

Taguchi Method Based Experimental Study on Performance and Emission Characteristics of a CI Engine Fueled with Biodiesel (Waste Cooking Oil)

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Abstract — Due to its performance above diesel fuel with little or no engine modification, biodiesel is a useful fuel today. This paper discusses waste cooking oil biodiesel production and attributes. Different Waste Cooking oil biodiesel-diesel blends and loads can be tested to improve biodiesel-fueled diesel engine performance. Experimental work uses a single-cylinder four-stroke CI engine. Taguchi design with Minitab software will be utilised to test different load and blend ratios for brake power, fuel consumption, thermal efficiency, and pollution. Lab tests were done as advised by the software. Finally, in CI engine, Diesel, waste cooking-oil biodiesel, and diesel are tested for performance and emission parameters and optimisation.

Keywords: Combustion Ignition (CI) Engine, Diesel, Mahua Oil Bio-Diesel, Efficiency and Emissions

I. INTRODUCTION

Energy demand has skyrocketed due to fast industrialisation and the ever-increasing transportation and industrial sectors. Compression Ignition (CI) engines mostly run on traditional fossil fuels like petrol and diesel. Nevertheless, these fuels do not contribute to renewable resources and exacerbate environmental issues including air pollution, greenhouse gas emissions, and climate change.

Because they outperform spark ignition engines in terms of efficiency, longevity, and fuel economy, CI engines see extensive use. Particulate matter (PM), hydrocarbons (HC), nitrogen oxides (NOx), and carbon monoxide (CO) are all harmful to humans and the environment that are released into the air while these engines run.

Researchers have been concentrating on renewable, environmentally benign, and long-term viable alternative fuels to tackle these issues. Biodiesel is quickly becoming a top contender among alternatives to traditional diesel fuel. Biodiesel can be made from a variety of sources, one of which being Waste Cooking Oil (WCO), which is both sustainable and inexpensive.

II. OBJECTIVES & METHODOLOGY

A. Objective

- To produce and evaluate waste cooking oil biodiesel as a sustainable fuel for CI engines by analyzing its properties and compatibility without engine modification.
- To study the effect of biodiesel–diesel blends and engine load on performance parameters (Brake Power, BTE, SFC) and emissions (CO, HC, NOx, smoke).
- To optimize engine performance and emissions using the Taguchi method (L9 design) and determine the best

blend ratio and load condition for efficient and cleaner combustion.

