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

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Abstract: *The most favorable way to transform this waste plastic into HDPE Pyrolysis oil is by pyrolysis process. The waste plastic can be used to produce waste 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. 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 0%- Biodiesel, 18- CR, IP – 200, 0- Load which gives the lowest Carbon Mono-oxide (CO), 100%- Biodiesel, 17-CR, 220– IP, 0- Load which gives lowest $NO_{x\ and}$ 0%- Biodiesel, 15 – CR, 180 – IP and 0 – Load which gives HC. From the experiment performed the experimental value and predicted value are very closer.*

Key Word*: HDPE Pyrolysis oil, Taguchi Method, Carbon Mono-oxide (CO), Nitrogen Oxide (NOx), Hydrocarbon (HC)*

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I. Introduction

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. Fossil Fuels are been conventionally used as the primary source for diesel fuel engines. This kind of fossil fuel is agriculture. The quantity of plastic waste has also increased from last years. This plastic waste can be converted into the fuel by catalytic cracking process. 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 HDPE Pyrolysis oil as an alternative fuel The optimization techniques that are used to study engine are Taguchi's method, RSM method.. 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 HDPE pyrolysis oil is used as an alternative fuel to obtain the best optimum value for CO, HC, NOx.

Nileshkumar 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 [1].**Kaimal et al (2016)** studied about combustion characteristics of DI diesel engine using waste plastic oil and its blends. Fuel used were PO(25),PO(50) and PO(75) blends. The study gave conclusion that among all blends PO(25) showed better emission characteristics and thermal efficiency with lower BSEC(brake specific energy consumption. With a slight improvement in the fuel quality, PO(25) can be considered as an effective replacement for diesel in CI engines without any alterations **[**2].**Sharuddin 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 [3].**Senthilkumar et al (2016)** studied about effect of jatropha methyl ester on waste plastic oil fueled DI diesel engine. The study gave conclusion that BTE of JME-WPO blends at full load conditions was higher as compared to waste plastic oils. BSFC increases with increase in JME blend ratio and decreases with an increase in engine load. CO & HC emissions decreased with increase in percentage of JME in WPO blends. NOx emission was slightly increased with increase in percentage of JME in WPO blends [4]. **Rinaldini et al (2016)**

studied about performance, emission and combustion characteristics of a 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 [5].**Kaimal et al (2017)** studied investigation of the combustion characteristics of a DI diesel engine fueled with PO(plastic oil) and RME(rice bran methyl ester). The study gave conclusion that the engine can be operated using 100% PO and RME. Thermal efficiency can be increased by advancing the injection timing. BSEC of WPO is less compared to diesel and RME. In cylinder pressure and peak pressure when using WPO and RME are higher than diesel. The peak heat release rate is also high for WPO and RME when compared to diesel **[**6**].Kalargaris et al (2017)** had studied about utilization of oils produced from plastic waste at different pyrolysis temperatures in a DI diesel engine. PPO 700, PPO 900, PPO 700 75, PPO 900 75 were used. The study gave conclusion that engine was able to operate stably at 75%, 85% & 100% load. PPO 900 had a significantly longer ignition delay period, higher peak heat release rate and shorter combustion period compared to PPO 700. Brake thermal efficiency was 3%-4% lower for PPO 900 and 2%-3% lower for PPO 700 in comparison to diesel. PPO 900 produced highest emissions, followed by PPO 700 and diesel [7]. **Pal et al (2019)** studied about effect of injection timing on performance and emission characteristics of single cylinder diesel engine running on blends of diesel and waste plastic fuels. The study gave conclusion that advancing the fuel injection timing is viable to solve the problem of lower thermal efficiency and higher carbon based emissions. Retarded fuel injection timing resulted in lower efficiency and higher emissions. The engine operation was smooth until certain percentage of plastic fuel blending with diesel i.e. 30% beyond which the operation was not smooth **(Pal, Chintala, Sharma, Ghodke, Kumar, Kumar) [**8].**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 blend 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 [9].**Kurniawati et al (2021)** studied about an experimental analysis of diesel fuel produced from HDPE (High density polyethylene) waste using thermal and catalytic pyrolysis with passive heat pipe cooling system. The study gave conclusion that despite higher cetane number of the catalytic pyrolysis oil, it has very low kinematic viscosity. Thus, the catalytic pyrolysis oil cannot be used directly but can be mixed with diesel to increase its cetane number and improve its performance in the combustion chamber [10].

