Production and Optimization using Taguchi Analysis of Fuel Derived from Different Waste Feedstocks

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Abstract - Power is generated through several processes and one of the popular and widely used method is reciprocating diesel engine. The diesel engines are lucrative due to its reliability, combined with higher efficiency. The cost of fuel per kilowatt produced is approximately 30 % to 50 % lower than gasoline engines. Apart from being used in automotive field, diesel engines are also commonly used as emergency or backup generators in many places. In spite of all its merits, there are few drawbacks which includes high initial cost, harmful emissions upon combustion and pungent odour, this calls for an alternative fuel or a substitute to minimize the undesirable properties of conventional diesel fuel. These are also known as diesel like fuels which have less carbon intensity than diesel, thereby contributing less harm to the environment. Our research focuses on producing diesel like fuel using Waste Lube Oil (WLO) and Waste Tyre Oil (WTO). Pyrolytic distillation process is used, in which the waste feed stock is heated to a specific temperature and the vapors collected is converted to the desired fuel. The optimization of fuel production was done using Taguchi analysis with a L12 orthogonal array to analyze the influence of process factors on performance parameters. The results indicate that among WLO and WTO fuels, the S/N Ratio for WLO was 46.51 and WTO was 45.46 and the total WLO and WTO yield obtained after the process was around 80 % and 70 %. Hence by the optimization method, the WLO yield was found to be better than WTO yield by 10 %.

***Key Words*: Pyrolysis, WLO, WTO, Taguchi Analysis, S/N Ratio.**

1. INTRODUCTION

The Production of WLO is assessed at 32 million tons every year all through the world, representing a critical treatment and removal issue for present day society WLO containing a blend of low and high sub atomic weight aliphatic and aromatic hydrocarbons likewise represent a potential well spring of high worth fuel and feedstock. [1]. As a major aspect of the developing enthusiasm for recycling, alternative methods have been investigated with the point of recovering both the chemical and energetic value of WLO [2]. Many disposal methods including land filling and incineration have also been studied. Pyrolytic distillation strategies have demonstrated incredible promise as an economical friendly disposal strategy for WLO [3]. The lube oils can be reused and re-utilized as diesel like fuels. Transformation of the WLO into diesel like fuel by utilizing pyrolytic refining has great impacts in environment, atmospheric air and furthermore gives better monetary worth. Since WLO are contains several metal particles, they must be disposed with care. In this procedure, WLO is taken into a reactor and heated. The out coming vapours are re-condensed to pyrolytic oil using a water-cooled condenser. [4]

Oil produced by utilizing rubber tires as raw material through the process of pyrolytic distillation is called WTO. Because of fast industrialization, the energy requirements are ever increasing globally. Roughly, 15 million tons of waste tyres is produced universally out of which India's contribution is around 1 million ton. Furthermore, disposing tyres is a troublesome task since it has high levels of harmful materials [5]. Therefore, significant care must be implemented for the recycling of waste tires. The vast majority of the tire oils are produced from squander tires and elastic materials. However, the waste rubber and tyre products pose an environmental hazard due to the presence of aromatic hydrocarbons, per- oxides, benzothiazole subsidiaries, phenols, amines and different contaminants. Usage of diesel-like fuels delivered from WTO and mixing it with diesel diminishes the utilization of oil-based fuels, preventing the emissions of hazardous chemicals. The WTO shows capability of being a significant source of energy, which could possibly substitute diesel in future [6].

Pyrolytic distillation is thermo chemical decomposition of natural materials at raised temperatures. This includes synchronous difference in chemical composition & physical phase. The pyrolysis procedure for lube oil takes carbon molecules and cracks them into shorter chains through heat and pressure. Essentially, the process breaks higher carbons into smaller carbon bonds. The pyrolytic distillation process takes place at intense heat in a closed system for a short period of time [7]. Anhydrous pyrolysis is also used to make diesel like fuel from raw lube oil, with good cetane index and reduced Sulphur content than standard diesel. Utilizing pyrolytic distillation to obtain fuel from waste oil is the second-best choice after recycling. It is naturally ideal and can help decrease reliance on remote petroleum products and geo extraction. [15]

2. MATERIALS AND METHODS

2.1 Materials

The Waste Lube oil and Waste Tyre oil in this study was derived from the pyrolytic distillation process of at temperature of 420 °C and 430 °C. The oil obtained was analyzed for various properties like density kinematic viscosity, calorific value etc, and the fuel production is optimized by taguchi analysis. The reactor and condenser setup were made of mild steel.

