Optimization production of simarouba biodiesel and performance study using design of Experiments in CI engine

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Abstract- In the areas of transportation, industrial development, and agriculture, petroleum fuel is important. Urbanization, rapid population expansion, and growing automotive density all contribute to an annual rise in the demand for petroleum products. Diesel engines have numerous uses, but they are also notorious for their harmful pollutant emissions that threaten human and environmental health. That's why it's crucial to find a new way to provide the world's energy needs. In this context, biofuels have emerged as one of the alternative viable treatments. Recent advances in nanotechnology have led scientists to investigate the possibility of employing nanoparticle, diesel biodiesel fuel mixes to enhance efficiency, cleaner combustion, performance, and emission characteristics. Many improvements in chemical and thermal physical characteristics of changed fuel were observed. As a result, the objective of our research is to assess the performance of a diesel engine supplied with a fuel containing a mixture of biodiesel and aluminium oxide nanoparticles as well as to find out more about the engine's emission characteristics. Compression ratio and injection pressure are only two of the variables played with to get the desired outcomes. As a result of this effort, we will be able to replace petroleum with a fuel made from nanoparticle-blended biodiesel.

Keywords*- Aluminium Oxide (Al_2O_3) Nanoparticles, Waste cooking oil Biodiesel, Diesel, Statistical Analysis, CI Engine*.

I. INTRODUCTION

Petroleum resources as fuels are running out every day, and the need for fuels, combined with increasingly stringent laws, is a challenge for science and technology. Vegetable oils, both edible and inedible, can be used to refuel non-compression ignition automobiles. Pungai, Jathropa curcas, Paradise Tree Oil, among others, are available non-food biodiesel feedstocks. The main disadvantage of vegetable oils is that their viscosity is substantially higher than that of diesel. As a result, fuel injection systems in diesel engines are extremely sensitive to changes in viscosity. Vegetable oils have a high viscosity that inhibits atomization and can result in a variety of problems, including poor combustion, injector jamming, distributor pump failure, ring sticking, dilution of lubricating oil from crankcase polymerization, and deposits in injectors. Vegetable oil with a lower viscosity is better for engine performance. Multiple additional methods, such as mixing and heating, were also explored by the researchers in an attempt to reduce viscosity. After being mixed, the oil's viscosity decreased, and its volatility increased. When the free fatty acid value is more than 10, long-chain triglycerides are converted into biodiesel utilising a two-step method.(Sharun Mendonca, 2018). When blended with diesel fuel, biodiesel improves both engine efficiency and exhaust emissions. Due to the greater oxygen content of biodiesel, exhaust gas nitrogen oxides (NOX) are raised while carbon monoxide and hydrocarbon emissions are decreased. Because to inefficient atomization, biodiesel's viscosity, pour point, and calorific value are all enhanced, leading to decreased effectiveness. (Jaikumar Methre, 2019). Biodiesel can be used alone or in any combination with diesel. In India, non-edible sources include Jathropa curcas, Simarouba, Honge and others. The feedstock, i.e. the processing methods and the vegetable oils, influence the characteristics of the biodiesel fuel, which are in turn determined by the viscosity of the feedstock. Nanofluids with a high surface-to-volume ratio will keep burning more thoroughly and productively. (Sharun Mendonca, 2018).

II. LITERATURE SURVEY

There are many ways to improve the properties of fuels and engines, and one of them is the use of nanoparticles. Nanoparticles have several advantages, including higher enthalpy of combustion, more complete combustion, lower pollutant emissions and so on (Vishal Saxena, 2017). Nanoparticles added to biodiesel provide a significant improvement in thermophysical properties and make it the best alternative to conventional diesel fuel with lower pollutant emissions. In order to enhance the engine's operational characteristics as a whole, scientists are conducting experimental examinations of key performance indicators including emissions, engine performance, and combustion parameters (Tina Kegl, 2020).

Various biodiesel blends with different proportions of CeO2 were produced using ultrasound technology (S. Ganesan J. S., 2018; Vishal Saxena, 2017). Parameters having numerous replies were optimized using grey relational analysis, and the resulting single response was employed in further analyses (S. Ganesan S. P., 2020). The Taguchi approach was used to evaluate the experimental data, and the findings showed that utilising biodiesel in a diesel engine is feasible without modifying the engine. The B30 blend was shown to be the most effective in experiments, producing diesel-like engine performance with less emissions. (S. Ganesan J. K., 2020) (B.R. Ramesh Bapu, 2020).

Nanofluids have a stated maximum stability of 7-17 days in liquid fuels, making it difficult to use nanoparticles in diesel-biodiesel blends. Studies have shown that the probability of agglomeration is high when nanoparticles are added to diesel (Vishal Saxena, 2017). With the addition of a specific amount of nano-additive to biodiesel, both the thermal efficiency and the rate of heat release both rise linearly. He arrived at the conclusion that diesel engines benefit from nano-additives because they boost mechanical performance while lowering emissions. (C. Syed Aalam, 2015) (D.K. Ramesh, 2018) (Manzoore Elahi M. Soudagar, 2018).

