Investigation of Algae and Corn Biodiesel Blends in a Diesel Engine

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Abstract
The increasing demand for renewable energy sources has prompted significant research into alternative fuels, particularly biodiesel. This study investigates the performance and emissions characteristics of biodiesel blends produced from algae oil and corn oil in a diesel engine. Algae and corn are both promising feed-stocks for biodiesel production due to their high oil content and rapid growth rates. The experiment involved blending algae biodiesel (A-B20) and corn biodiesel (C-B20) at different concentrations with conventional diesel (D100) and testing them in a single-cylinder, direct-injection diesel engine. The engine performance was assessed by measuring parameters such as brake thermal efficiency (BTE), specific fuel consumption (SFC), and exhaust emissions, including nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO_2), and particulate matter (PM). The results indicated that biodiesel blends, particularly algae and corn biodiesel, show a potential for improved combustion efficiency compared to pure diesel, with algae biodiesel blends exhibiting slightly better overall performance. Additionally, the biodiesel blends demonstrated reduced particulate emissions and CO levels, while NOx emissions were observed to increase. The study suggests that algae and corn biodiesel blends are viable alternative fuels for diesel engines, offering environmental benefits, though further optimization of blend ratios and engine calibration is necessary to minimize NOx emissions.

Keywords: Algae biodiesel, Corn biodiesel, Diesel engine, Emissions, Alternative fuels, Biodiesel blends, Engine performance.

1. Introduction

The growing concerns over environmental degradation, greenhouse gas emissions, and the depletion of fossil fuel reserves have led to an urgent need for sustainable and renewable energy alternatives. Among the various alternatives, biodiesel has emerged as a promising renewable fuel that can be used in diesel engines with minimal modifications. Biodiesel is derived from renewable biological sources such as vegetable oils, animal fats, and algae. It is a clean-burning alternative that offers reduced carbon emissions and is biodegradable, making it an environmentally friendly choice compared to conventional diesel fuel [1]. Algae, due to its high lipid content, rapid growth, and ability to grow in diverse conditions, has garnered considerable attention as a potential feedstock for biodiesel production. Similarly, corn is one of the most widely cultivated crops globally, and its oil can also be converted into biodiesel. Both algae and corn have the potential to significantly contribute to biodiesel production, offering an opportunity to diversify feedstock sources and reduce reliance on traditional agricultural oils like soybean and palm oil [1].

Biodiesel derived from these sources, when blended with conventional diesel, can alter engine performance and emissions. Engine performance parameters such as brake thermal efficiency (BTE), specific fuel consumption (SFC), and exhaust emissions are influenced by the chemical composition and combustion characteristics of the biodiesel blends. Moreover, the emissions produced from biodiesel combustion, including nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO_2), and particulate matter (PM), are key factors in determining the environmental impact of these fuels. This study aims to evaluate the performance and emissions characteristics of biodiesel blends made from algae and corn oils in a diesel engine. The focus is on determining how these biodiesel blends affect the engine's efficiency and emission profile, providing insights into their feasibility as sustainable fuel alternatives for diesel engines. Through a series of experiments, this research will compare algae and corn biodiesel blends against conventional diesel fuel, thereby contributing to the understanding of the potential of these alternative fuels in real-world engine applications [2].

2. Algae Biodiesel Pilot Plant

2.1 Algae Cultivation System: The first step in algae biodiesel production is growing the algae. This is usually done in either open pond systems or closed photobioreactors.

- **Open pond systems** are large, shallow ponds that utilize natural sunlight and CO_2 for algae growth. They are cheaper but more prone to contamination.
- **Photobioreactors (PBRs)** are closed systems designed to provide better control over the growth environment and prevent contamination, although they are more expensive to build and operate [1].

2.2 Harvesting and Dewatering: Once algae have grown to a sufficient concentration, it needs to be harvested and separated from the water. Common methods include:

- **Flocculation:** The process of adding chemicals or using electrical charge to aggregate the algae, making it easier to separate.
- **Centrifugation:** Spinning the algae culture at high speeds to separate algae from water.
- **Filtration:** Passing the culture through a mesh or filter to collect the algae biomass.

