Parametric Optimization of NO_x Emissions using Taguchi Method for C.I Engine Fuel with Plastic Pyrolysis Oil

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Abstract— Fossil fuel shortage and severe environmental problems have attracted great attention on the exploitation of clean renewable energies. Researchers are continuously finding best alternative solution, which gives the best performance and fuel characteristics. The objective of the study is to optimize the parameters such as plastic pyrolysis oil diesel blend %, injection pressure and applied load of the single cylinder diesel engine through the Taguchi method. This paper investigated the emission characteristics of various blends of plastic pyrolysis oil with diesel on a Single cylinder four stroke diesel engine, and the other effect of parameters injection pressure and load are taken as variable for optimization. Plastic pyrolysis oil can be blended and used in many different concentrations, including P0D100 (pure biodiesel), P10D90 (10% plastic pyrolysis oil, 90% diesel), P20D80 (20% plastic pyrolysis oil, 80% diesel) and P30D70 (30% plastic pyrolysis oil, 70% petroleum diesel). As the experiment required simultaneously optimization of three parameter with four levels, taguchi method of optimization is used in this experiment. The results of taguchi experiment identifies that that Injection pressure 200 bar, blend P30D70 and engine load 1 kg are optimum parameter setting for lowest NO_x emission. Engine performance is mostly influenced by engine load and is least influenced by injection pressure.

Key words: Low Density Poly Ethylene, High Density Poly-Ethylene, Poly Ethylene Terephthalate, Polypropylene, Polystyrene, Poly Vinyl Chloride

I. INTRODUCTION

Due to the fossil fuel crisis in past decade, mankind has to focus on developing the alternate energy sources such as biomass, hydropower, geothermal energy, wind energy, solar energy, and nuclear energy. The developing of alternative-fuel technologies are investigated to deliver the alternate of fossil fuel. In this context, waste plastics are currently receiving renewed interest. Depleting fossil fuel reserves and increasing cost of the petroleum products are the big troubles of today's world. Environmental pollution due to plastic wastes is a global phenomenon today. Recycling waste plastics into reusable plastic products is a conventional strategy followed to address this issue for years. However this technique has not given impressive results as cleaning and segregation of waste plastics was found difficult but indispensible in this technique. It is estimated that approximate 10 thousand tons of plastics waste per day is generated in our country. Plastic wastes include different type viz. Low Density Poly Ethylene (LDPE), High Density Poly-Ethylene (HDPE), Poly Ethylene Terephthalate (PET), Polypropylene (PP), Polystyrene (PS), Poly Vinyl Chloride (PVC) etc. As the plastic waste isolation is difficult it was essential to have novel technologies for plastic waste disposal. Today, refined technologies are available for plastic waste management. Pyrolysis is one such technique used not only for waste disposal but to produce useful products like industrial diesel, gaseous fuel, carbon black etc.

II. LITERATURE REVIEW

Roy et al [1] conducted experiments on the recycling of scrap tires to oil and carbon black by vacuum pyrolysis. In this work, a step-by-step approach has been used, from bench-scale batch systems, to a process development unit and finally a pilot plant, to experiment and develop vacuum pyrolysis of used tires. It was reported that the yield is 55% oil, 25% carbon black, 9% steel, 5% fiber and 6% gas. The maximum recovery of oil is obtained at 415 °C below an absolute pressure of 2 kPa. The specific gravity of this oil was 0.95 and its gross heating value was 43 MJ/kg and total sulphur content about 0.8%. It was rich in benzyl and other Petrochemical components. The heat of pyrolysis for the reactions is low and is estimated to be 700 kJ/kg S.Murugan et al [2] carried out to evaluate the performance and emission characteristics of a single cylinder direct injection diesel engine fuelled by 10, 30 and 50 percent blends of Tire pyrolysis oil (TPO) with diesel fuel (DF).Results showed that the brake thermal efficiency of the engine fuelled by TPO-DF blends decreased with increase in blend concentration and higher than Diesel. NO_x, HC, CO and smoke emissions were found to be higher at higher loads due to high aromatic content and longer ignition delay. M. Mani et al [3] conducted performance test on diesel engine by using waste plastic oil as alternate fuel. The experimental results have showed stable performance with brake "thermal efficiency similar to that of diesel. Carbon dioxide and unburned hydrocarbons were marginally higher than that of the diesel baseline. The toxic gas CO emission of waste plastic oil was higher than diesel. Smoke reduced by about 40% to 50% using waste plastic oil at all loads. Tushar Patel et al [4] conducted Performance analysis of single cylinder diesel engine fuelled with Pyrolysis oil -diesel and its blend with Ethanol. It was concluded that It was concluded that DP95 E5(95% of 85% pyrolysis oil-Diesel blend and 5% ethanol) found less fuel consumption and better brake thermal efficiency and can be used as an alternative fuel for Diesel engine without any engine modification.