- Suggestions from Literature Review :

1. Has better performance characteristics but the exhaust parameters show scale up.

- Literature review objectives of this research paper :

1. To compare the emission and performance of HDPE Pyrolysis oil to diesel fuel.
2. To reduce the exhaust emission.

II. Material and Methods

- HDPE Pyrolysis oil includes good low temperature impact resistance.
- HDPE Pyrolysis oil is Highly Flammable, not Biodegradable, High Thermal Expansion.
- Pyrolysis refers to a thermal degradation of long-chain organic molecules into smaller hydrocarbons.
- Pyrolysis is the heating of an organic material, such as biomass, in the absence of oxygen.
- Pyrolysis is commonly used to convert organic materials into a solid residue containing ash and carbon, small quantities of liquid and gases.

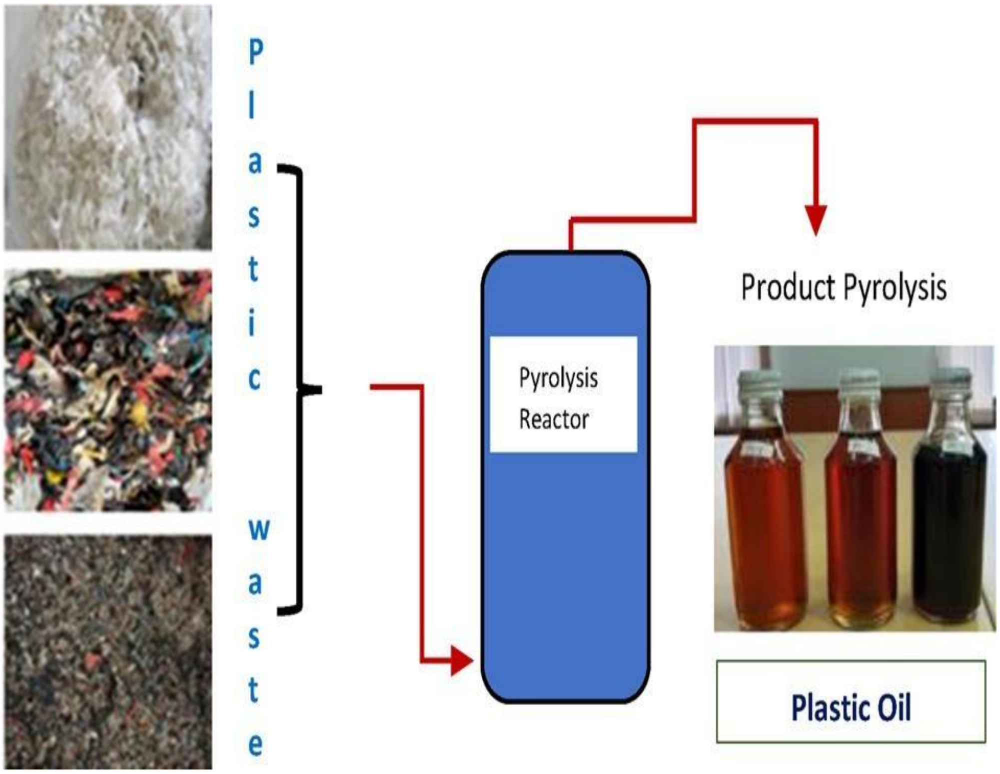

Figure 1: Pyrolysis of plastic waste

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. 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 :

