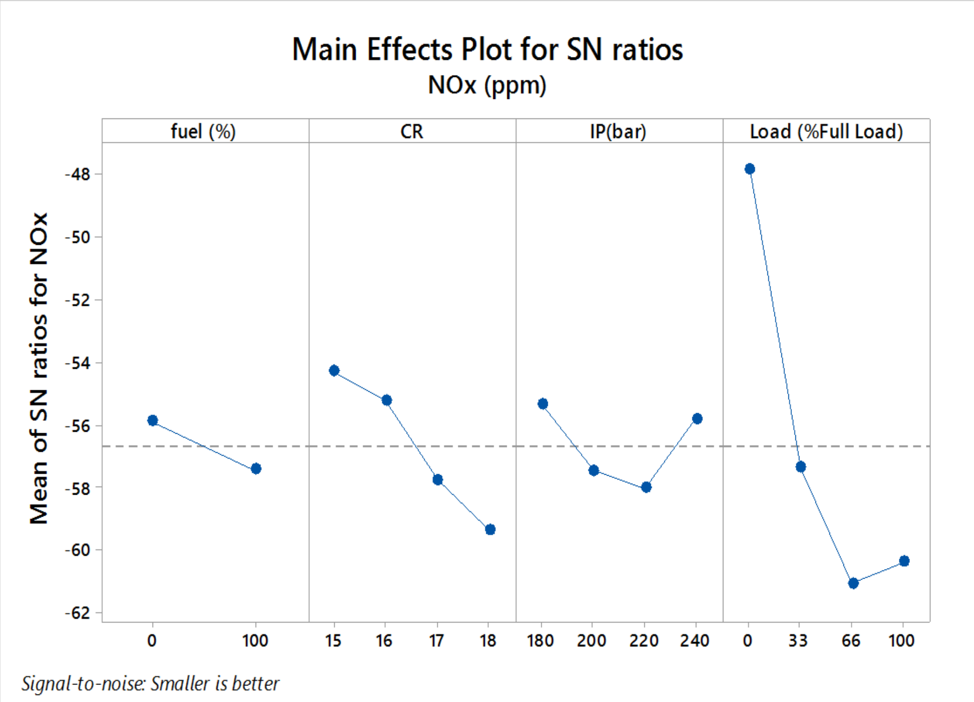

Fig 9: Main Effect for SN Ratios NO_x (ppm)

Table no. 9: Response Table for Signal to Noise Ratios NO_x (ppm) (Smaller is better)

Level	% Biodiesel (%)	CR	IP (bar)	Load (%Full Load)
1	-55.9	-54.3	-55.34	-47.8
2	-57.41	-55.2	-57.45	-57.35
3		-57.8	-58.02	-61.07
4		-59.4	-55.81	-60.39
Delta	1.51	5.08	2.67	13.27
Rank	4	2	3	1

Table no. 10: Predicted Values for S/N Ratio plot NO_x (ppm)

OPTIMUM SET OF PARAMETERS					
% Biodiesel	CR	IP	LOAD	S/N ratio	Predicted Value
0	15	180	0	-43.361	88.5625

Table no. 11: Validation Experiment Results and Error NO_x (ppm)

Basis	Fuel (%)	CR	IP (bar)	Load (% full Load)	Predicated NOx (ppm)	Experimental NOx (ppm)	Error
S/N ratio	0	15	180	0	88.5625	99	2.66%

- Validation experiments results are very closer to predicted results. The errors are less than 2.66%.
- 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) NOx (ppm) is achieved when Fuel=0%, CR=15, IP (bar)=180, Load=0%. It is also called optimum set of parameters. The predicted value of NOx (ppm) with optimum set of parameters is 99.

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 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.
- For CO, Validation experiments results are very closer to predicted results. The errors are less than 0.10%.
- Hence, the optimum (minimum) CO (% Vol) is achieved when Fuel=100%, CR=18, IP (bar)=240, Load=33%. It is also called optimum set of parameters. The predicted value of CO (% Vol) with optimum set of parameters is 0.05.
- For HC, Validation experiments results are very closer to predicted results. The errors are less than 2.03%.
- Hence, the optimum (minimum) HC (ppm) is achieved when Fuel=0%, CR=18, IP (bar)=180, Load=0%. It is also called optimum set of parameters. The predicted value of HC (ppm) with optimum set of parameters is 15.
- For NOx, Validation experiments results are very closer to predicted results. The errors are less than 2.66%.
- Hence, the optimum (minimum) NOx (ppm) is achieved when Fuel=0%, CR=15, IP (bar)=180, Load=0%. It is also called optimum set of parameters. The predicted value of NOx (ppm) with optimum set of parameters is 99.

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