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Performance and Emission Testing of Methyl Ester of Aloe Vera using Metal Oxide as Additive in CI Engine

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Abstract*: This experimental research evaluate the performance and emission characteristics of a single cylinder 4 – stroke multi-fuel VCR engine, we obtained gel from the aloe vera as the raw material for biodiesel production in the transesterification process. We blended the obtained biodiesel in various ratios with the diesel and it was named B10, B20, and B30. The properties of the biodiesel were tested before it was used as a fuel. The performance and emission testing were done in a single cylinder 4 – stroke multi-fuel VCR engine with an eddy current dynamometer. The biodiesel played a major role in reducing hydrocarbon and carbon monoxide emissions. But it resulted in certain disadvantages of using aloe vera biodiesel in CI engines i.e., it emits more nitrous oxide than diesel and also it has more fuel consumption. To eliminate these drawbacks, aluminum oxide (Al2O3) was used as a nano additive. Based on the performance and emission results obtained, we chose the best blend using a design optimization software called "design expert". The performance and emission results were used in the software which will offer comparative tests, screening, and optimization to choose the best biodiesel blend. B20 was chosen as the best blend and aluminum oxide nano additive was used in two percentages as 50 ppm and 100 ppm with the B20 blend. These nanoparticles added to the biodiesel reduced the ignition delay during the combustion process which resulted in improved thermal efficiency, brake specific fuel consumption and reduction in nitrogen oxide emissions to meet the objectives of this research.

Keywords: Fossil fuels, biodiesel, aloe vera, emission, nano additives, aluminum oxide, ignition delay

I. INTRODUCTION

The diesel engine is the major prime mover that is running the world currently. The diesel fuel used currently is the main reason for the pollution emitted from the vehicle. The emitted pollutions like HC, CO_2, CO, and NO_X are the major contributors to air pollution.

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These gases are called greenhouse gases. It directly produces a more harmful effect on the environment and also to human beings. So it is necessary to seek an alternative and the better one to choose as an alternative is biodiesel. Whenever a new idea or a research activity is to be performed one needs to study the previous works done by various scientists around the world. The investigation of various activities would help a new researcher to get a clear idea about the work which is to have experimented.

II. PREPARATION OF ALOE VERA BIODIESEL

Macrelo Silva et al in 2015 investigated the biodiesel production process starting from aloe vera. This research stated that there are countless advantages in the use of aloe vera as a raw material for biodiesel production. The reason is that it is native to arid and tropical regions and also it does not need plenty of water. The aloe's gel which is colorless and viscous obtained from aloe vera is the raw material used in the transesterification process. After performing various tests they concluded that this gel has the various potential for using it as a raw material for biodiesel production. High viscosity and rapid oxidation are the two problems found while using this aloe's gel. But the transesterification process is used to solve these problems. [1]

The extraction was initially made manually by making a longitudinal cut with the knife. The leaf was split into two parts. The inner part containing the gel was removed from the leaf using a spatula. But this procedure displayed errors. The gel was mingled with fibers, yellow resins and so it generated more waste in the transesterification process. So this method was a failure. So to reduce the waste another method was searched simply. Now a medium-sized manual press was used to extract by squeezing the leaf and extracting juice from it. In this way, fiber contamination was reduced. After that, the gel was filtered to eliminate the contamination visible to the naked eye. After the extraction, the gel is stored in a way that it should not be exposed to light and heat because it may speed up the oxidation process. Therefore it must be stored in a dark container. And also the sample must be used within thirty minutes to prevent early oxidation. This method improved the success rate of the gel extracted from the aloe vera.

This study is in an initial stage which aims to use aloe vera as the raw material for biodiesel production. With the improvements proposed in every research of aloe vera, this is very clear that in future the aloe vera can be a viable raw material for biodiesel production. [1]

Andre E. Machado et al in 2015 studies the pre-treatment and transesterification process of aloe vera. It stated that transesterification is the most commonly used method for biodiesel production. In spite of the other methods like the microemulsion, pyrolysis and petrol derived diesel dilution, the transesterification is the most suitable method due to the reason that it costs low, it occurs on a single-stage under ambient pressure and this the only method capable of producing oil and fat alkyl ester. [2]

Firstly, it is necessary to ensure that the raw material is free of wastes which came from the extraction process. The wastes if present should be removed through a filtration process using a folded gauze in the inner part of the funnel using a paper filter. The pre-treatment process is required to minimize the humidity and acidity of the raw material because during the transesterification process it leads to the formation of a soapy substance.