- Check feasibility of HDPE Pyrolysis oil as a substitute fuel for Diesel Engines.
- A test rig with a single cylinder, 4-strock CI engine used which contains the engine setup and various measuring equipment.
- Waste HDPE Pyrolysis oil was converted to HDPE Pyrolysis oil through pyrolysis process.
- Take the readings i.e. for performance and emission, using diesel and HDPE Pyrolysis oil blends at different selected parameter.
- Compare and analyse the results and find the optimum fuel or blend.
- Parameters that are taken for optimization are :
    a) Compression ratio
    b) Engine load
    c) Injection pressure

The steps involved in experimental methodology are given in below Figure 2;

Arrange basic Engine setup

Decide levels of various parameters to be analyzed

Provide complete electronic control system with data acquisition

Experiments are to be performed in normal condition mode

Performance, emissions and combustion characteristics measured for diesel with different load and varying injection pressure Performance: BTHE, SFC, BP, & Emissions: CO_2, CO, NO_x, HC

Same set of experiments are repeated for blend of diesel

All data to be tabulated and analysed for comparing results

Figure 2 : Experimental Methodology

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

Table no 2 : Diesel & HDPE CV and Density Value

FUEL	CV (kj/kg)	Density (kg/m^3)
Diesel	41990	830
HDPE	40644	790

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.

Figure 3: Front View of Experimental Setup

Table no. 3 : 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

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 HC (ppm)**

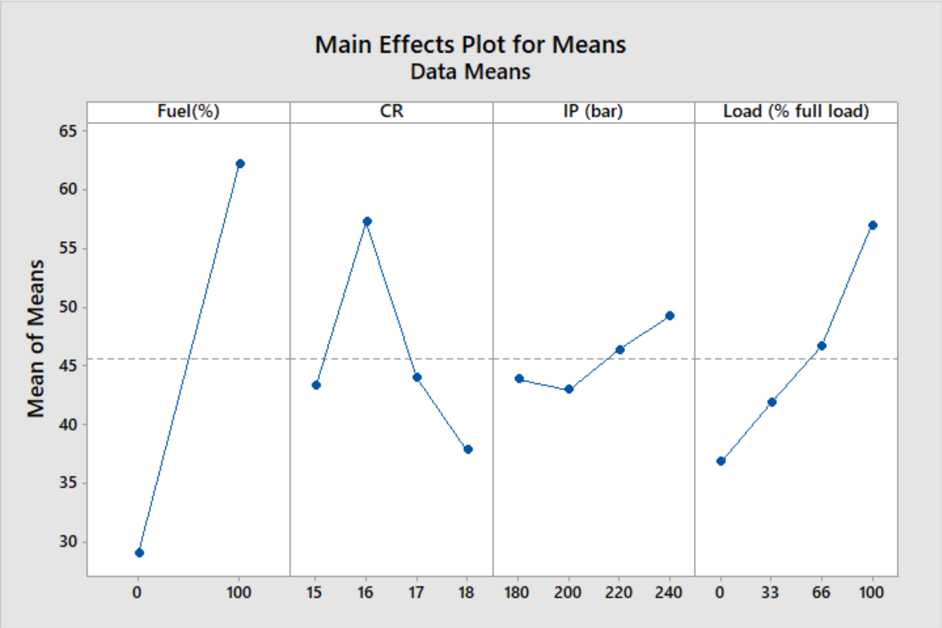

Figure 4: Main Effects Plot for Means data Means HC (ppm)