A case study looked at the application of nanoparticles and nanofluids in compression ignition engines.In order to boost diesel engines' efficiency, emissions, and combustion, metallic additives are sometimes mixed in with diesel fuel. Improved heat/mass transport and radioactive characteristics are seen when a base fluid is combined with nano-sized metallic additives/carbon nanotubes (CNTs). There is hope that if the fuel's thermophysical qualities can be enhanced, the ignition delay and droplet evaporation time in a diesel engine may be cut down. The addition of diesel fuel to the nanoparticles shouldn't, however, result in a novel form of air pollution. To reduce emissions, research on the quantity and degree of stability of nanoparticles in a base fluid is required. (singh, 2020) (Thakur, 2015) (Himanshu Tyagi, 2008) (S. Jaichandar, 2012).

III. EXPERIMENTAL PROCEDURE

3.1. Selection of Biodiesel

Biodiesel fuels are the ideal alternative to diesel oil because they are renewable, environmentally friendly, non-toxic and sulphur-free. The viscosity and other properties of virgin oil are altered by the transesterification process (R. Anand, 2010). First, the Simarouba seeds are collected and dried in the heat of the sun. The seeds are ground in a mechanical extraction process. Compression ignition (CI) engines are incompatible with vegetable Simarouba oil due to its high viscosity. (Soon Zheng Fai, 2022). The oil yield is calculated using formula weight of the simarouba oil produced to the weight of the simarouba seeds used. The oil yield is obtained 58%in mean. The extracted simarouba oil properties are checked to find the suitability in the engine. The properties tested are Free fatty acid (FFA), specific gravity, acid value, viscosity, moisture content and iodine value. Into the flask goes a combination of simarouba oil and methanol. There will be one hour of heating at 650 degrees Celsius and stirring in this flask. Biodiesel and glycerine are created using potassium hydroxide as a catalyst. Three washing methods are used to remove the glycerine from the biodiesel. In order to determine how much biodiesel may be produced from a given amount of simarouba oil, a formula is being used.

3.2. Biodiesel Blend Preparation

The B20 biodiesel blend is made from 80% diesel and 20% waste oil biodiesel. Engines running on B20 deliver the best performance compared to other biodiesel blends,

3.3. Nanoparticles Selection

The selected alumina nanoparticles with a size of 50 nm support the literature work. Diesel with nanoparticles in it has a higher heat transfer capacity and a longer ignition delay than regular diesel. (Mohammed S Gad, 2021).

3.4. Preparation of Nano-Biodiesel Blend

An ultrasonic bath is best for the preparation of mixtures. At a level of 50 parts per million, the nanoparticles are added to the B20 biodiesel. To mix alumina nanoparticles in biodiesel, we took a 1 litre sample of B20 and added 0.050 g of alumina nanoparticles to achieve a dosage of 50 ppm (C. Syed Aalam, 2015). After adding the alumina nanoparticles, it is thoroughly shaken, then poured into an ultrasonic bath and stirred for about 30 minutes. It must then be shaken thoroughly before use, as the silent nanoparticles settle to the bottom of the solution (Rushdan Ahmad Ilyas, 2018).

Fig 1: Bath Type Ultrasonicator

3.5. Properties of Fuel

Biodiesel, B20, and B20 with added Al2O3 (at a concentration of 50 ppm) had their characteristics evaluated. The flash point and burning point were determined using the Cleveland Open Cup apparatus. Kinematic viscosity was measured using a Redwood viscometer, and calorific value was calculated using a bomb calorimeter. Density figures for all three fuel types were also determined. You may find the property values in the table below.

Table 1: Properties of Fuel

Properties	Diesel	B20	B20+50 ppm Al_2O_3
Flash point °C	64	68	68
Fire point °C	69	72	73
Kinematic viscosity at 40°C	0.0457	0.0456	0.0458
Calorific value kJ/kg	41627.04	40261.5	40289
Density kg/m^3	0.8208	0.8362	0.837

3.6. Experimentation

For the experiment, a single-cylinder, four-stroke VCR diesel engine with computer control is coupled to an eddy current dynamometer that generates loads. The fundamental design of the experimental apparatus is shown in Fig. The engine soft software package is offered to examine the engine performance from a lab perspective in order to accurately evaluate performance. Data acquisition can be done in real time by connecting the experimental setup to a computer via the software. The experiment was conducted with different fuel mixtures.

Table 2: Engine specifications

Engine parameters	**Specifications**
No. of cylinders	1
No. of strokes	4
Fuel	High Speed Diesel
Rated power	3.5 kW @1500 RPM
Cylinder diameter	87.5 mm
Stroke length	110 mm
Connecting rod length	234 mm
Compression ratio	12 to 18:1
Orifice diameter	20 mm
Dynamometer arm length	185 mm

Tests were conducted to evaluate engine performance and emissions by varying injection timing and compression ratio.