2.3 Oil Extraction: Algae are rich in lipids (oils), which are crucial for biodiesel production. The oil is extracted from the algae biomass through processes such as:

- **Solvent extraction:** Using chemical solvents (e.g., hexane) to dissolve the oils.
- **Mechanical pressing:** Physically pressing the algae biomass to extract oil [2].

- **Supercritical CO_2 extraction:** A more advanced and environmentally friendly method that uses CO_2 at high pressure and temperature to extract oils.

2.4 Transesterification Process: The extracted algae oil is then converted into biodiesel through a chemical process called transesterification. In this process, the oil reacts with an alcohol (usually methanol or ethanol) in the presence of a catalyst (e.g., sodium hydroxide or potassium hydroxide). This reaction produces biodiesel (fatty acid methyl esters, FAME) and glycerol as a by-product.

- **Methanol or ethanol** is used to break down the triglycerides in the algae oil, producing biodiesel and glycerin.
- The biodiesel is then purified and separated from the glycerin.

2.5 Biodiesel Purification: After transesterification, the biodiesel is purified to remove impurities such as unreacted alcohol, catalyst, and glycerol. The purification process includes:

- **Washing:** The biodiesel is washed with warm water to remove residual impurities.
- **Drying:** After washing, the biodiesel is dried to remove any remaining water content.
- **Filtering:** The final product is filtered to remove any remaining particulates.

2.6 Storage and Distribution: Once the biodiesel is purified, it is stored in tanks and can be distributed for use in diesel engines. Algae biodiesel, like other biodiesel types, can be blended with conventional diesel at varying percentages (e.g., B20, B100).

2.7 Corn oil Biodiesel Pilot Plant

Corn oil is a vegetable oil extracted from the germ of corn kernels (*Zea mays*), and it is widely used in cooking, as well as in industrial applications, such as biodiesel production. Corn oil is considered a valuable renewable resource for producing biodiesel, due to its favorable fatty acid composition and high oil yield per acre. Below is an overview of the properties, extraction methods, uses, and significance of corn oil, particularly in biodiesel production [1].

2.8 Composition: Corn oil is primarily composed of triglycerides (fats), which consist of fatty acids and glycerol. The fatty acid profile of corn oil is rich in polyunsaturated fats, particularly linoleic acid (C18:2), which accounts for around 55-60% of the total fatty acids. It also contains monounsaturated fats (oleic acid) and a small proportion of saturated fats (palmitic acid).

2.9 Viscosity and Freezing Point: Corn oil has a relatively low viscosity, which is ideal for use in biodiesel production. Its freezing point is typically around -17°C (1°F), making it suitable for year-round applications in temperate climates.

2.10 Oxidative Stability: While corn oil is prone to oxidation, it has relatively high stability compared to other vegetable oils, making it a viable candidate for biodiesel production.

2.11 Biodiesel Production: Corn oil is a significant feedstock for biodiesel production due to its high oil content (around 40-50% of the corn kernel). It is transesterified into biodiesel through a chemical process involving methanol and a catalyst (usually sodium hydroxide or potassium hydroxide), producing fatty acid methyl esters (FAME), which can be used as an alternative to conventional diesel fuel [2].

Corn oil biodiesel is produced through the transesterification process, where corn oil reacts with methanol to form biodiesel (FAME) and glycerol. Table 1. Depicts the Properties and comparisons of Algae and Corn Oil and Table 2. Shows the Properties of Methyl Esters Algae and Corn Oil compared with Diesel. The process is similar to the production of biodiesel from other vegetable oils like soybean or sunflower oil [3].

Table 1. Properties and Comparisons of Algae and Corn Oil

Property	Algae Oil	Corn Oil
Fatty Acid Composition	High in monounsaturated and polyunsaturated fatty acids.	High in polyunsaturated fatty acids (mostly linoleic acid).
Viscosity	Lower viscosity, suitable for Biodiesel.	Lower viscosity, suitable for Biodiesel.
Iodine Value	High (100-140), indicating high unsaturation.	High (110-130), indicating high unsaturation.
Energy content	37–40 MJ/kg.	37–39 MJ/kg.
Density	0.91–0.93 g/cm³	0.91–0.93 g/cm³
Flash point	230–260°C	230°C
Oxidative stability	Higher stability due to Monounsaturated fats.	Higher stability due to Polyunsaturation.