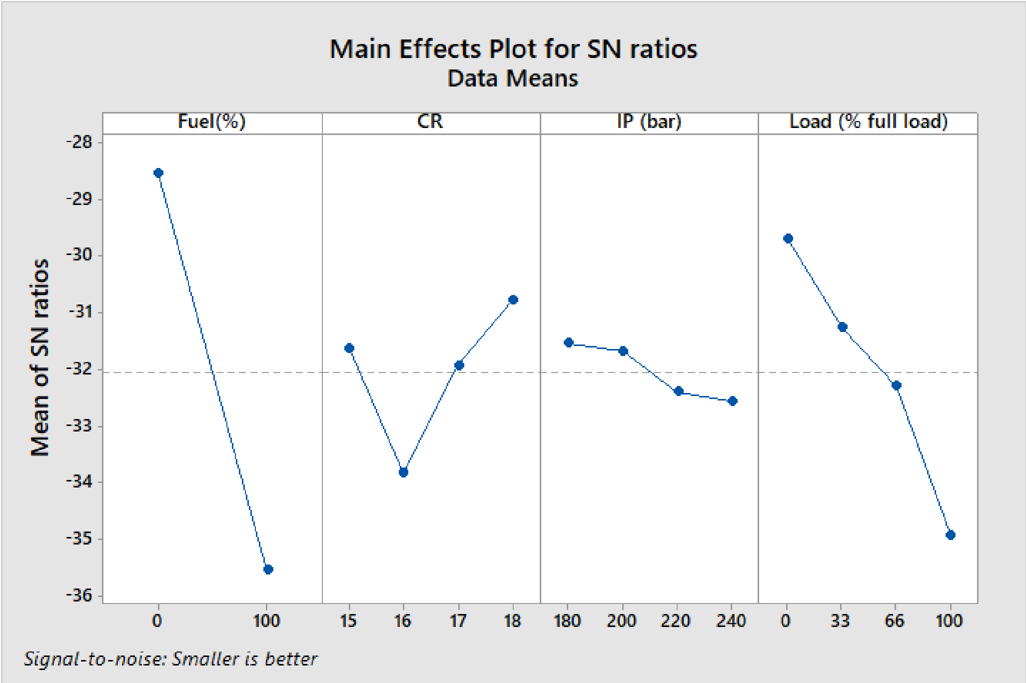

Figure 5 : Main effect for SN ratios HC (ppm)

Table no 4 : Response Table for Means HC (ppm) (Smaller is better)

Level	Fuel (%)	CR	IP(bar)	Load(% full load)
1	29.06	43.38	43.88	36.88
2	62.19	57.25	43.00	41.88
3		44.00	46.38	46.75
4		37.88	49.25	57.00
Delta	33.13	19.38	6.25	20.13
Rank	1	3	4	2

Table no 5 : Predicated Values for Means of Means Plot HC (ppm)

Optimum Set of Parameter				S/N Ratio	Predicted HC (ppm)
Fuel (%)	CR	IP(bar)	Load (% full Load)		
% of HDPE	15	180	0	15	16.1

Table no 6 : Validation Experiment Results and Error HC (ppm)

Basis	Fuel (%)	CR	IP (bar)	Load (% full Load)	Predicated HC (ppm)	Experimental HC (ppm)	Error
Means of Means	0	15	180	0	16.1	15	1.1%
S/N ratio	100	16	180	33	88	90	2%

- Validation experiments results are very closer to predicted results. The errors are less than 1.1%.
- 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=15,IP(bar)=180,Load=0%.It is also called optimum set of parameter. The predicted value of HC (ppm) with optimum set of parameter is 15.