A 200 ml sample of distilled water was heated without crossing its boiling point and along with it aloe vera and sodium hydroxide were added to remove the free fatty acids. After that, the gel was subjected to a drying process or dehumidification process by heating it above 120C, not only to remove the water added but also to minimize the high humidity rate present in the gel. The drying process should be done only at the end of the pre-treatment process to guarantee that the water rate would not inhibit the transesterification process.

After the pre-treatment process, the oil is now ready to undergo the alkaline transesterification process. The pre-treated oil was heated until 40°C and 0.4 g of sodium hydroxide and 40 ml of methanol was added. The mixture was then undergone a stirring process approximately for 20 minutes until it becomes homogeneous. After this process, the mixture is rested for nearly 24 hours. In this way, the pre-treated oil with a low free fatty acid rate can be Trans esterified with an alkaline catalyst to convert the triacylglycerol into methyl ester. After 24 hours of rest, it was possible to observe the phases separation. The glycerol is separated from the methyl ester and it can be used as a biofuel. [2]

III. EXPERIMENTAL SET-UP

The setup consists of a single-cylinder, four-stroke, stationary VCR (Variable Compression Ratio) Diesel engine, at a rated speed of 1500 rpm and develops a 5.4 kW power output. It is connected to an eddy current type dynamometer for applying various loads. By specially designed tilting cylinder block arrangement, the compression ratio can be changed without stopping the engine and without altering the combustion chamber geometry. Different sensors are employed to check the running conditions of the engine. The mass flow sensor is used to find the mass flow rate of air enters into the cylinder.

A non-contact PNP sensor gives a pulse output at each revolution of the crankshaft which measures the engine RPM. Using 'K' type thermocouples, the temperature of gases and water at various points are evaluated. The fuel consumption is measured with the help of a pair of optical sensors, one at top and another at the bottom to give the signal to the computer to start and stop the time taken. The time taken for the consumption of fuel at a fixed volume is calculated.

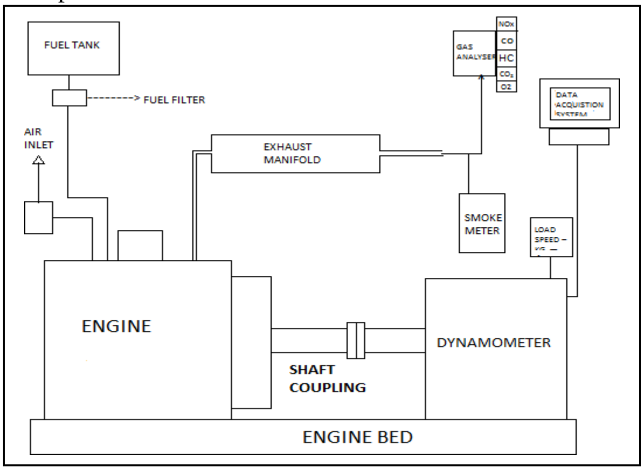

Fig 1. Engine setup layout

Using a load cell transducer type of strain gauge base, torque is measured. The output of the electronic load cell is connected to the load cell transmitter. Then, through the interface card, the output of the load cell transmitter is connected to the USB port. Using a piezoelectric transducer, the cylinder pressure is calculated. Then, signals are fed to the charge amplifier from the pressure transducer. For cooling water and calorimeter, water flow measurement rotometers are used. Also, the rotary encoder is used to record the engine speed and also the crank angle position. These are all provided with the engine setup for measuring combustion pressure and crank-angle measurements. Through an in-built data acquisition system, the engine is interfaced with the computer.

Table – I: Smoke meter Specifications

Model	AVL 437
Measuring range	0-100 opacity in %
	0-99.99 absorption m^{-1}
	400……6000 min^{-1}
	0…..150°C
Accuracy and reproducibility	$\pm$ 1% Full-scale reading
Max smoke temperature at the entrance	250°C

By engine performance analysis software, the engine performance and combustion parameters such as brake power (BP), brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), mechanical efficiency, heat balance, cylinder pressure, and heat release rate were determined. The smoke opacity of the exhaust gas from the engine is measured by the AVL 437C smoke-meter. Emissions like NO, CO, HC, CO_2 are measured using AVL 444 - 5 Gas Analyzer. Experimentation can be done at different compression ratios with different loads.