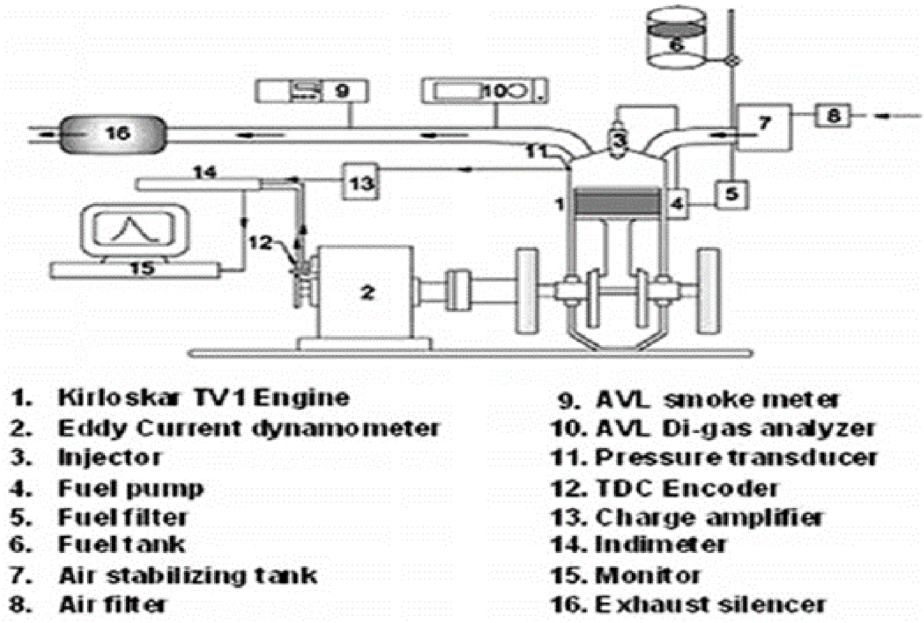

Fig 2: Engine setup

IV. DESIGN OF EXPERIMENTS

The Taguchi approach was used to develop the experimental strategy.Table 3 lists the variables that can be controlled and the values that were chosen for the study (Vezir Ayhan, 2020).

Table 3: The Controllable Factors and Levels Selected

Symbol	Factor	Level 1	Level 2	Level 3
A	Fuel	Diesel	biodiesel	B20+50 ppm
B	Injection timing	23	19	25
C	Compression ratio	17.5	17	18
D	load	6	9	12

s mentioned in the table, 4 factors and 3 stages were considered. Fuel (3 stages; diesel, biodiesel, B20+), injection timing (3 stages; 23,19,25), compression ratio (3 stages; 17.5,17,18) and load (3 stages; 6,9,12) were selected. Full factorial experimental designs have a detrimental effect on time and expense because of the massive number of trials required to reach statistical significance. The Taguchi experimental design use orthogonal experimental designs to carry out many elements and levels of variables with a minimum number of trials. During the experiment, the orthogonal arrangement is the mapping from one factor's values to those of the others (Vezir Ayhan, 2020).

Based on the components and the number of levels chosen and entered, a suitable orthogonal array (OA) was built for this inquiry using the Minitab application. The OA, denoted by L27 in Table 4, is shown (34). The following table displays the results of 27 independently replicated experiments. Using the data acquired during the engine testing, estimates for the engine performance metrics of brake specific fuel consumption (BSFC) and brake thermal efficiency were created (BTE). Gas analyzers were utilised to track the emission characteristics of carbon monoxide, hydrocarbons, and nitrogen oxides (CO). The averages of the parameters from the three runs were used for the calculations and the analysis (Vezir Ayhan, 2020).

The most essential feature of the Taguchi experiment is the signal-to-noise ratio. The signal-to-noise ratio will be high if the brake has a high thermal efficiency, and it will be even higher if the brake has a low specific fuel consumption and low emissions.(Vezir Ayhan, 2020). The following are the S/N ratio formulas:

1. Higher is better:

$$\textbf{S/N} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{y_i}^2}\right]$$

2. Lower is better;

$$\textbf{S/N} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}{y_i}^2\right]$$

Where the n in the OA stands for the quantity of trial repetitions, the yi for the measured value, and the I for the quantity of design parameters.(Vezir Ayhan, 2020).

S/N ratios for all of the performance indicators and emissions were examined. In light of the findings, the most effective combinations were chosen, and Analysis of Variance (ANOVA) was conducted to determine the relative importance of each element. (Vezir Ayhan, 2020). The analysis of variance (ANOVA) equations are as follows:

$$\textbf{SST} = \left[\sum_{i=1}^{N}\left(\frac{S}{N}\right)i^2\right] - \frac{T^2}{N}$$

$$\textbf{SSA} = \left[\sum_{i=1}^{K_A}\left(\frac{{A_i}^2}{n_{Ai}}\right)\right] - \frac{T^2}{N}$$

Vtotal = N-1

Vfactor = $\frac{SS_{factor}}{\vartheta_{factor}}$

Ffactor = $\frac{V_{factor}}{V_{error}}$

Table 4: L27 Orthogonal Array for Experiment

Fuel	IT	CR	Load
1	1	1	1
1	1	2	2
1	1	3	3
1	2	1	2
1	2	2	3
1	2	3	1
1	3	1	3
1	3	2	1
1	3	3	2

2	1	1	2
2	1	2	3
2	1	3	1
2	2	1	3
2	2	2	1
2	2	3	2
2	3	1	1
2	3	2	2
2	3	3	3
3	1	1	3
3	1	2	1
3	1	3	2
3	2	1	1
3	2	2	2
3	2	3	3
3	3	1	2
3	3	2	3
3	3	3	1