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

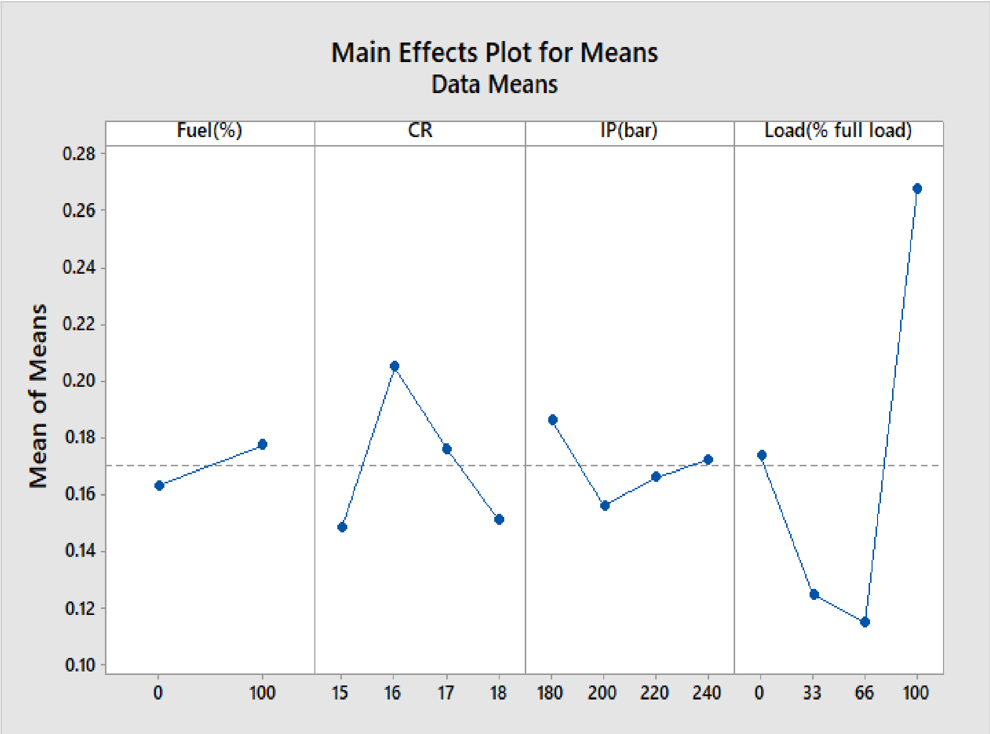

Figure 6 : Main effects plot for means data means CO (% vol)

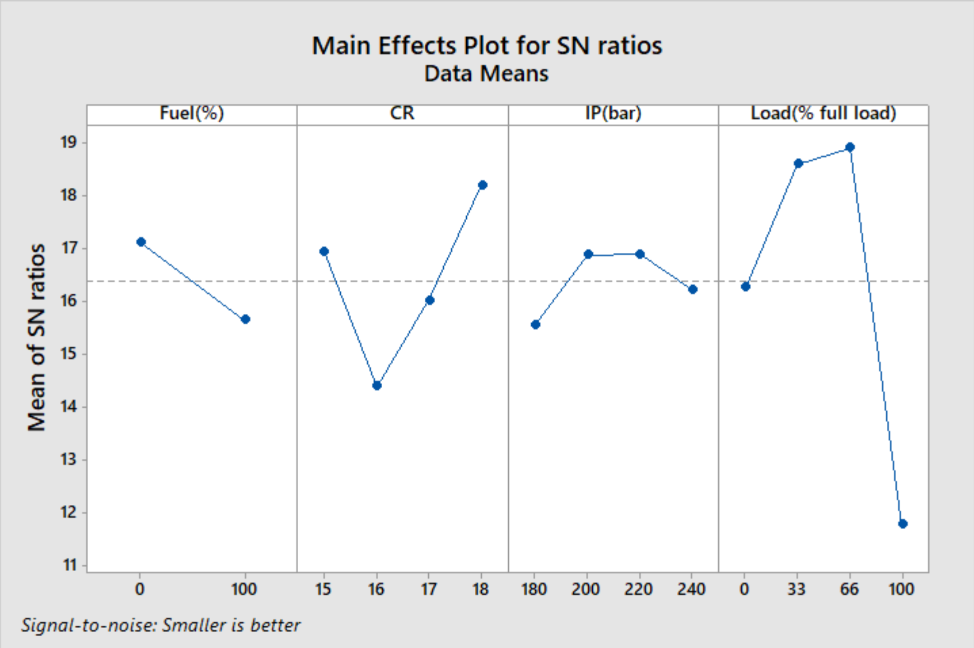

Figure 7 : Main effect for SN ratios CO (%vol)

Table no 7 : Response Table for Means CO (%vol) (Smaller is better)