IV. EXPERIMENTAL TESTING PROCEDURE

The experimental testing is done in a single-cylinder four-stroke VCR engine which is water-cooled. The following procedures are followed while testing the performance, emission and combustion characteristics of aloe vera biodiesel.

Table-II: Engine Specifications

Make	Kirloskar
Power and Speed	3.5 kW
Type of engine	Single cylinder 4 stroke multi-fuel VCR engine with Eddycurrent dynamometer
Compression ratio	18:1
Bore and Stroke	87.5 mm and 110 mm
Method of cooling	Water cooling
Type of ignition	Compression ignition
Fuel injection timing	23° before TDC
Nozzle opening pressure	210bar
Lube oil	SAE40

1) The engine must be water-cooled before it is to be started. Therefore, coolant motor is started and the coolant level is monitored continuously.
2) The battery is connected with the engine.
3) The air blocks are released before starting the process.
4) The fuel is filled in the fuel tank.
5) The engine must be allowed to run for at least 5 minutes before starting the test.
6) The gas analyzer is connected to the exhaust pipe. The filter of the analyzer should be changed before the testing.
7) The load is given in the dynamometer as 0%, 25%, 50%, 75% and 100%. The load should not be increased suddenly. A gradual increase in load should be required.
8) The performance results are tabulated in the data acquisition system and the emission results are displayed in the analyzer screen which is noted. These results are obtained for all the loads.
9) After obtaining the results the engine is stopped and the fuel is drained.
10) The procedure is repeated for all biodiesel blends.

Table-III: Gas analyzer specifications

Type	AVL DiGas 444
Measured quality	Measuring range
CO	0….10% volume
CO_2	0….20% volume
HC	0…..20000 ppm
O_2	0… 22% volume
NO_X	0….5000 ppm

V. RESULTS AND DISCUSSIONS

A. Performance characteristics of biodiesel blends

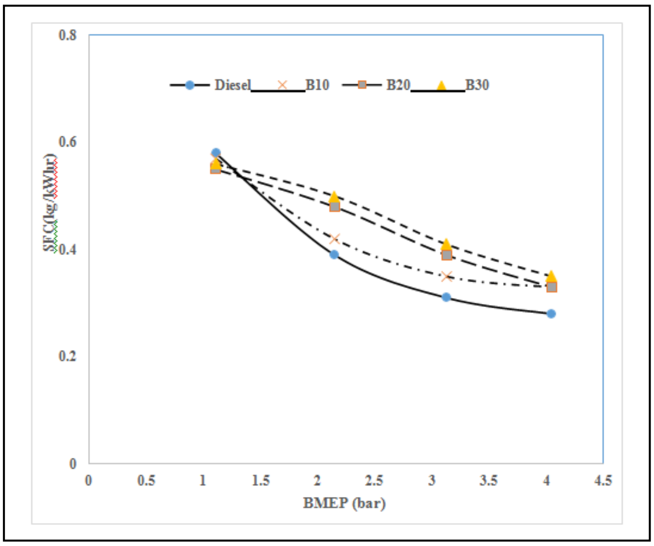

Fig 5.1. Variation of SFC with various BMEP

The performance of fuel is mainly based on the power output that it produces when a fuel is burnt in the combustion chamber. The aloe vera biodiesel in different blends with diesel is tested in the variable compression engine with a constant compression ratio of 18:1. The performance of Specific Fuel Consumption (SFC) and Brake Thermal Efficiency (BTE) for different blends of aloe vera biodiesel are compared with the diesel. Figure 5.1 shows the comparison of SFC with the Brake Mean Effective Pressure for different aloe vera blends and pure diesel.

Specific fuel consumption is the amount of fuel consumed to produce one unit of power. Figure 2 gives the comparison of fuel consumption for various blends of aloe vera biodiesel. From the figure, it is clear that whenever the load is increased the specific fuel consumption is decreased. Among all the blends diesel has a lower amount of fuel consumption because of its higher calorific value whereas all the other blends have more fuel consumption than diesel. B30 has more amount of fuel consumption than the other biodiesel blends. B10 has the least fuel consumption among the three-biodiesel blends.