III. PYROLYSIS PROCESS FOR CONVERSION OF WASTE PLASTIC INTO FUEL

Pyrolysis is a process of thermal degradation in the absence of oxygen. Plastic waste is continuously treated in a cylindrical chamber and the pyrolytic gases condensed in a specially designed condenser system to yield a hydrocarbon distillate comprising straight and branched chain aliphatics, cyclic aliphatics and aromatic hydrocarbons. The resulting mixture is essentially equivalent to petroleum distillate. The plastic is pyrolised at 370ºC- 420ºC and the pyrolysis gases are condensed through a distillation tower to produce the distillate.[5]

The essential step in the pyrolysis of plastics involves:

1) Purging oxygen from pyrolysis chamber.
2) Evenly heating the plastic to a narrow temperature range without excessive temperature variations.
3) Pyrolising the plastics.
4) Catalytic conversion of the gases to specific carbon chain lengths.
5) Managing the carbonaceous char by-product before it acts as a thermal insulator and lowers the heat transfer to the plastic.
6) Careful condensation and fractionation of the pyrolysis vapours to produce fuels of excellent quality and consistency.
7) Removal of sulphurs and residual contaminants.

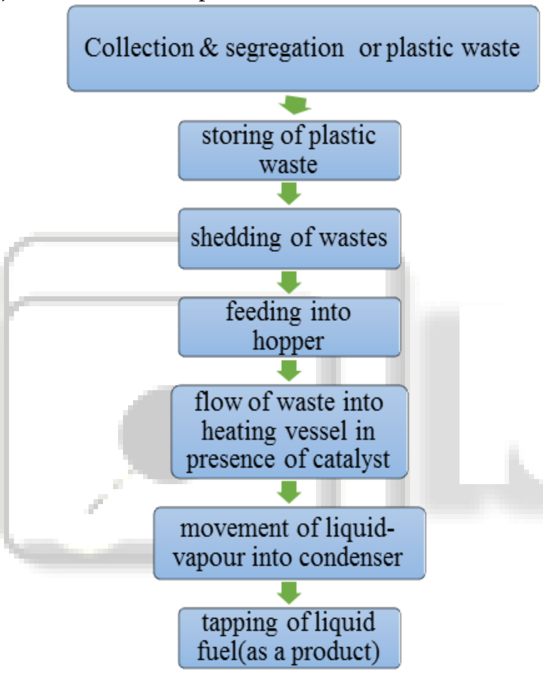

Fig. 2: Conversion of Plastics waste into Liquid Fuel

IV. EXPERIMENT SETUP

A single-cylinder, 4-Stroke, water-cooled diesel engine of 5 hp rated power is considered for the experimentation. The engine is coupled to a rope brake dynamometer through a load cell. It is included with a data acquisition system to store the data for the off-line analysis. The schematic layout of the experimental set up is shown in below Figure-3. A stationary, 5 hp direct injection diesel engine is used to conduct experiments. Its specifications are given in Table 1.The Rope brake dynamometer is attached to a brake drum or flywheel attached to moderate sized engine. A rope is wound around the brake wheel as shown in Figure 3.

One end of rope is connected to the spring balance suspended from overhead and other end carries the load. Air suction rate and exhaust airflow rates are measured with the help of an air velocity meter. Automatically increases with increase of speed and vice versa so that steady speed conditions are more easily achieved.

Fig. 3: Experimental Setup of Diesel Engine

Parameter	Details
Engine	Single Cylinder High Speed Diesel Engine
Cooling	Water cooled
Bore × Stroke	80 mm × 110 mm
Compression ration	16 : 1
Maximum Power	5 hp or 3.7 Kw
Rated speed	1500 rpm
Capacity	553 CC

Table 1: Engine Specification

V. EFFECT OF PARAMETER

Parameter plays most significant and effective role in internal combustion engine. Parameter affect on the emission, fuel consumption, performance of internal combustion engine significantly.

A. Injection Pressure:

Injection pressure is a pressure which is required to inject the fuel into cylinder. For smooth function of injector, it is required that the injection pressure is higher than cylinder pressure. Higher the injection pressure gives better the dispersion and penetration of the fuel into all desired locations in combustion chamber.