Level	Fuel (%)	CR	IP	Load
1	17.13	16.94	15.56	16.27
2	15.65	14.39	16.88	18.60
3		16.02	16.89	18.91
4		18.19	16.22	11.77
Delta	1.48	3.81	1.34	7.13
Rank	3	2	4	1

Table no 8 : Predicated Values for S/N Ratio Plot CO (% vol)

Optimum set of parameter				S/N Ratio	Predicted CO (% vol)
Fuel (%)	CR	IP (bar)	Load (% full Load)		
% of HDPE	17	200	100	19.1721	9.6297

Table no 9 : Validation Experiment Results and Error CO (% vol)

Basis	Fuel (%)	CR	IP (bar)	Load (% full Load)	Predicated CO (% vol)	Experimental CO (% vol)	Error
Means of Means	0	18	200	0	0.11	0.07	0.4%
S/N ratio	0	17	200	100	9.6297	0.33	9.3%

- Validation experiments results are very closer to predicted results. The errors are less than 0.4%.
- 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=0%,CR=18,IP(bar)=200,Load=0%.It is also called optimum set of parameter. The predicted value of CO (% vol) with optimum set of parameter is 0.07.

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

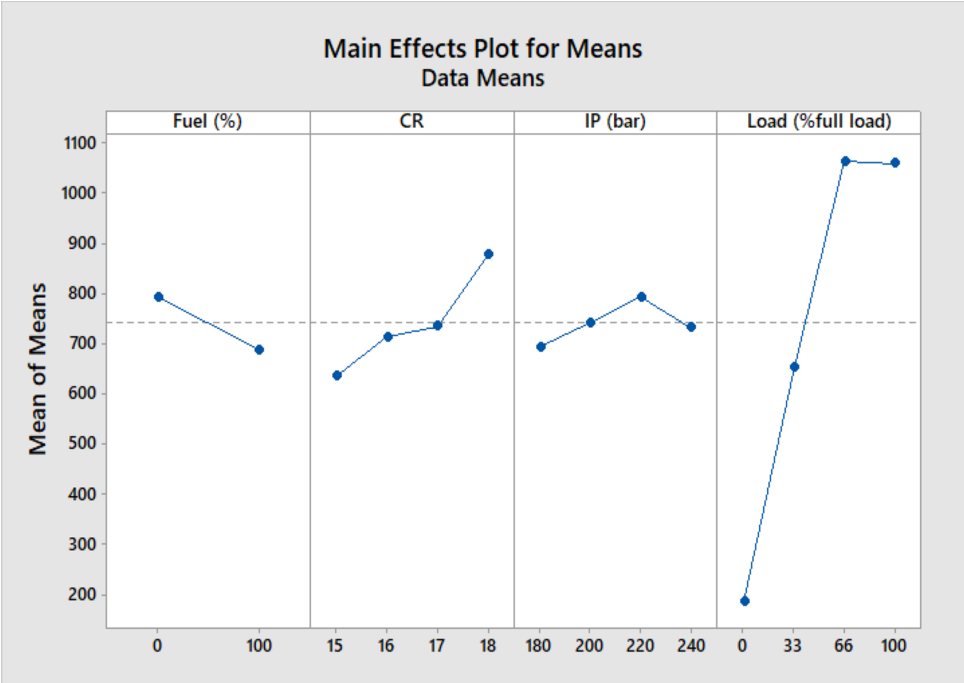

Figure 8 : Main Effects Plot for Means data Means NOx (ppm)