4.1: Minitab Results

4.1.1. Engine Performance Parameters

4.1.1.1. Brake Specific Fuel Consumption

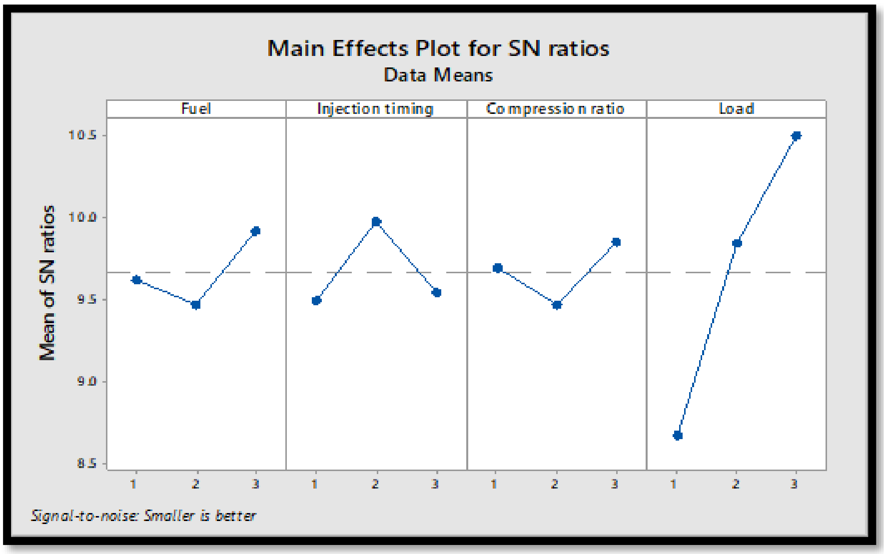

Fig 3: S/N Values of Factor Levels for BSFC.

Fig 3. Shows Using the Taguchi approach, determine the elements that influence engine brake fuel usage (Vezir Ayhan, 2020). The optimum BSFC value was obtained at B20+50 ppm Al_2O_3 fuel, 19^0bTDC injection timing, 18 compression ratio, 12 kg load. The best combination is "A3-B2-C3-D3". A greater BSFC will come from an engine's increased fuel consumption at a given load when using gasoline with a higher viscosity and lower calorific value (Mohit Vasudeva, 2016). Due to the fact that the percentage increase in braking power with load is greater than the percentage increase in fuel consumption, it was found that BSFC decreases with increasing load.

The components are effective for a certain fuel usage in the range of 98.16 percent to 99.58 percent, according to the ANOVA findings. The most effective characteristic is engine load, followed by ignition timing and fuel, with compression ratio being the least effective (Vezir Ayhan, 2020).

4.1.1.2. Brake Thermal Efficiency

Fig. 5 displays the results of a Taguchi study of the factors affecting brake thermal efficiency. (C. Syed Aalam, 2015). Through testing, we found that the best BTE value was produced by diesel fuel, 190 bTDC injection time, a load of 12 kg, and an 18:1 compression ratio.The ideal set up is "A1-B2-C3-D3". As the fuel is fed at a greater temperature and pressure, a more complete combustion occurs as the compression ratio is increased. As a result of decreased heat loss and increased power, the BTE rises with increasing load for all tested fuel mixtures.

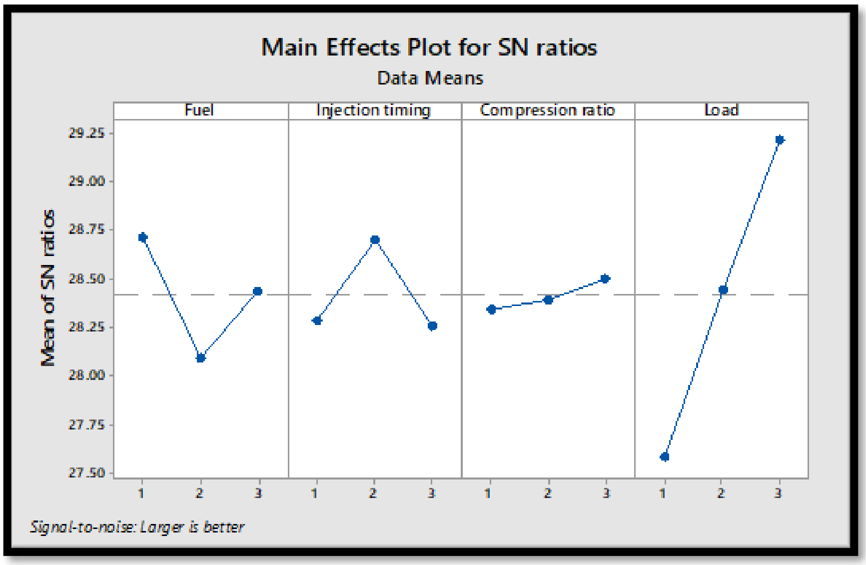

Fig 5: S/N Values of Factor Levels for BTE

According to the analysis of variance, the optimal range for the thermal efficiency of brakes is between 95.43% and 99.58%. In order of efficacy, engine load is best, then fuel and ignition timing and fuel, and last compression ratio.