B. Blend Proportion:

Blend ratio is percentage of alternate fuel or additive in the convention fuel by V/V ratio. When bland ratio increase or decrease, its changes the fuel consumption and consequently brake power and mechanical efficiency also change in brake thermal efficiency. When alcohol is a content of blend, it provides oxygen. So that, combustion becomes smooth and complete. Sometimes due to additive in the blend, there may be decrease in CO and HC emission. Blend ratio is vastly influence on the combustion characteristics, performance and emission. So that, if change in blend ratio, it may be change in above characteristics.

C. Engine Load:

As engine speed increases, the loss of heat during compression decreases with the results that both temperature and pressure of the compressed air tends to rise, thus the increase in turbulence, however may tend to increase the heat loss in some cases.

VI. OPTIMIZATION METHOD

In this method, the fuel selected for research is mixed with standard diesel oil in various proportions on volume basis and its properties such as calorific value was evaluated before admission. The blends are in 10%, 20% & 30% plastic pyrolysis oil with standard diesel fuel. A method called "Taguchi" was used in the experiment for simultaneous optimization of engine such as injection pressure and load condition.

A. *Taguchi Method of Optimization:*

Taguchi method is a simplest method of optimizing experimental parameters in less number of trials. The number of parameters involved in the experiment determines the number of trials required for the experiment. More number of parameters led to more number of trials and consumes more time to complete the experiment. Hence, this was tried in the experiment to optimize the levels of the parameter involved in the experiment. This method uses an orthogonal array to study the entire parameter space with only a small number of experiments .To select an appropriate orthogonal array for the experiments, the total degrees of freedom need to be computed. The degrees of freedom are defined as the number of comparisons between design parameters that need to be made.[6]The present study uses three factors at four levels and hence, an L16 orthogonal array was used for the construction of experimental layout (Table 2, column -1, 2, 3&4).The L16 has the parameters such as blend, injection pressure and load arranged in column 1, 2 and 3. According to this layout, sixteen (16) experiments were designed and trials were selected at random, to avoid systematic error creeping into the experimental procedure. For each trial the NO_x was calculated and used as a response parameter. There are three kinds of signal to noise ratios are in practice. Of which, the smaller-the-better S/N ratio was used in this experiment because this optimization is based on lower NO_x. The taguchi method used in the investigation was designed by statistical software called "Minitab 16" to simplify the taguchi procedure and results. A full range experiment for the selected blend was also conducted for after modifying the engine operating parameters. This is mainly to optimize the performance characteristics of pyrolysis oil-diesel blend.

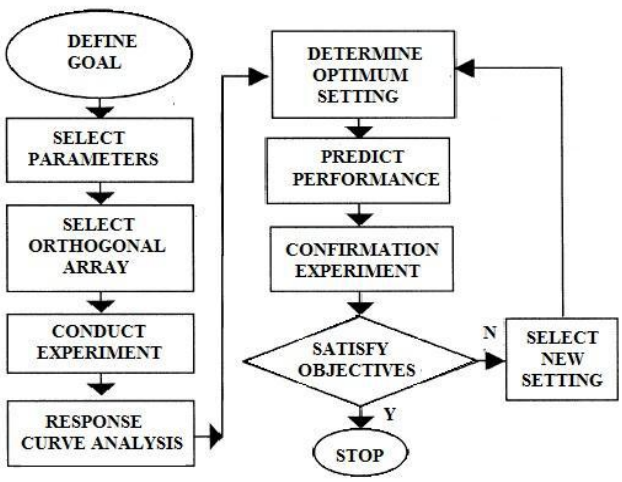

Fig. 4: Flow chart of the Taguchi method

VII. RESULT AND DISCUSSION

Experiment was done for selection sets of parameters by Minitab software and find NO_x emission for those sets of parameters. NO_x for those sets are given in table 2.

A. *Response Curve Analysis:*

Response curve analysis is aimed at determining influential parameters and their optimum levels. It is graphical representations of change in emission characteristics with the variation in process parameter. The curve give a pictorial view of variation of each factor and describe what the effect on the system performance would be when a parameter shifts from one level to another. Figure-5 shows significant effects for each factor for five levels.