Table 2. Properties of Methyl Esters Algae and Corn Oil compared with Diesel

Properties	Diesel	Algae and Corn Diesel				
		B20	B40	B60	B80	B100
Density at 150^0C, kg/m^3	840	850	865.9	889	907.5	927.5
Kinematic viscosity,40ºC, cSt	2.6	3	4.1	6.56	9.97	16
Higher calorific value, kJ/kg	44420	44372.1	43282.7	42612.3	41941.9	41271.5
Flash point, ºC	51	56	61	68	74	172
Carbon residue, %	0.12	0.17	0.18	0.3	0.4	0.46
Cetane Number	50	52.4	52.4	52	51	50
Water content	Nil	Nil	Nil	Nil	Nil	Nil
Sulphur	0.012	0.017	0.021	0.021	0.031	0.038
Sediments	0.0018	0.0028	0.0041	0.015	0.018	0.023
Pour point		-14	-10	-7	-4	4
85% Distillation point, 4^0C	300	315	340	324	338	352
95% Distillation point, 4^0C	303	317	342	350	345	370

3. ENGINE AND EXPERIMENTAL SET UP

3.1 EXPERIMENTAL APPARATUS

Test engine used in the experiment is a single cylinder direct injection Kirloskar diesel engine. It is naturally aspirated water – cooled four stroke diesel engine. The photograph is shown in Fig 1.

Fig 1. Experimental Set Up

The Kirloskar engine is one of the widely used engines in agricultural, pump sets, farm machinery and medium scale commercial purposes. The engine can withstand higher pressures encountered during tests because of its rugged construction. Further, the necessary modification on the cylinder head and piston crown can be easily carried out in this type of engine. A single cylinder, water cooled, four stroke direct injection compression ignition engine with a displacement volume of 661 cc, compression ratio of 17.5:1, developing 5.2 kW at 1500 rpm was used for the present study. Fig 2. Shows the Schematic Diagram of Experimental Set Up.

Variable load tests are conducted for no load, 1.25, 2.51, 3.76 and 5.02 kW power output at a constant rated speed of 1500 rpm, with fuel injection pressure of 200 bars and cooling water exit temperature at 60^0C. Table 3. Shows the Engine Specifications.

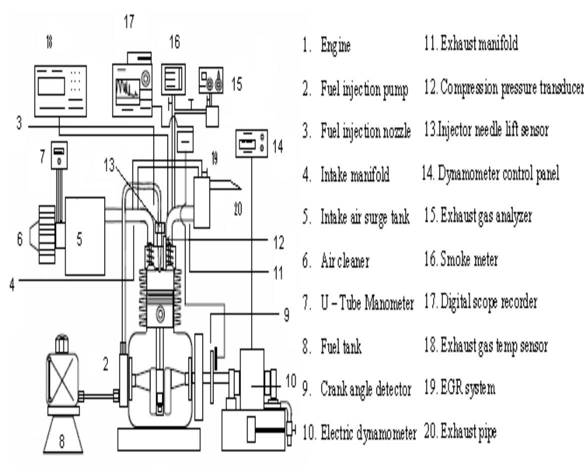

Fig 2. Schematic Diagram of Experimental Set Up

Table 3. Engine Specifications

Manufacturer	Kirloskar Oil Engines Ltd
Model	SV1
Type of Engine	Vertical, 4-Stroke cycle, Single acting, single cylinder, high speed compression ignition diesel engine
Speed	1500 RPM
Rating at 1500 rpm	5.2 KW
Bore (B)	87.5
Stroke (S)	110
Compression ratio	17.5:1
Fuel injection timing	27^0 BTDC
Method of cooling	Water cooling
Injection pressure	200-205 bar

3.2 Modifications required for using Bio Diesel in Diesel Engine

1. By varying the injection timings.
2. Reduction of injection pressure.
3. Use of EGR systems.
4. Addition of carbinol along with bio diesel
5. Injection of hydrogen peroxide.
6. By using oxygenated fuels.
7. H_2O_2/water/diesel emulsions.