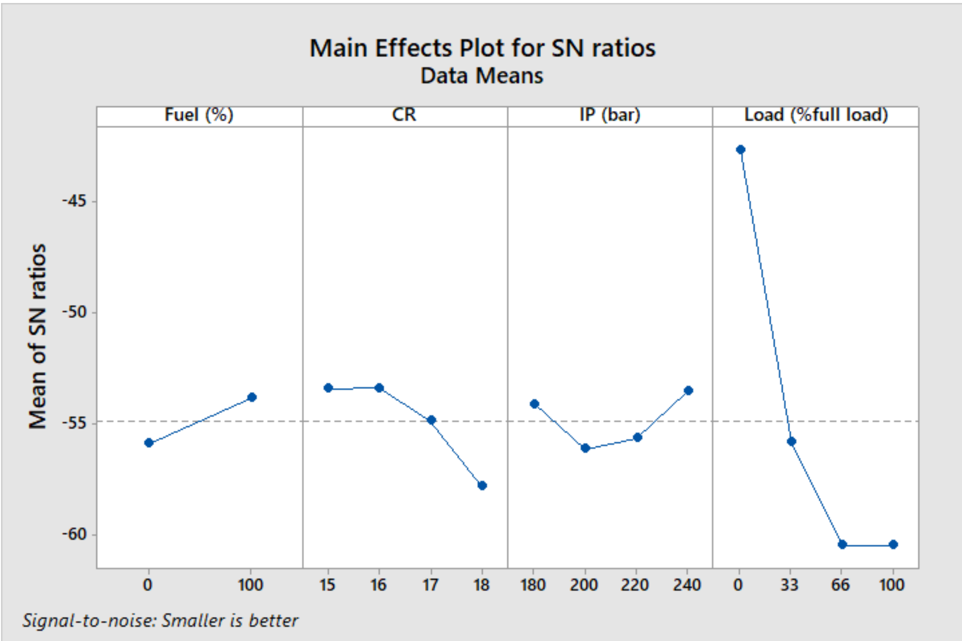

Figure 9 : Main Effect for SN Ratios NOx (ppm)

Table no 10 : Response Table for Means NOx (ppm) (Smaller is better)

Level	Fuel (%)	CR	IP(bar)	Load(% full load)
1	793.3	635.8	694.5	185.6
2	688.4	713.8	743.0	654.0
3		735.0	793.9	1064.6
4		878.9	732.0	1059.1
Delta	104.8	243.1	99.4	879.0
Rank	3	2	4	1

Table no 11 : Predicated values for Means of Means Plot NOx (ppm)

Optimum Set of Parameter				S/N Ratio	Predicted NOx (ppm)
Fuel (%)	CR	IP(bar)	Load (% full Load)		
% of HDPE	17	220	0	99	58.2

Table no 12 : Validation Experiment Results and Error NOx (ppm)

Basis	Fuel (%)	CR	IP (bar)	Load (% full Load)	Predicated NOx (ppm)	Experimental NOx (ppm)	Error
Means of Means	100	17	220	0	58.2	56	2.2%
S/N ratio	0	18	240	66	1230	1227	3%

- Validation experiments results are very closer to predicted results. The errors are less than 2.2%.
- 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=100%, CR=17, IP (bar)=220, Load=0%.It is also called optimum set of parameter. The predicted value of NOx (ppm) with optimum set of parameter is 56.

VII. Conclusion

The best and efficient technique found to 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 HC, Validation experiments results are very closer to predicted results. The errors are less than 1.1%.
- Hence, the optimum (minimum) HC (ppm) is achieved when Fuel=0%,CR=15,IP(bar)=180,Load=0%.It is also called optimum set of parameter. The predicted value of HC (ppm) with optimum set of parameter is 15.
- For CO, Validation experiments results are very closer to predicted results. The errors are less than 0.4%.
- Hence, the optimum (minimum) CO (% vol) is achieved when Fuel=0%,CR=18,IP(bar)=200,Load=0%.It is also called optimum set of parameter. The predicted value of CO (% vol) with optimum set of parameter is 0.07.
- For NOx, Validation experiments results are very closer to predicted results. The errors are less than 2.2%.
- Hence, the optimum (minimum) NOx (ppm) is achieved when Fuel=100%, CR=17, IP (bar)=220, Load=0%. It is also called optimum set of parameter. The predicted value of NOx (ppm) with optimum set of parameter is 56.

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