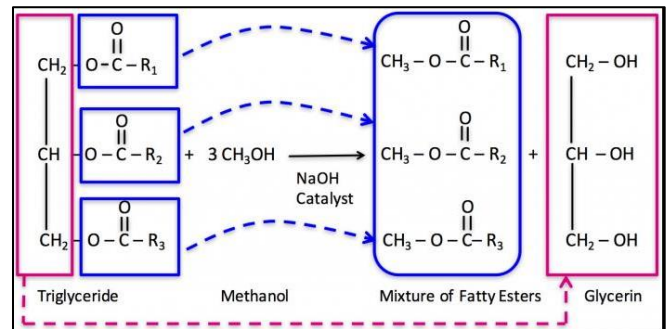


Fig. 1: Chemical Reaction

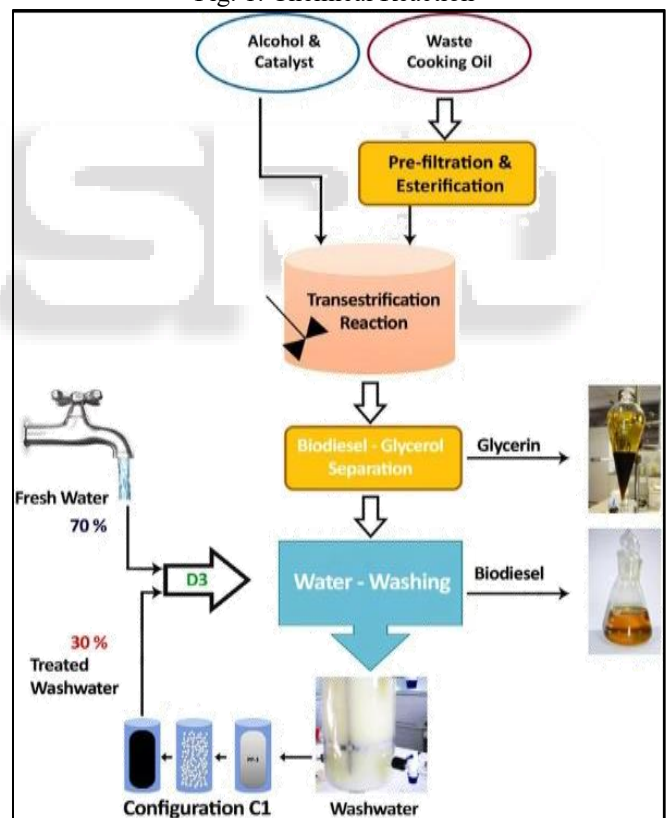


Fig. 2: Step By Step Process

B. Experimental design in minitab-16

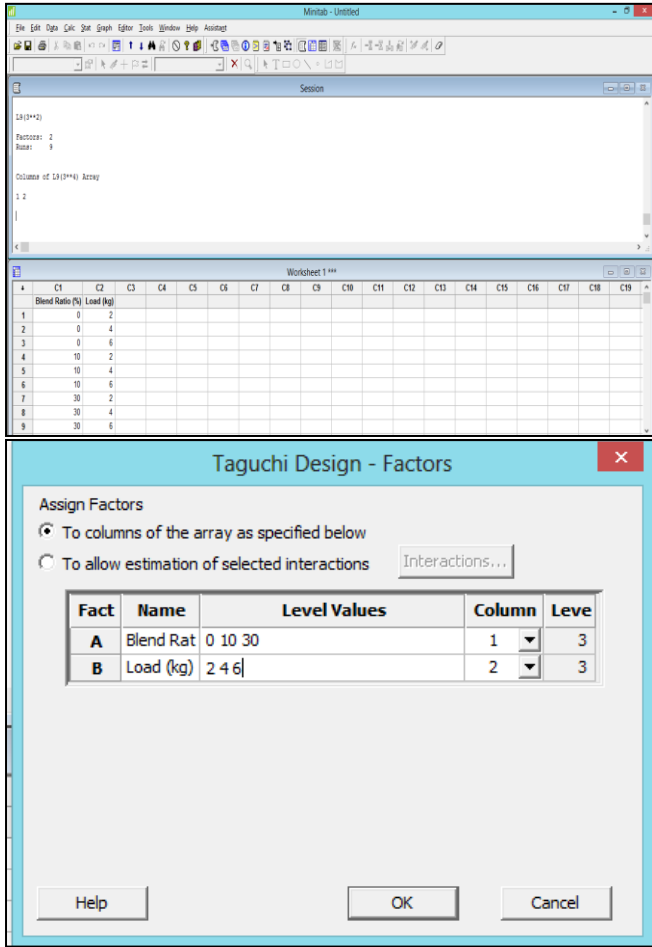


Fig. 3: Work-Sheet of Minitab-16

Ex. No.	Blend Ratio (%)	Load (kg)	CO (%vol.)	HC (ppm)	CO ₂ (%vol.)	NO _x (ppm)	O ₂ (%vol.)
1	0	2	0.05	32	2.4	115	17.19
2	0	4	0.06	37	2.7	135	15.41
3	0	6	0.08	39	3.3	178	13.53
4	10	2	0.05	30	2.3	162	17.03
5	10	4	0.05	31	2.4	188	15.59
6	10	6	0.06	28	2.8	212	13.89
7	30	2	0.03	22	2.0	185	17.11
8	30	4	0.04	25	2.1	210	15.39
9	30	6	0.05	27	2.3	253	13.90

Table III: EMISSION for B0, B10, B30 Fuel

Ex. No.	Blend Ratio (%)	Load (kg)	BP (kw)	SFC (kg/kwhr)	BTE (%)
1	0	2	0.5848	0.6836	12.283
2	0	4	1.7598	0.2555	32.869
3	0	6	2.8632	0.1919	43.760
4	10	2	0.5848	0.6862	12.263
5	10	4	1.7598	0.2850	29.523
6	10	6	2.8632	0.2102	40.029
7	30	2	0.5848	0.6928	12.169
8	30	4	1.7598	0.2877	29.307
9	30	6	2.8632	0.2121	39.740

Table IV: Result parameters for B0, B10, B30 fuel

Ex. No.	Blend Ratio (%)	Load (kg)
	0	2
	0	4
	0	6
	10	2
	10	4
	10	6
	30	2
	30	4
	30	6

Table I: L9 Orthogonal array levels

C. Engine Observation

Ex. No.	Blend Ratio (%)	Load (kg)	FC (kg/hr)	Torque (N-m)
	0	2	0.3998	3.7228
	0	4	0.4498	11.2034
	0	6	0.5497	18.2274
	10	2	0.4013	3.7228
	10	4	0.5016	11.2034
	10	6	0.6019	18.2274
	30	2	0.4052	3.7228
	30	4	0.5063	11.2034
	30	6	0.6075	18.2274