2.2 Components used for extraction

• Reactor: A Reactor is an apparatus in which the waste feed stock undergoes various controlled and independent thermo chemical reactions. A rubber gasket is provided to prevent leakage of fumes. The center of upper cover contains a main hole through which a pipe is welded at 90 degrees, to provide as the outlet of produced fumes. The pipe and condenser are welded properly and sealant is provided between the pipe and the condenser.

• Condenser: The condenser is a double pipe construction in which two pipes of different diameters are used. It is a water-cooled condenser. The pipe with smaller diameter is used to carry the fumes generated from the reactor and it is placed inside another pipe of larger diameter. The outer pipe is used to recirculate water for cooling. Tap water is used for condensing the fumes coming out from the reactor. Water inlet and outlet connections are provided to the condenser for the continuous circulation of the water flow.

• Heater: The type of heater used is a commercial gas burner. It can provide temperatures up to 600 °C. A thermocouple is utilized to observe the temperature inside the reactor. The flames from the burner can be adjusted by a knob with respect to the amount of heat required.

• Temperature control setup: Temperature controller setup is used to monitor the reactor temperature as well as to control it. This setup consists of a thermocouple and temperature indicator.

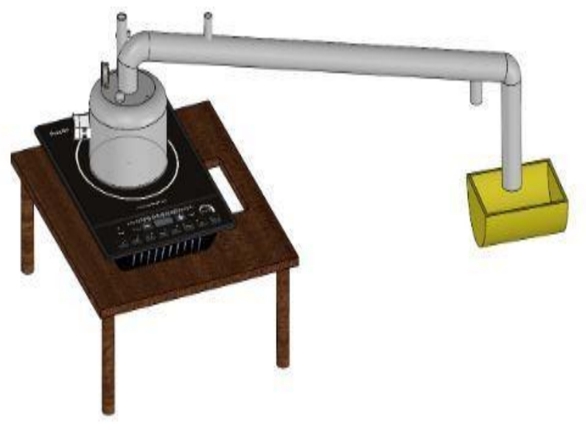

Fig -1: 3D Modeling of Experimental Setup

2.3 Modeling and fabrication of pyrolytic distillation setup

2.3.1 The Variables considered during the modeling and fabrication of the reactor are:

• Height of the boiler - 140 mm

• Total height of the boiler including condenser - 190 mm

• Inner Diameter – 195 mm

• Outer Diameter – 200 mm

• Width of the reactor – 30 mm

• Thickness of Reactor – 5 mm

• Fumes outlet pipe diameter – 50 mm

2.3.2 Volume of the Reactor Core: V = (π*r2*h)

• π = 3.14

• r = 100 mm

• h = 140 mm

Volume of the Reactor Core = 4.398 Liters.

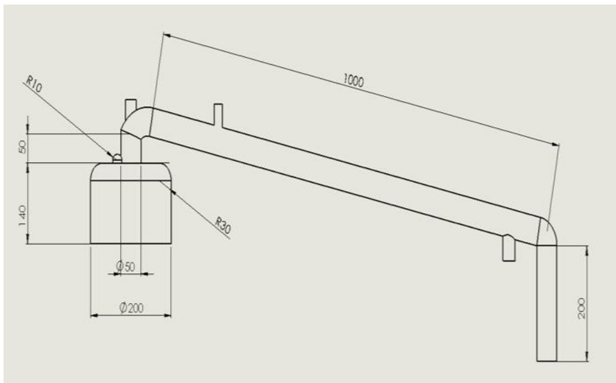

Fig -2: 2D Modeling of Reactor

2.4 Methodology

2.4.1 Procedure for production of diesel like fuels from WLO and WTO

The purified waste lube oil and waste tyre oil is fed into the reactor separately. A rubber gasket is fitted between the upper cover and the bottom unit for perfect sealing and to prevent the leakage of vapours. Then close the reactor using nuts and bolts. Insert the thermocouple through the hole on the upper cover and measure the internal temperature.