4.1.2 Emission Parameters

4.1.2.1 Hydrocarbon Emission

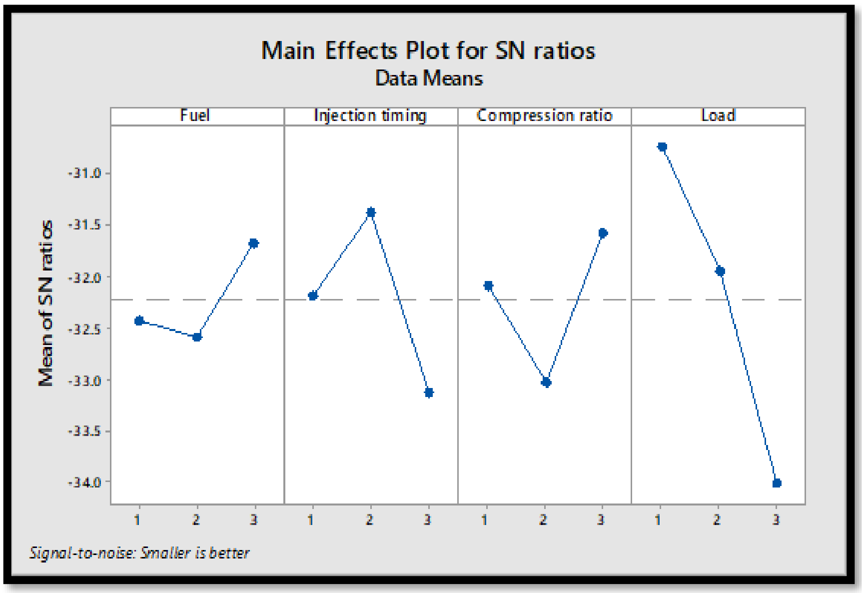

Fig 6: S/N Values of Factor Levels for HC

To show how the Taguchi approach might be used to analyze the causes of hydrocarbon emissions, consider the graphic in Fig. 6. Using B20+50 ppm Al2O3 fuel, 190bTDC injection time, 18 compression ratio, and 6 kg load, the highest HC value was achieved. It's why "A3-B2-C3-D1" is the optimal sequence. The decrease in hydrocarbon emissions is due to an increase in oxygen-based fuel (Vezir Ayhan, 2020). If the load is increased, more fuel is added, which in turn increases HC emissions. Reduced exhaust gas temperature results from delayed ignition, which slows the oxidation process of unburned hydrocarbons. The combustion of the biodiesel is improved by the presence of additional oxygen, and HC emissions are reduced as a result of the higher temperatures produced by increasing the compression ratio.

Using an analysis of variance on experimental data, we find that the variables' effectiveness for reducing hydrocarbon emissions falls in the range of 88.64% and 97.38%. (Vezir Ayhan, 2020). The load on the engine is the single most important factor, followed by the ignition timing and the compression ratio, and lastly the fuel.

4.1.2.2. Carbon Monoxide Emission

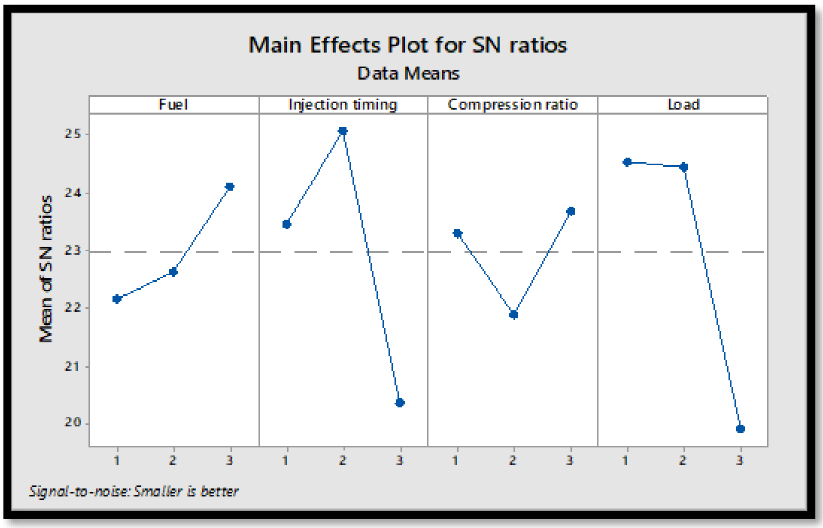

Fig 7: S/N Values of Factor Levels for CO

By using the Taguchi approach, Fig.7 displays the variables that influence CO2 emission. With B20+50ppm Al2O3 fuel, 190 bTDC injection time, 18 compression ratio, and 6 kg load, the highest CO value was achieved. "A3-B2-C3-D1" is the ideal combo. When utilised as fuel, biodiesel's increased combustion impact from the oxygen content resulted in fewer CO emissions. (Vezir Ayhan, 2020). When the workload is increased, more fuel is delivered, leading to a higher CO production. Increased temperature results from a larger compression ratio, and oxygen added to biodiesel will improve combustion, resulting in reduced CO emission levels.

Experimental data was analyzed using an ANOVA procedure, and the findings showed that the variables had an efficacy of between 98.95% and 99.58% (Vezir Ayhan, 2020) with regard to carbon monoxide emission. Compression ratio is the least important factor whereas engine load is the most important factor. Ignition timing and fuel also play crucial roles.