The method implemented in this work was varying the injection timing. By advancing, the injection timing from the standard value there is more time available for mixture formation this can lead to better combustion and improved engine performance. The engine has the standard injection timing 27˚ BTDC as recommended by manufacturer which is also determined in the usual way by observing the spill cut off of the injection pump [4]. The injection was advanced by changing the position of the fuel injection pump with respect to the fuel injection cam. Experiments were carried out by advancing 3˚ and 6˚ from the standard injection timing of 27˚ BTDC, which gives the injection timing of 30˚ BTDC and 33˚ BTDC

3.3 Procedure for Varying Injection Timing

Mark the TDC position from the p-theta diagram obtained from the oscilloscope for the given engine at designed injection timing which is at 27 deg. Insert shim sheet inside the fuel pump correspondingly measure the difference obtained or shift of TDC position from 27 deg. Fig 3. Represent the Valve Timing diagrams for Biodiesel Blend.

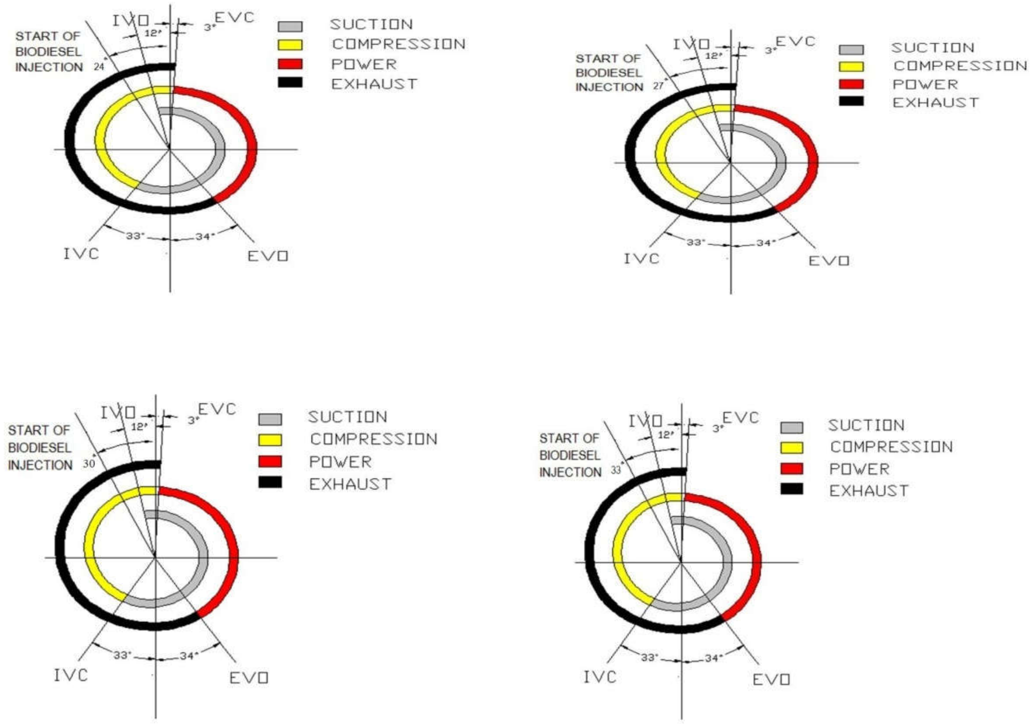

Fig 3. Valve Timing diagrams for Biodiesel Blend

4. Results and Discussions