The thermocouple is connected directly to the temperature display unit. Check all the connections to heater, thermocouple and temperature indicator for safety. The condenser is connected with the pipe coming out from the reactor. [12]

A small submersible motor is used to recirculate the water, within the inlet and outlet connections of the condenser for cooling the vapours.

A beaker is kept at the end of the condenser for collection of fuel at the end of the process.

Fig -3: WLO sample collected in a beaker

Fig -4: WTO sample collected in a beaker

Fig -5: Experimental Setup of Pyrolytic Distillation

2.4.2 Result

• Continuous WLO fuel flow was obtained at 420 °C and Continuous WTO flow was obtained at 430 °C.

• From 10 litres of waste raw oil, 8 litres of WLO and 7 Litres of WTO was obtained in 10 hours. The total yield of WLO obtained was around 80 % and the total yield of WTO obtained was around 70 %.

Table -1: Properties of WLO fuel acquired from Pyrolytic Distillation Process

Test Parameters	Results
Density (kg/m^3)	830
Kinematic Viscosity @ 40 °C (cSt)	4.9
Calorific Value (kJ/kg)	37,870
Fire point (°C)	38
Flash point (°C)	32
Carbon Residue	0.1 % by mass
Sulphur Content	0.17 % by mass
Reaction Temperature (°C)	420
Reaction Time (For 1 Litre)	50 (min)

Table -2: Properties of WTO fuel acquired from Pyrolytic Distillation Process

Test Parameters	Results
Density (kg/m^3)	909
Kinematic Viscosity @ 40 °C (cSt)	5.2
Calorific Value (kJ/kg)	36,730
Fire point (°C)	47
Flash point (°C)	42
Carbon Residue	0.1 % by mass
Sulphur Content	0.19 % by mass
Reaction Temperature (°C)	430
Reaction Time (For 1 Litre)	60 (min)

2.5 Taguchi Analysis

Conventional exploratory strategies are convoluted and hard to rehearse, the manual advancement is a hard undertaking to perform. Moreover, with the expansion in process parameters and levels the quantity of tests increments to a greater extent. To determine this issue, taguchi analysis uses the orthogonal arrays to examine the total parameter plot with lesser number of preliminaries. The Taguchi method is a robust design of experiments method based on orthogonal arrays. It utilizes a special orthogonal array to study the complete parameter plot with lesser number of trials. It provides a set of minimum number of experiments which will give the complete information about the influence of all the factors on the performance parameter. The acquired outcomes are converted into a signal-to-noise (S/N) ratio [9]. The taguchi technique is a powerful structure of experimental strategy dependent on symmetrical exhibits.

It gives the least number tests which will provide the total data about the impact of the all the components on the exhibition parameters. The technique gives diminished difference to the experiment with ideal qualities to explore the impact of various factors on the extraction process. In improvement of the extraction parameters the S/N ratio, which is log change of mean square deviation, is the essential function that is used for enhancement of desired yield. Signal (S) denotes the mean (desired yield) and noise (N) denotes the standard deviation (undesired disturbances). By using all the data, the experimental information of this analysis can be studied by plotting the information and by visual examination with the assistance of ANOVA method [10]. This method solves optimization in two categories called as Static Problem and Dynamic Problem. The main aim of this analysis is to decrease the variations in the output even though noise is present in the process, hence this is called as Robust method.

For the optimization of performance parameters, the S/N Ratio is calculated for every experiment. In Table III, the types of S/N ratio that can be used upon the main objective of an experiment are shown. In this analysis the S/N ratio criteria used was Larger is better for obtaining maximum response value and the main parameters considered were Temperature and Duration. The input amount of raw WLO and WTO used was around 500 ml. The temperatures observed for WLO was 270 °C, 320 °C, 420 °C and 440 °C and the temperatures observed for WTO was 260 °C, 370 °C, 430 °C and 445 °C. The time duration observed for both the fuels were 5, 10 and 15 minutes. [8]

Table -3: Taguchi Analysis

S/N ratio Criteria	Objective of the experiment	S/N Ratio formula
Larger is better	To maximize the response	$S/N = -10 * \log(\Sigma(1/Y^2)/n)$
Nominal is best	Target the response and base the S/N ratio on standard deviations only	$S/N = -10 * \log(Y^2/sd^2)$
Smaller is better	To minimize the response	$S/N = -10 * \log(\Sigma(Y^2)/n))$