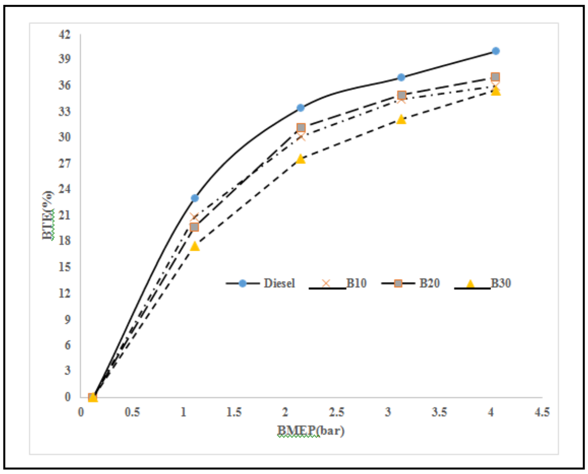

Fig 5.2. Variation of BTE with various BMEP

Fig 5.2 represents the variation of brake thermal efficiency with various BMEP. The brake thermal efficiency is lower for B30 than all the other blends of biodiesel. Diesel has higher efficiency at all loads. B20 increases gradually from lower loads and reaches higher at top load. The efficiency for B10 is also similar to the B20 efficiency

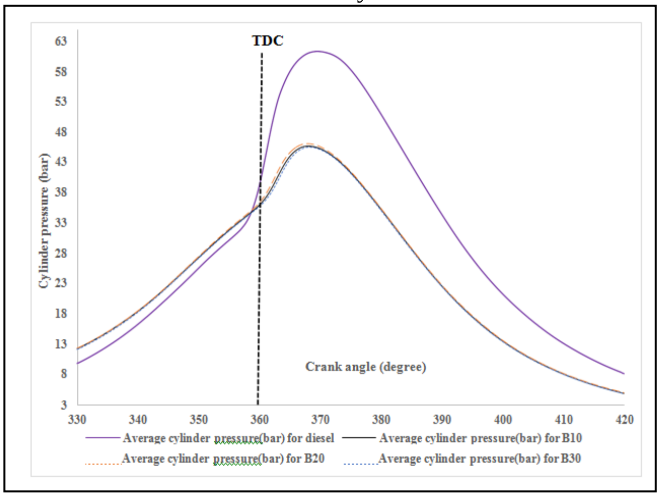

Fig 5.3. Combustion characteristics of various biodiesel

The variation of cylinder pressure for different blends of biodiesel is represented in Fig 5.3. From the graph, it is evident that the cylinder pressure of diesel (61.31 bar) was substantially high in comparison with all blends of biodiesel. For biodiesel, the peak pressure was found to be almost similar for all the blends. The peak pressure of B10, B20, and B30 was found to be a 45.72 bar, 46.11 bar, and 45.54 bar respectively. B20 has slightly higher peak pressure, which was a result of slightly improved combustion. B30 had slightly poor combustion. The peak pressure of B20 biodiesel occurred 3° crank angle before the peak pressure of diesel. This was due to the improved cetane index of B20.

The emission results for various blends of aloe vera is compared with the diesel. Hydrocarbon, Carbon dioxide, Carbon monoxide, and Nitrous oxide emissions are compared with pure diesel.

1) Hydrocarbon emissions

The emission of hydrocarbon is formed from the unburnt fuels released from the engine combustion chamber. Figure 5.4 shows the comparison of Hydrocarbon emissions for B10, B20, and B30 aloe vera blends with pure diesel. From the graph, B10 shows the highest amount of HC emissions for all the loads among biodiesels. The maximum amount of HC emission occurs at a maximum load of 100%. Diesel is the more amount of HC emitter. HC emissions for the B20 blend is similar to the B30 emissions. But B20 emits comparatively lower CO. so comparatively B20 blend has the least amount of HC emissions than all other fuels.