4.1 Performance Testing for various Injection Timings

4.1.2 Total Fuel Consumption (TFC)

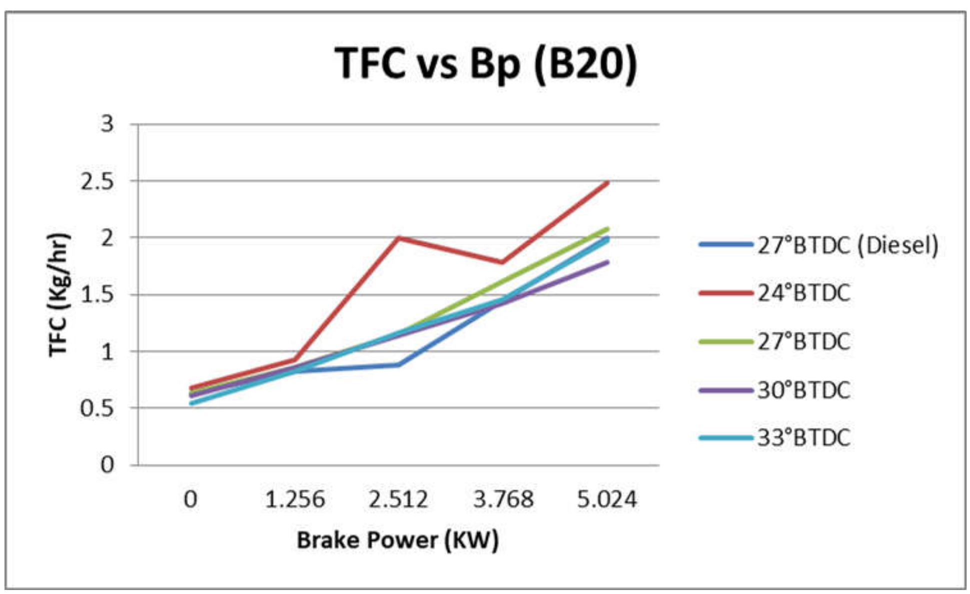

Fig 4. Fuel consumption with respect to Brake power

The Total fuel consumption of engine was increased with increase in amount of biodiesel blends is shown in Fig 4. In the case of *jatropha* biodiesel alone, the fuel consumption was about 12 per cent higher than that of diesel. This may be due to higher specific gravity and lower calorific value of the biodiesel fuel as compared with diesel fuel. The calorific value of the *Jatropha* biodiesel was about 8 per cent lower than that of diesel fuel. When injection timing is increased the TFC decreases.

4.1.3 Brake Specific Fuel Consumption (BSFC)

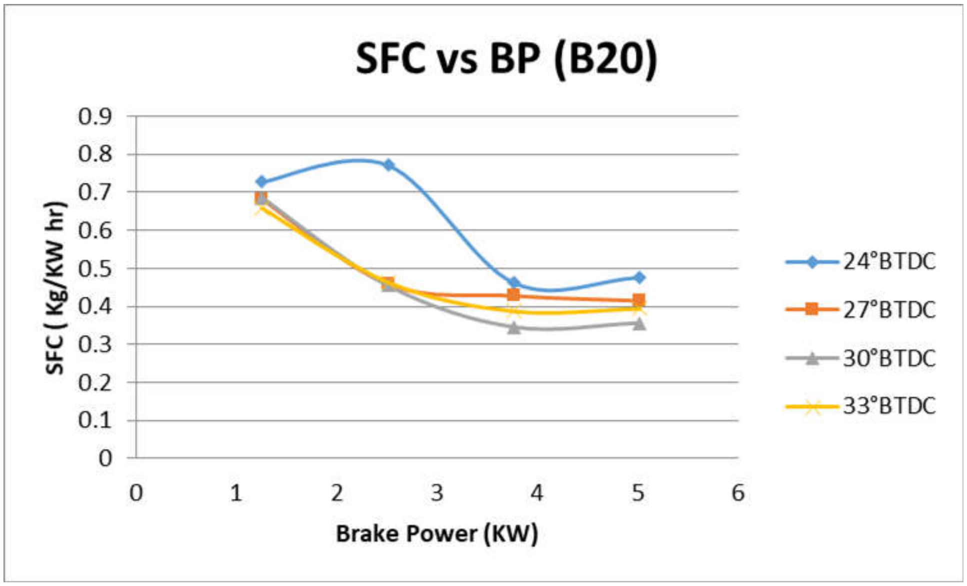

Fig 5. SFC with respect to brake Power

The specific fuel consumption of engine was increased with increase in amount of biodiesel blends is shown in Fig 5. When injection timing is increased the BSFC also increases. The percent increase in specific fuel consumption was increased with decreased amount of diesel fuel in the blended fuels. This may due to lower heating value of the fuels and higher mass of fuel flow to meet the engine loads [5].