2.5.1 Optimization of fuel at various time and temperatures

Table -4: Extraction of WLO at Different Time and Temperatures

Sl No	Temperature (°C)	Duration (min)	Total WLO Yield (ml)
1	270	5	25
2	270	10	40
3	270	15	65
4	320	5	40
5	320	10	65
6	320	15	85
7	420	5	140
8	420	10	230
9	420	15	300
10	440	5	130
11	440	10	220
12	440	15	285

Sl No	Temperature (°C)	Duration (min)	Total WTO Yield (ml)
1	260	5	20
2	260	10	35
3	260	15	60
4	370	5	70
5	370	10	100
6	370	15	180
7	430	5	120
8	430	10	200
9	430	15	275
10	445	5	110
11	445	10	190
12	445	15	250

Table -5: Extraction of WTO at Different Time and Temperatures

Table -6: S/N Ratio Values for WLO Blends

Level	Temperature (°C)	Duration (min)	S/N Ratio	Max WLO Yield (ml)
L1	270	5	32.09	25
L2	320	10	35.63	65
L3	420	15	46.51	300

Table -7: S/N Ratio Values for WTO Blends

Level	Temperature (°C)	Duration (min)	S/N Ratio	Max WLO Yield (ml)
L1	260	5	30.82	20
L2	370	10	40.67	100
L3	430	15	45.46	275