Table II: Experimental Observations for B0, B10, B30 Fuel

III. RESULT AND DISCUSSION

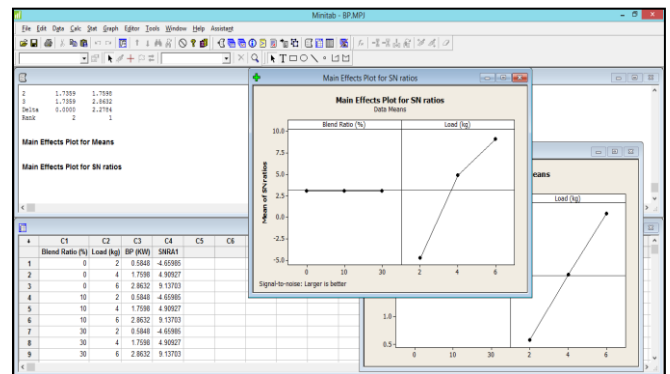


Fig. 4: Minitab Sheet for Brake Power

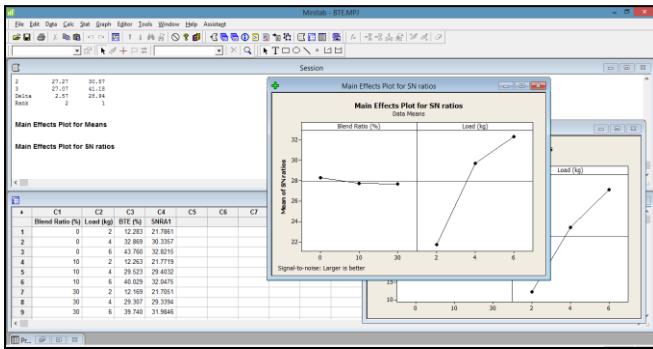


Fig. 5: Minitab Sheet for BTE

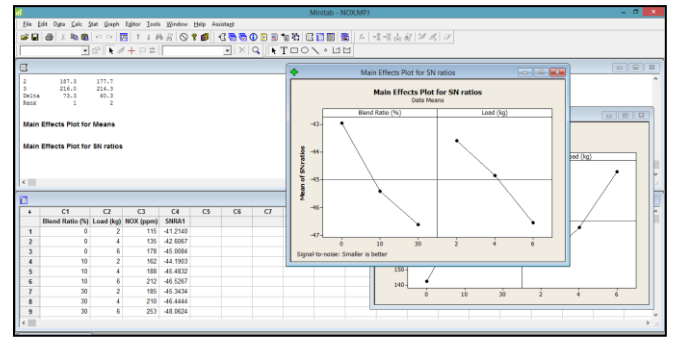


Fig. 10: Minitab Sheet for NO_x

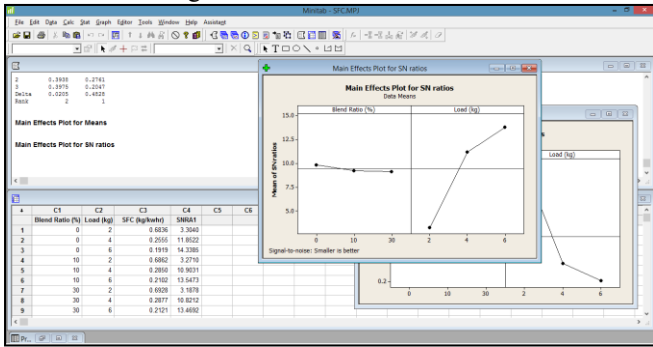


Fig. 6: Minitab Sheet for SFC

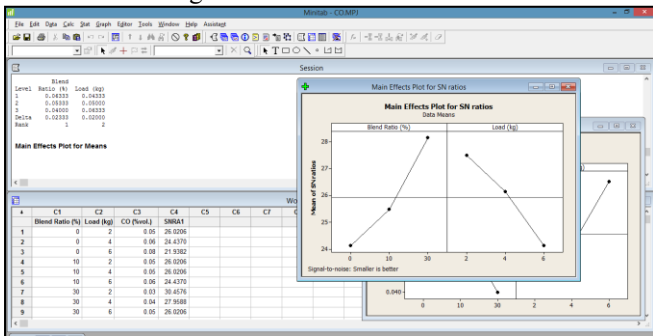


Fig. 7: Minitab Sheet for CO

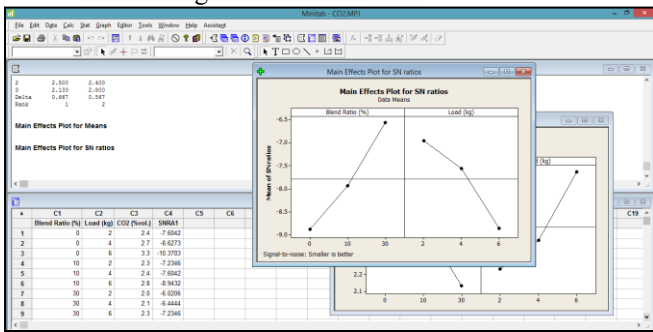


Fig. 8: Minitab Sheet for CO₂

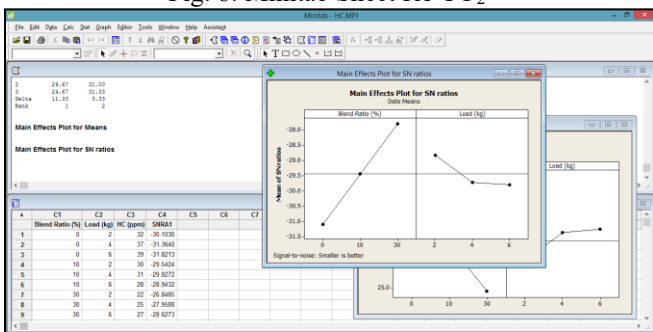


Fig. 9: Minitab Sheet for HC

IV. CONCLUSION

Mahua biodiesel–diesel blends of 0% (B0), 10% (B10), and 30% (B30) by volume were used in the experimental study. The study's primary controllable parameters were engine load (2 kg, 4 kg, and 6 kg) and fuel blend ratio. The best parameter combinations for performance and emission parameters, such as Brake Power (BP), Specific Fuel Consumption (SFC), Brake Thermal Efficiency (BTE), and exhaust emissions (CO, CO₂, HC, NO_x), were found using the Taguchi method.

A. Brake Power (BP)

- The analysis indicates that engine load has the most significant influence on brake power, whereas the fuel blend has a comparatively minimal effect.
- Brake power increases with increasing load due to higher fuel input and combustion pressure.

B. Specific Fuel Consumption (SFC)

- The optimal parameter combination for minimum SFC is:
 - Blend: 0% (B0)
 - Load: 6 kg
- It was observed that:
 - Load has the dominant effect, while blend has a minor influence.
 - SFC increases with increasing biodiesel percentage, primarily due to:
 - Lower calorific value of biodiesel
 - Higher viscosity leading to poorer atomization

C. Brake Thermal Efficiency (BTE)

- The optimal parameter combination for maximum BTE is:
 - Blend: 0% (B0)
 - Load: 6 kg
- Observations:
 - Engine load is the most influential parameter.
 - BTE decreases with increase in biodiesel content, due to:
 - Lower heating value of biodiesel
 - Incomplete combustion characteristics at higher blends

D. Carbon Monoxide (CO) Emission

- The optimal parameter combination for minimum CO emission is:
 - Blend: 30% (B30)

- Load: 2 kg
- Findings:
 - Fuel blend has the maximum influence, while load has minimal impact.
 - CO emission decreases with increasing biodiesel content due to:
 - Presence of inherent oxygen in biodiesel
 - Improved oxidation of carbon during combustion

E. Carbon Dioxide (CO₂) Emission

- The optimal parameter combination for minimum CO₂ emission is:
 - Blend: 30% (B30)
 - Load: 2 kg
- Observations:
 - Blend is the dominant factor.
 - CO₂ emission decreases with increasing biodiesel percentage, indicating reduced carbon content in fuel.

F. Hydrocarbon (HC) Emission

- The optimal parameter combination for minimum HC emission is:
 - Blend: 30% (B30)
 - Load: 2 kg
- Findings:
 - Blend has the maximum effect.
 - HC emissions decrease with higher biodiesel blends due to:
 - Better combustion efficiency
 - Oxygenated nature of biodiesel

G. Nitrogen Oxides (NO_x) Emission

- The optimal parameter combination for minimum NO_x emission is:
 - Blend: 0% (B0)
 - Load: 2 kg
- Observations:
 - Blend significantly influences NO_x formation.
 - NO_x emissions increase with increasing biodiesel content, due to:
 - Higher combustion temperatures
 - Excess oxygen availability promoting NO_x formation

H. Overall Technical Summary

- Engine load predominantly affects performance parameters (BP, SFC, BTE).
- Fuel blend ratio has a stronger influence on emission characteristics (CO, CO₂, HC, NO_x).
- Biodiesel blends improve emission performance (except NO_x) but reduce engine efficiency metrics due to lower calorific value.

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