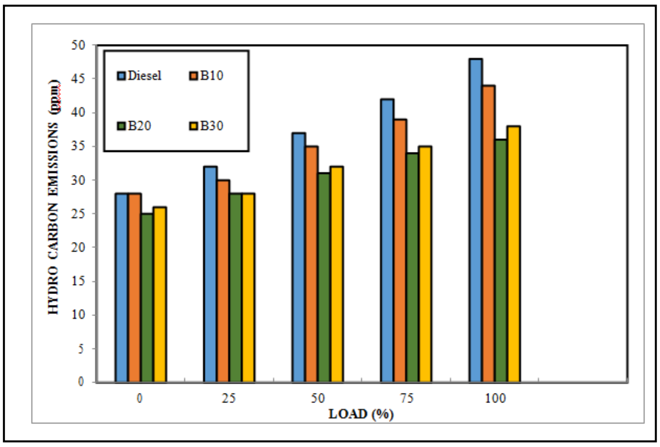

Fig 5.4. Variation of HC with various engine loads

2) Carbon dioxide emissions

The fuel used to propel the vehicle consists of carbon ad hydrogen atoms. The carbon atoms present in the fuel combines with the oxygen from the inlet manifold and forms carbon dioxide during the combustion process. Figure 5.5 shows the amount of CO_2 emissions for B10, B20, B30, and diesel fuel. Pure diesel emits the lowest amount of CO_2 compared with the other blends. At 20% and 50% load the emission is low but at higher loads, the emission reaches the lower level compared with the other blends. For B10 and B20 the CO_2 emission occurs maximum at 100% load. For B30 emissions, the emission is more and it is the maximum among all blends at higher load. For B20 emissions, the emission is initially more at the lower loads but when the load is increased, the emission is lower compared with the other blends.

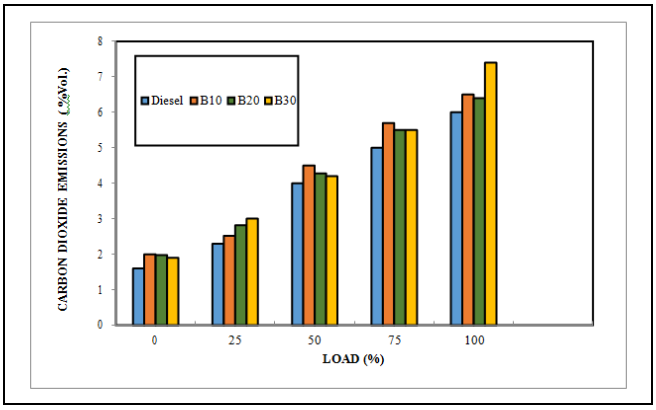

Fig 5.5. Variation of CO_2 with various engine loads

3) Carbon monoxide emissions

Figure 5.6 shows the comparison of carbon monoxide emissions with B10, B20 and B30 blends with diesel. Carbon monoxide is the result of the unavailability of oxygen in the diesel engines. It is formed because of the partial oxidation of the carbon components.

Usually, carbon dioxide is formed due to incomplete combustion. But when there is insufficient oxygen for oxidation carbon monoxide will be formed. From the graph, it is clear that B20 and B30 blend has lower CO emissions. Diesel has more amount of CO emissions for most of the loads. The emission results for B30 are constantly increasing for the various engine loads but it is lower at low loads.

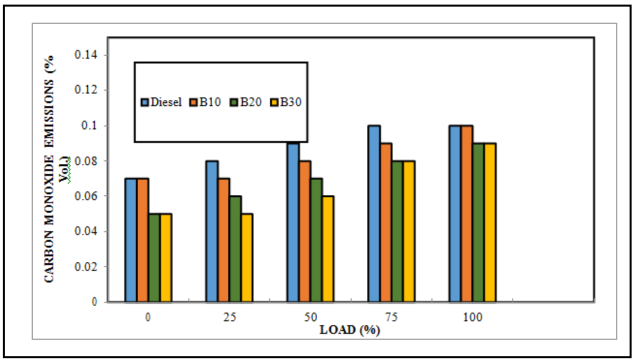

Fig 5.6. Variation of CO with various engine loads

4) Nitrous oxide emissions

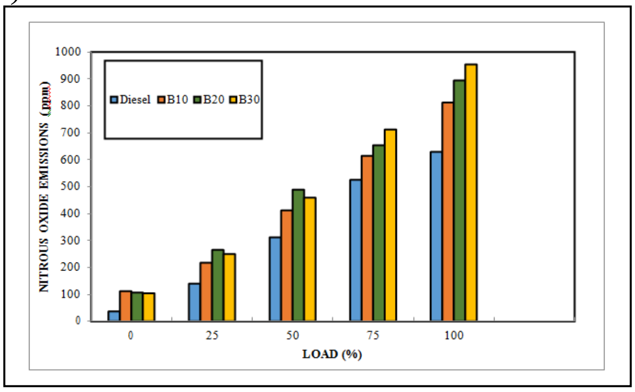

Fig 5.7. Variation of NOx with various engine loads

Nitrous oxide is formed due to the higher temperature obtained in the combustion chamber. When the temperature is increased in the combustion chamber, the nitrogen present in the fuel gets oxidized and due to that oxidation reaction, nitrous oxide is formed. Figure 5.7 represents the variation of Nitrous oxide emissions with various engine loads. Diesel emits the lower amount of Nitrous oxide for all the loads whereas the B30 blend has the more amount of nitrous oxide emissions which increases constantly from 0 to 100% load among all the other blends. B10 emits lower emission values in all loads comparatively. B20 blend has more amount of emission at low loads but at higher loads, the emission is lower.