4.1.2.3. Oxides of Nitrogen Emission

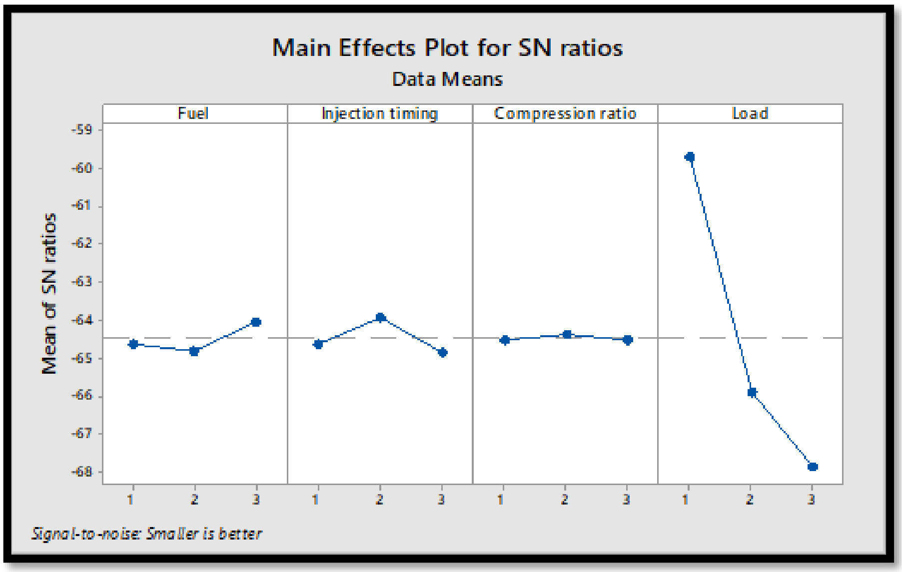

Fig 8: S/N Values of Factor Levels for NOx

Nitrogen oxides emission factors as determined by the Taguchi approach are shown in Fig.8. B20+50 ppm Al2O3 fuel, 190 bTDC injection time, 17 compression ratio, and 6 kg load yielded the lowest NOx value. The optimal combination is [A3] + [B2] + [C2] + [D1]. Because biodiesel has a high oxygen content and thus improves combustion, using fuel mixes that include it led to decreased NOx emissions. (Vezir Ayhan, 2020). As load is increased more fuel is supplied which in turn increases NOx emission. Increase in combustion temperature takes place as we increase compression ratio which increases NOx formation.

Experiment data was analyzed using an ANOVA procedure, and the findings showed that the components were accountable for a reduction in Nitrogen oxides of between 98.23% and 99.59% (Vezir Ayhan, 2020). Engine load is the most effective parameter followed by ignition timing and fuel whereas compression ratio is the least effective parameter.

V. RESULTS AND DISCUSSION

The engine was noted to operate exceptionally quietly under the rated load. We contrast and analyse the engine performance and emission characteristics of diesel, B20, and fuels containing aluminium oxide nanoparticles.

5.1 Engine Performance Parameters

5.1.1. Brake Thermal Efficiency(BTE)

Figure 9. All fuels evaluated at varying engine loads are shown in the diagram, along with the link between brake thermal efficiency and load. An increase in engine load is accompanied by a rise in brake thermal efficiency, as shown by the data. According to the results, the WBW of all fuel blends improved continuously over the base diesel at all engine loads (Y.H. Teoh,

2019). This might be as a result of the increased power and decreased heat loss that occur along with an increase in load. The thermal efficiency of the engine is increased by adding more ester to the mixtures. (Shiva Kumar, 2019).