SR NO	BLEND	INJECTION PRESSURE	LOAD	NOx
1	B0D100	160	1	84
2	B0D100	180	4	177
3	B0D100	200	7	257
4	B0D100	220	10	344
5	B10D90	160	4	168
6	B10D90	180	1	109
7	B10D90	200	10	360
8	B10D90	220	7	262
9	B20D80	160	7	246
10	B20D80	180	10	354
11	B20D80	200	1	77
12	B20D80	220	4	139
13	B30D70	160	10	345
14	B30D70	180	7	230
15	B30D70	200	4	125
16	B30D70	220	1	78

Table 2: L16 Orthogonal array

The S/N ratio for the emission curve were calculated at each factor level and average effects were determined by taking the total of each factor level and dividing by the number of data points in the total. The greater difference between levels, the parametric level having the lowest S/N ratio corresponds to the parameters setting indicates highest performance. From fig.5, mean is average value for reading taken for particular parameter.

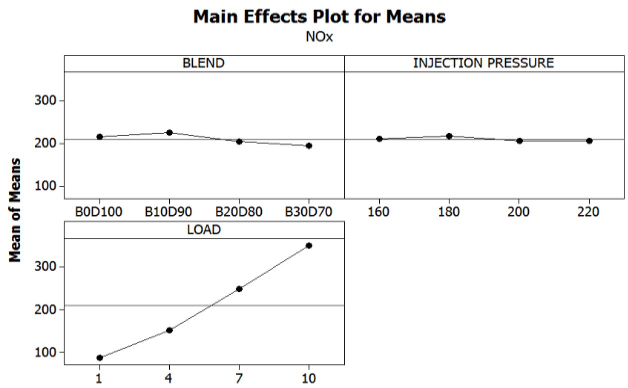

Fig. 5: Main effects of parameter

From graph, mean value is maximum (224.75) for P10D90 blend and minimum (194.5) for P30D70 blend. Mean value is maximum (217.5) for 180 bar injection pressure and minimum (204.75) for 200 bar injection pressure. Mean value is maximum (350.75) for 10 kg load and minimum (87) for 1 kg load.Delta is difference of maximum value and minimum value. Delta value is maximum for load (263.75) and minimum (12.75) for injection pressure parameter. Blend Delta value is between other two parameter. So that effect of load is maximum and effect of injection pressure is minimum on NO_x emission.

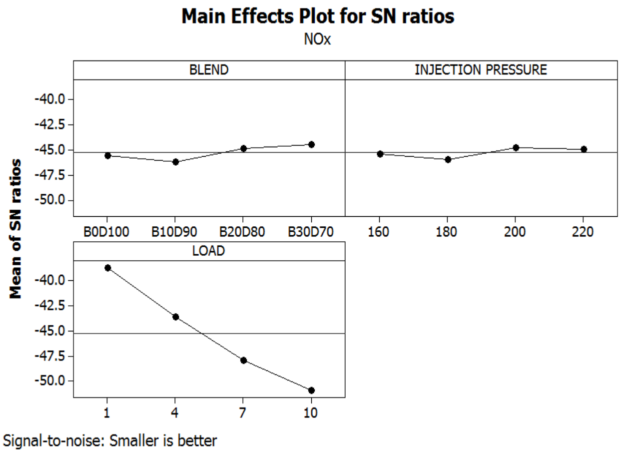

Fig. 6: Main Effect for SN ratio

Referring (Fig.6) the response curve for S/N ratio, the lowest S/N ratio was observed at blend(P30D70), injection pressure(200 bar) and load(1 kg), which are optimum parameter setting for lowest NO_x emission. From delta values as mention above maximum (12.20) for engine load and minimum (1.23) for injection pressure. Parameter engine load is most significant parameter and injection pressure is least significant for NO_x emission.

B. Choosing Optimum Combination of Parameter Level:

Level	BLEND	INJECTION PRESSURE	LOAD
1	-45.59	-45.39	-38.70
2	-46.19	-45.98	-43.57
3	-44.85	-44.75	-47.90
4	-44.44	-44.95	-50.90
Delta	1.74	1.23	12.20
Rank	2	3	1

Table.3 Response Table for Signal to Noise Ratios

The term optimum set of parameters is reflects only optimal combination of the parameters defined by this experiment for lowest NO_x emission. The optimum setting is determined by choosing the level with the highest S/N ratio.Referring fig.6 and table.3, the response curve for S/N ratio, the highest performance at set P30D70 blend, ,injection pressure 200 bar and engine load 1 kg which is optimum parameter setting for lowest NO_x emission.

VIII. CONCLUSION

The results of the taguchi experiment identifies that Injection pressure 200 bar, blend P30D70 and engine load 1 kg are optimum parameter setting for lowest NO_x emission. Engine performance is mostly influenced by engine load and is least influenced by injection pressure.

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