4.1.4 Brake Thermal Efficiency (η_{BT})

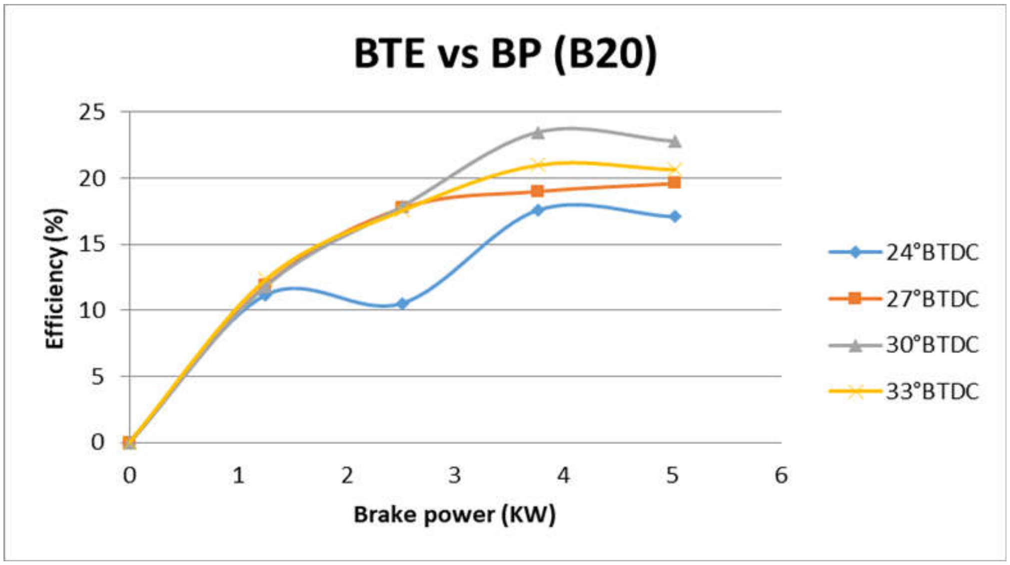

Fig 6. Brake Thermal Efficiency with respect to brake power

The Brake Thermal Efficiency (η_{BT}) of engine was decreased with increase in amount of biodiesel blends is shown in Fig 6.When injection timing is increased the efficiency also increases, 30˚ btdc as injection timing the efficiency is maximum for B20.

4.2 Emission Testing for various Injection Timings

4.2.1 Carbon Monooxide (CO)

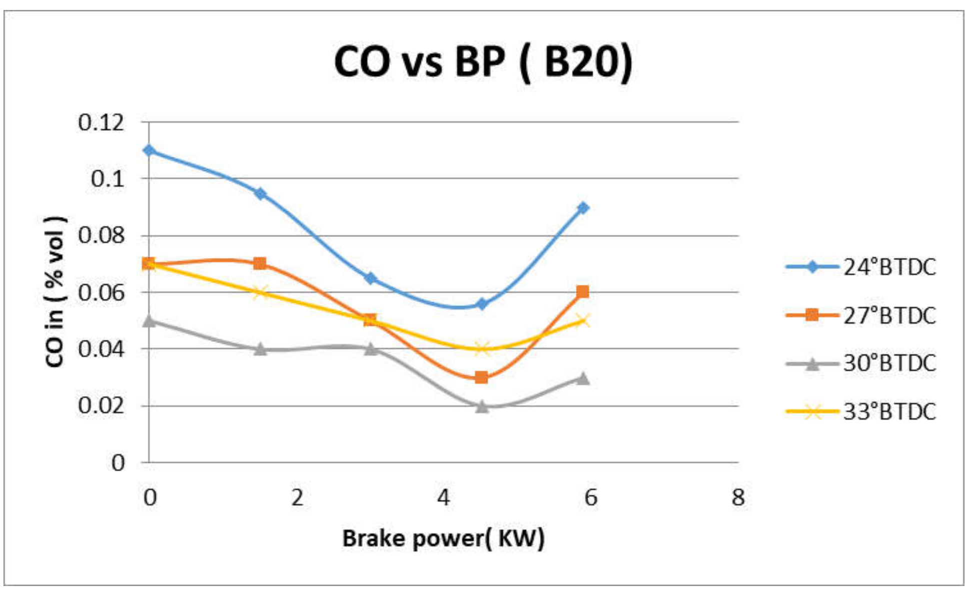

Fig 7. Emission with respect to Brake power

The carbon monoxide (CO) emission of engine was increased with increase in amount of biodiesel blends is shown in Fig 7.When injection timing is increased the CO also increases. 30˚

btdc as injection timing the CO emission is maximum for B80. 27˚ btdc as injection timing the CO emission is minimum for B20, which is even less than diesel.