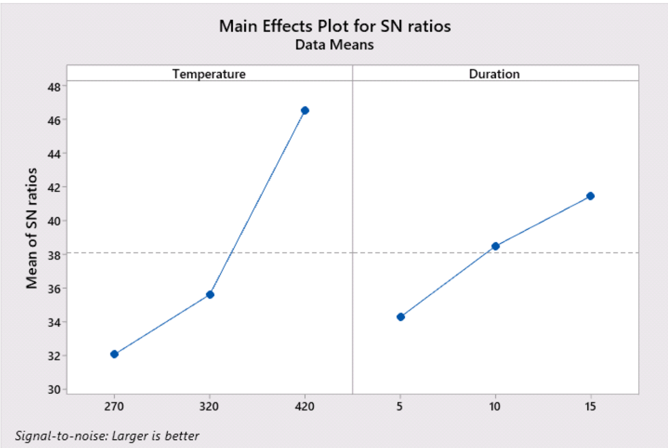

Fig -6: Response table for signal to noise ratio – WLO

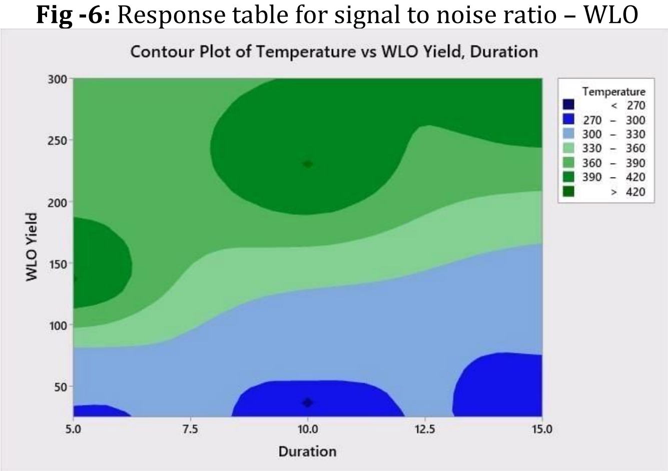

Fig -7: Contour Plot of Temperature, WLO yield & duration

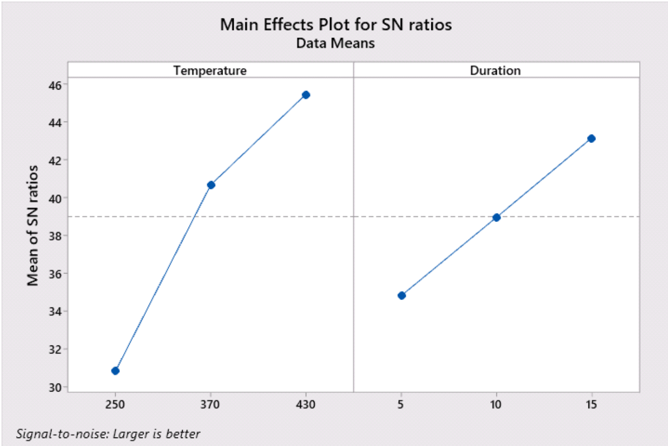

Fig -8: Response table for signal to noise ratio – WTO

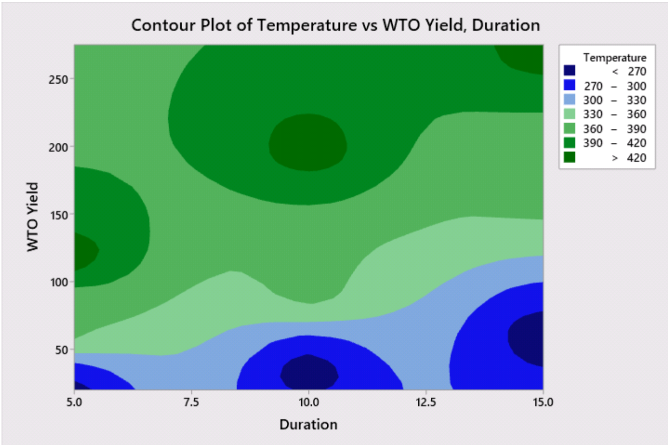

Fig -9: Contour Plot of Temperature, WTO yield and Duration

2.6 OUTPUT AND RESULT

In our work, the maximum diesel like fuel yield was taken as objective. Therefore, larger S/N ratio was best for the performance parameter for both WLO and WTO fuels. The S/N ratio values of WLO at 270 °C, 320 °C and 420 °C was 32.09, 35.63 and 46.51, the total average of the S/N ratio was 38.096. In case of WLO, the S/N ratio was very high (46.51) at level 3, in which the temperature and time duration was found to be 420 °C and 15 minutes. The S/N ratio values of WTO at 260 °C, 370 °C and 430 °C was found to be 30.82, 40.67 and 45.46, the total average of the S/N ratio was 38.98. In case of WTO, the S/N ratio was very high (45.46) at level 3, in which the temperature and time duration was 430 °C and 15 minutes.

2.6.1 Effect of Extraction Duration

Time duration of the extraction process is a significant parameter affecting the yield of WLO and WTO fuels. To evaluate the effect of time duration parameter, it was varied from 5 to 15 minutes. By increasing the reaction time, yield increased and 15 minutes was found optimum to maximum WLO and WTO fuel production.

2.6.2 Effect of Temperature

The effect of temperature was observed by varying the temperature from 260 °C to 445 °C. After optimum temperature, further increment in temperature, decreases the yield considerably for all feedstocks. Experimental results showed that raising the temperature above 420 °C and 430 °C, decreases the production of WLO and WTO fuels. Increment in yield was observed due to the steady increase in the reaction rate and proper condensation with increasing temperature. But beyond a certain temperature, the condensation of fuel was not fully complete which resulted in decreased yields.

The production and optimization by taguchi analysis of diesel like fuel was carried out successfully. The high efficiency of pyrolysis process resulted in the production of 8 litres and 7 litres of WLO and WTO from 10 litres of raw oil. The yield of WLO was around 80 % and the yield of WTO was around 70 %. The yield and S/N Ratio of WLO is higher than WTO which shows that the production of WLO fuel was better than WTO fuel.

2.7 FUTURE SCOPE

The scope for alternative fuels in future is exceptionally high because of the consumption of non-renewable energy sources. As the energy from these sources are depleted quickly, it is anticipated that non-renewable energy sources will be drained sooner rather than later. This diesel like fuel will help to produce a substitute fuel for diesel engines as well as it will help keeping the environment clean. The conversion of waste raw oil to bio fuels can also be made more efficient by using different production techniques and also by adding different enhanced catalysts to develop the production of diesel like fuel. The cost of fuel production can also be decreased to a great extend if the production of WLO and WTO is made in larger scale.

2.8 CONCLUSION

This paper focuses on the production and optimization of diesel like fuels derived from different waste feedstocks such as WLO and WTO. The production of these diesel-like fuels is done by pyrolytic distillation method. The extraction process parameters are optimized using Taguchi analysis which shows that the yield of WLO was 10 % more than that of WTO. Considering the recycling and conversion of waste material into valuable products, the WLO and WTO can be a potential source for production of diesel like fuels which may simultaneously give regional and national benefits in the future.

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