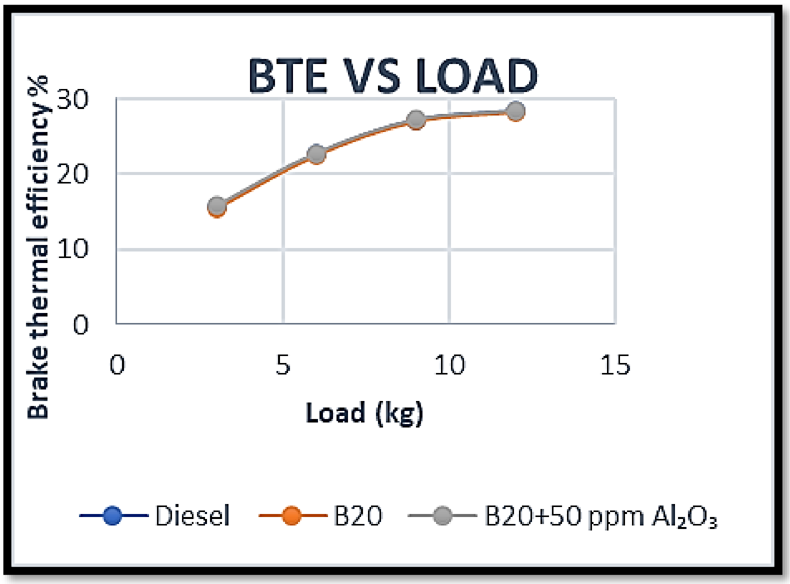

Fig 9: Brake Thermal Efficiency Vs Load

5.1.2. Brake Specific Fuel Consumption(BSFC)

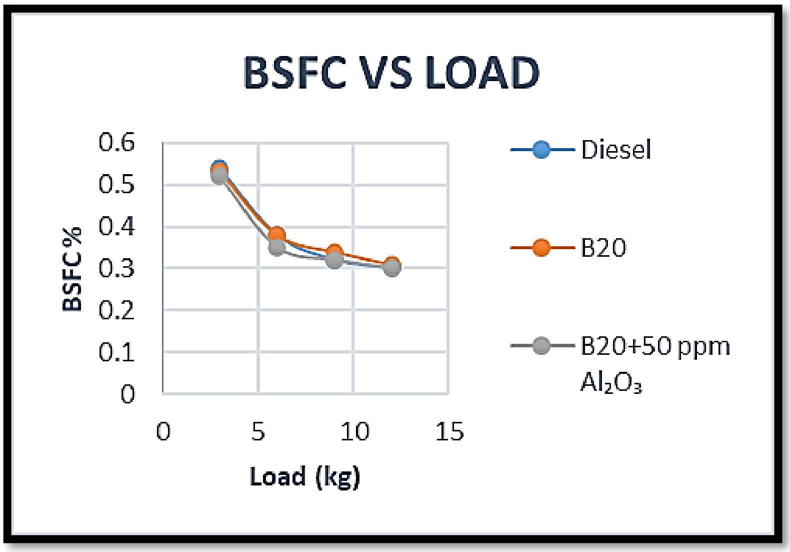

Fig 10: Brake Specific Fuel Consumption Vs. Load

As a function of brake load, diesel, diesel mixed with biodiesel (B20), and B20 blended with 50 ppm alumina nanoparticles all display various patterns of fuel use (see Figure 10). The BSFC increases as the Al2O3 nanoparticles oxidise the carbon particles in the engine cylinder, enhancing combustion and cutting fuel consumption. Al2O3 nanoparticles were added, which boosted the fuel's density while decreasing its calorific value. Under the same operating conditions, a greater BSFC is achieved by injecting more fuel into the mixture while its density is higher. (Harish Venu, 2016).

5.2. Emission Parameters

5.2.1. Hydrocarbon Emission

The following diagram shows the hydrocarbon emissions as a function of loading for diesel, B20 and B20 with 50 ppm alumina nanoparticles as an admixture. We discover that blending biodiesel fuel with 50 ppm Al2O3 greatly lowers HC emissions at the same load and that adding 20% biodiesel to pure diesel reduces HC emissions. Because biodiesel is less volatile than diesel, it has a greater effect on the variation in HC emissions at low engine loads. The biodiesel mixture was supplemented with alumina nanoparticles to enhance combustion and lower HC production.

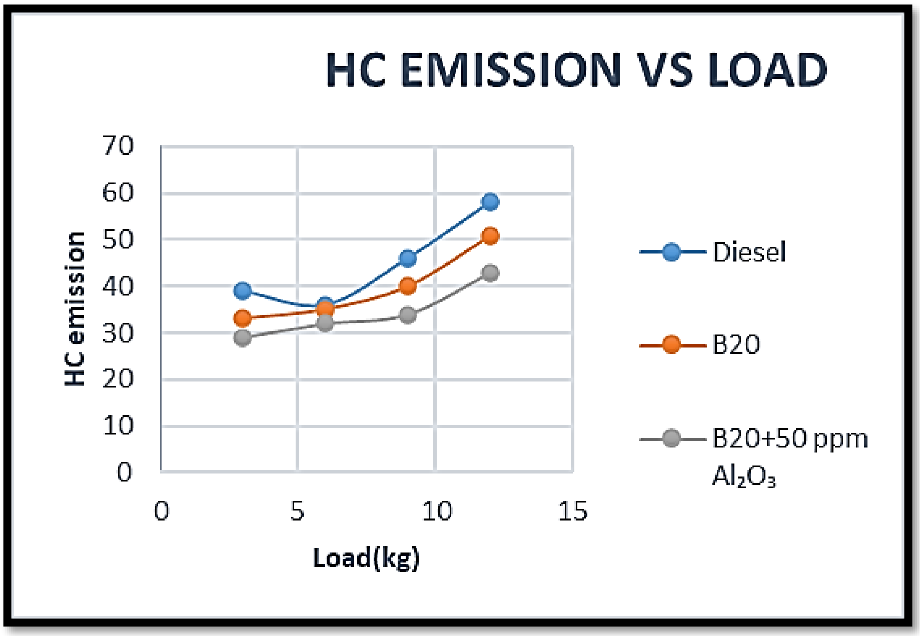

Fig 11: Hydrocarbon Emission Vs Load

5.2.2. Carbon Monoxide Emission

Figure 12 CO Emissions as a function of load for diesel, diesel combined with biodiesel (B20) and B20 with 50 ppm alumina nanoparticles. Due to improvements in the combustion process, it was found that as the load increases, so do the CO emissions. The diagram shows that pure diesel emits a lot of CO, while B20 mixed with nanoparticles emits the least and Waste Cooking Oil mixed with diesel emits a lot of CO. Adding alumina nanoparticles, which function as an oxidation catalyst and encourage more complete burning, reduced CO emissions. (Siddavatam Naresh Kumar Reddy, 2021) (Tamilvanan A., 2020).