4.2.2 Oxides of Nitrogen (NO_X)

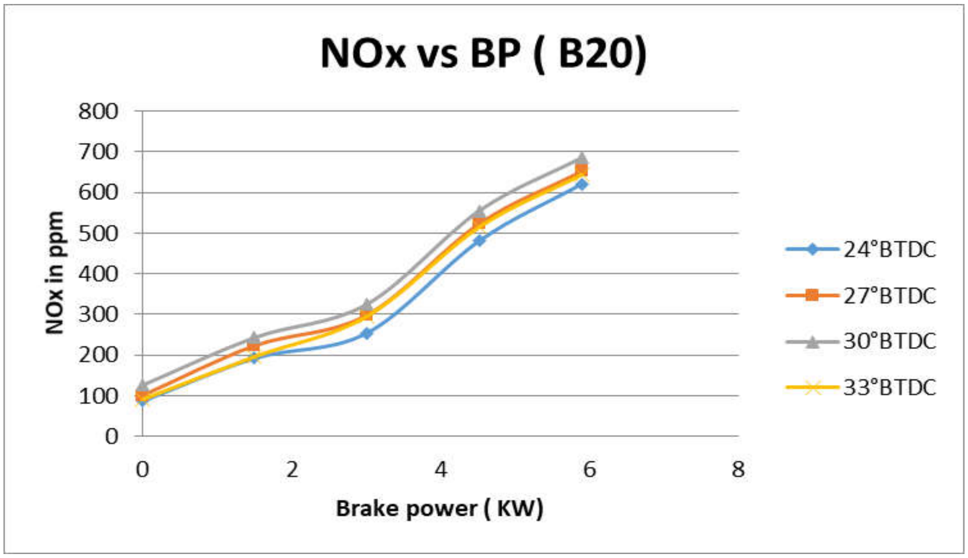

Fig 8. Nox Emission with respect to brake power

The NOx emission increased with increase in biodiesel amount in the blended fuels and also found that NOx emission from the biodiesel fuel was higher than that of diesel. Probable reasons for increase in NOx concentration by about 2 to 10 per cent from biodiesel fuelled engine was due to higher oxygen level in the fuel. The NOx emission of engine was increased with increase in amount of biodiesel blends is shown in Fig 8, Fig 9 & Fig 10.When injection timing is increased the NOx increases. At 33˚ btdc as injection timing the NOx emission is maximum for B80.

4.2.3 Hydrocarbon (HC)

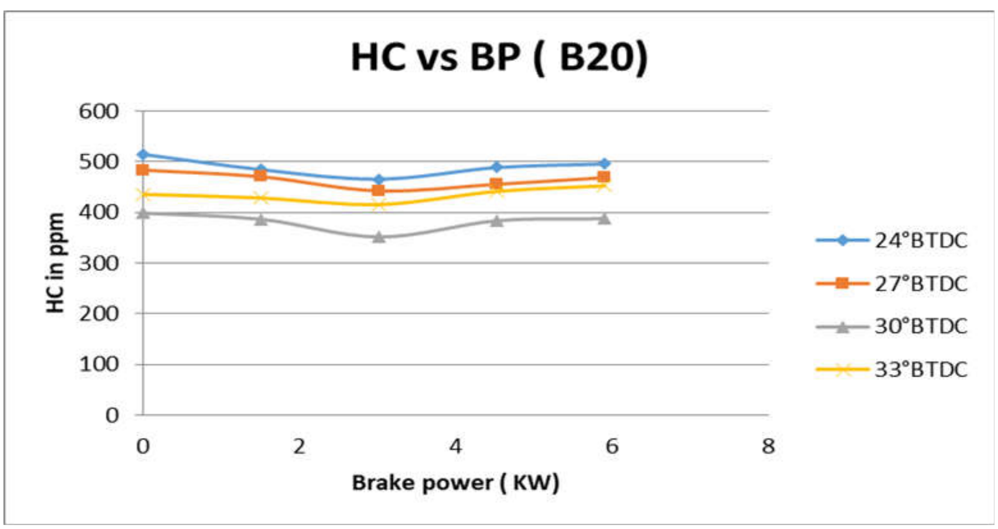

Fig 9. HC Emission with respect to Brake power

The Hydrocarbon (HC) emission of engine was increased with increase in amount of biodiesel blends is shown in Fig 9. The HC emission increased with increase in biodiesel amount in the blended fuels and also found that HC emission from the biodiesel fuel was higher than that of diesel, when injection timing is increased the HC increases [6].