B. Result optimization of biodiesel blends

From the performance, combustion and emission characteristics studied for various biodiesel blends, the following results were obtained.

- Among all the blends B20 and B30 have similar fuel consumption. However, diesel has lower fuel consumption. So comparatively, diesel is the better fuel in case of specific fuel consumption.
- B20 has better brake thermal efficiency than all other blends. B30 has slightly equal efficiency with the B20 blend. Diesel and B10 blend have lower efficiency.
- B20 blend has better combustion among all the other blends but comparatively, it is lower than the diesel.
- B10 and B30 have more Hydrocarbon emissions among the other blends. B20 has lower emissions comparatively.
- B10 and B20 give better results for carbon dioxide emissions but B30 gives more emissions. Diesel has lower emissions at low loads and higher emissions at higher loads.
- B10 and B20 have less carbon monoxide emissions at various loads comparatively but B30 and diesel have more emissions.
- Diesel alone has a lower amount of nitrous oxide emissions but remaining all the other blends of biodiesel has more emissions.

From the results obtained, the best blend among biodiesel is chosen with the help of a software called "Design Expert". Using this software among the various blends, B20 performs well better than all other blends. However, there are certain drawbacks of using this blend because it consumes more fuel than diesel and has more nitrous oxide emissions. So to eliminate

C. Performance characteristics of Aloe vera biodiesel (B20) with additive

Figure 5.8 represents the variation of SFC for various BMEP at various loads. The results of B20 with 50 ppm additive and B20 with 100 ppm additive have lower specific fuel consumption but B20 without additive and diesel has more fuel consumption than other blends. However, in all the blends the SFC is decreased when the BMEP is increased.

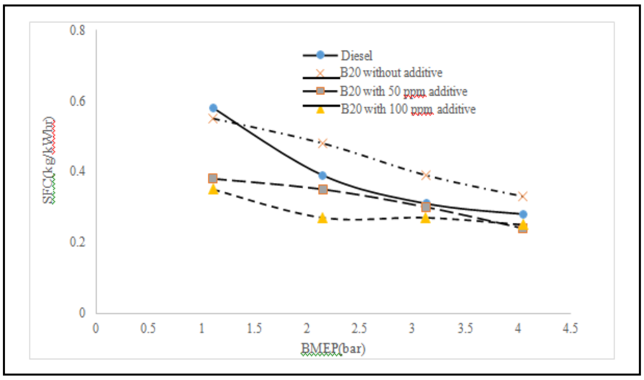

Fig 5.8. Variation of SFC with various BMEP for B20 with additive

Figure 5.9 represents the variation of brake thermal efficiency with various BMEP. The BTE of B20 with 100 ppm additive is better than B20 with 50 ppm additive but both the blends are better than the diesel and B20 without additive. At maximum BMEP both the additive blends have nearly equal efficiency.

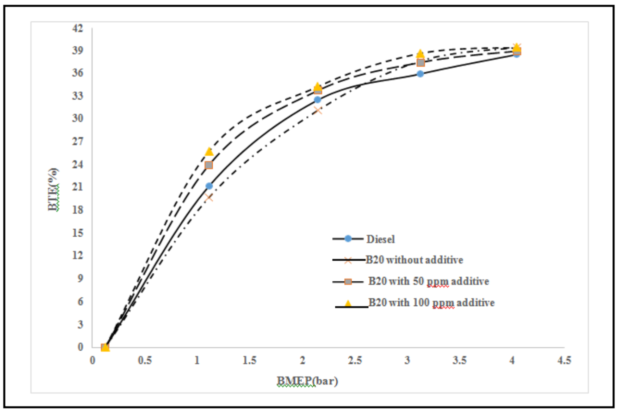

Fig 5.9. Variation of BTE with various BMEP for B20 with additive

The variation of cylinder pressure for different blends of biodiesel is represented in Fig 5.10. From the graph, it is evident that the cylinder pressure of diesel (61.31 bar) was substantially high in comparison with all blends of biodiesel.