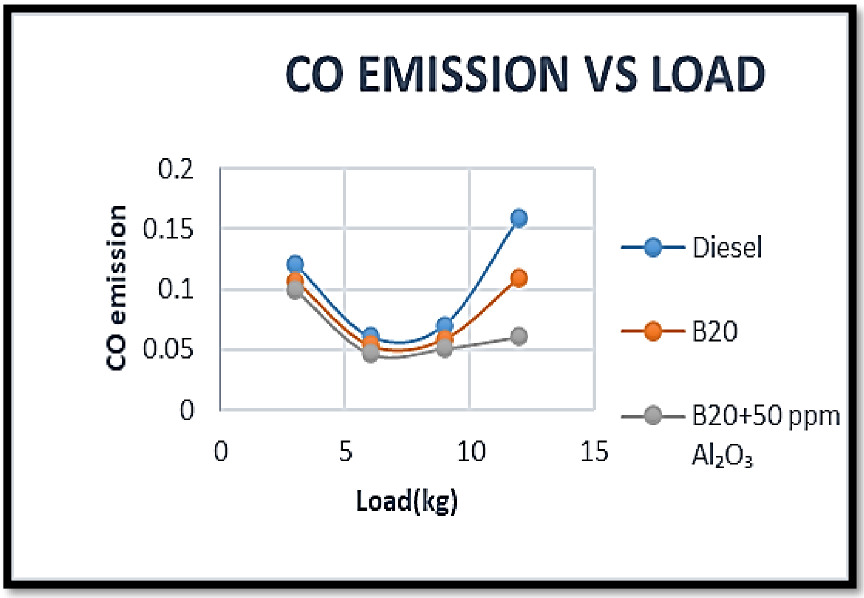

Fig 12: Carbon Monoxide Emission Vs Load

5.2.3. Oxides of Nitrogen Emission

For diesel, B20, and biodiesel blends with the inclusion of nanoparticles, variation in NOx emissions with load is shown visually. For all of the investigated fuel types, NOx emissions increase as the load increases. When compared to B20 and diesel, NOx emissions from biodiesel are reduced because to the inclusion of Al2O3 nanoparticles. Biodiesel emits the greatest NOx compared to all other combinations because of its low calorific value.However, compared to B20 and diesel, NOx emissions from biodiesel-nanoparticle blends were lower. This is due to the fact that biodiesel-Al_2O_3-nanoparticle blends have better combustion properties because of the catalytic effect and better reactivity due to the larger surface area (Sneha Nayak, 2018).

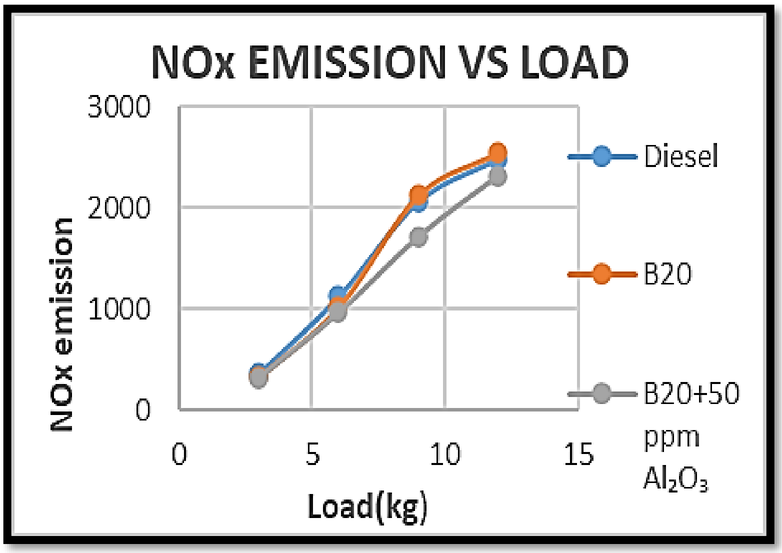

Fig 13: Oxides of Nitrogen Emission Vs Load

VI. CONCLUSION

- The properties of simarouba biodiesel measured with ASTM D6751 and EN 14214 specifications.
- In this work, aluminum oxide nanoparticles, which are rich in oxygen, were introduced to a diesel-biodiesel fuel combination in order to enhance its combustion quality (Mani Ghanbari, 2021).
- It has been demonstrated that alumina nanoparticles can enhance performance and reduce emissions from diesel engines with straightforward designs. As a result, it becomes an intriguing candidate for usage as an alternative fuel in the effort to reduce air pollution in big cities (Mani Ghanbari, 2021).
- The Taguchi technique for optimising certain design elements of a diesel engine for low emissions was investigated using a single-cylinder diesel engine. The Taguchi approach may be used to understand how engine design and operation affect emissions. While changing three parameters simultaneously, an attempt was made to optimise the engine's responses by including several parameters.

VII. FUTURE SCOPE

Diesel fuel is five times more popular than petrol in India due to the widespread use of diesel engines in transport, earthmoving equipment and heavy vehicles. Diesel may be replaced with several alternative energies, such as biodiesel, biogas, and alcohol. Due to its similarity in qualities to diesel fuel but lower pollution output, biodiesel may be mixed with diesel fuel at varying proportions. It is also renewable, non-toxic and sulphur-free. Biodiesel as a base fuel with nanoparticles as a stabiliser is in high demand as it can reduce exhaust emissions, pollution and performance compared to diesel. Biodiesel is also cost-effective as it is made from recycled materials such as animal fat and vegetable oil, which are less expensive than fossil fuels. Nanoparticles are proven to be effective in reducing pollutants and emissions (Nitin Uttamrao Kautkar, 2022).

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