4.2.4 Smoke Emissions

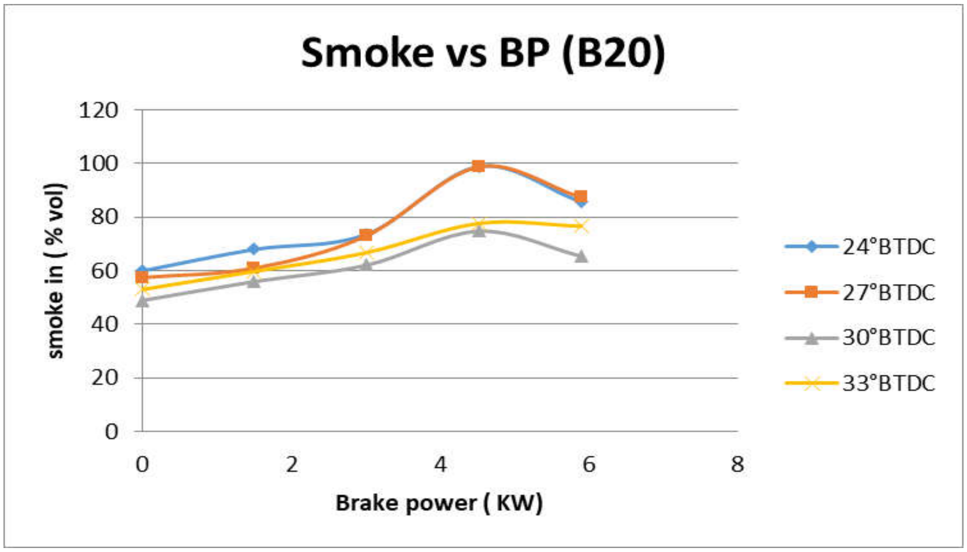

Fig 10. Smoke Emissions with respect to Brake power

The variation of the smoke emissions with respect to brake power shown in figure to figure are discussed for, bio diesel-diesel blends [7]. Fig 10. Shows the variation of smoke in HSU with brake power. For all the blends, the smoke increases with increase in brake power. The high smoke emission formed is indicative of incomplete combustion. The amount of smoke present in the exhaust gas is measured to quantify the particulate matter present in the exhaust gas. It is clearly observed from the fig that the smoke emissions are reduced with advance injection timing in normal diesel engine [8-10].

5. Conclusion

In conclusion, while both algae and corn biodiesel blends show promise for use in diesel engines, algae-based biodiesel appears to offer more significant long-term potential in terms of performance, environmental benefits, and sustainability, though it currently faces challenges in cost and scalability. Corn biodiesel, on the other hand, provides a more established solution in the near term but is constrained by agricultural limitations.

IF WE CONSIDER PERFORMANCE ALONE FOLLOWING STATEMENTS HOLDS GOOD For B20, good efficiency is achieved (23.47%) @ 30°BTDC.

IF WE CONSIDER EMISSION ALONE FOLLOWING STATEMENTS HOLDS GOOD For B20, less CO (.02 % vol), HC (384 ppm), Smoke (74.8 % vol), Nox (555 ppm) emissions is achieved @ 30°BTDC.

IF WE WANT ONLY ONE BLEND FOR CONSIDERABLY BETTER PERFORMANCE AND LESS EMISSIONS FOLLOWING HOLDS GOOD B 20 at 30°BTDC gives good efficiency (23.14%) and less emissions, but slightly less efficiency when compared to B20, however it over comes its drawback in reducing emissions. Algae biodiesel, being more chemically similar to diesel due to its higher energy content and low oxygen content, often demonstrates better engine performance than corn biodiesel, especially at higher blends. These results in less power loss and better efficiency compared to corn-based biodiesel.

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