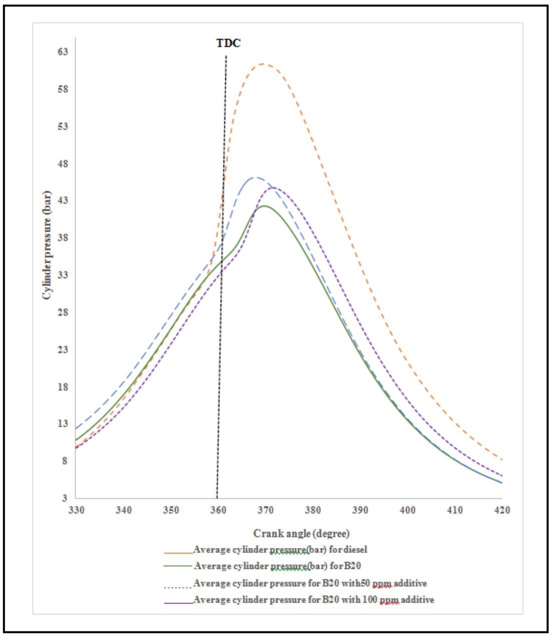

Fig 5.10. Combustion characteristics of B20 additive

The peak pressure of B20 with 50 ppm additive and B20 with 100 ppm additive was found to be 46.11 bar and 44.54 bar respectively. B20 with 50 ppm additive has slightly higher peak pressure which was a result of slightly improved combustion. This was due to the improved characteristics of the fuel due to the presence of additives. B20 without additive had slightly poor combustion.

1) Hydrocarbon emissions

Figure 5.11 represents the variation of hydrocarbon emissions with various engine loads. The hydrocarbon emissions after adding an additive to the B20 blend is very much reduced nearly 10 ppm compared with the pure diesel at higher loads.

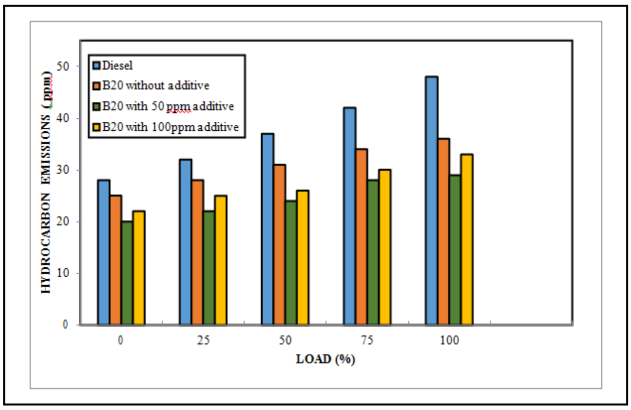

Fig 5.11. Variation of HC with engine load for B20 additive

But when the additive is added at 50 ppm the emission is lower than adding additive at 100 ppm. When a load is increased the emission is also increased but which is lower than the normal biodiesel and diesel.

2) Carbon dioxide emissions

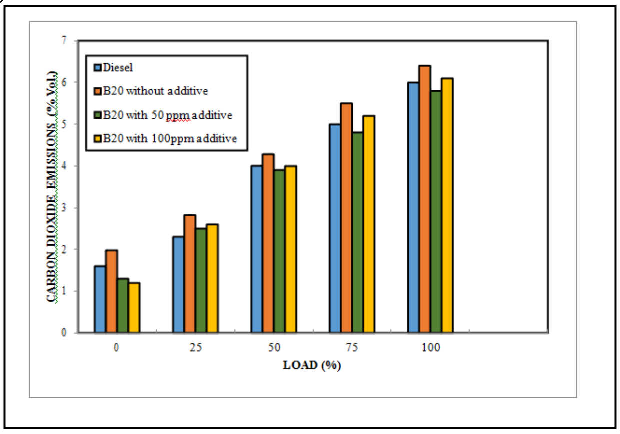

Fig 5.12. Variation of CO_2 with engine load for B20 additive

The variation of carbon dioxide with varying engine loads for the B20 additive is shown in Figure 5.12. The CO_2 emission is higher for all biodiesel blends. The CO_2 emission is not reduced majorly by adding additives to the B20 blend. Additives at 50 ppm and 100 ppm gave results of nearly equal emissions. At 100 ppm additive, the emission is increased for higher loads than 50 ppm additive but it is equal to 50 ppm additive at lower loads

3) Carbon monoxide emissions

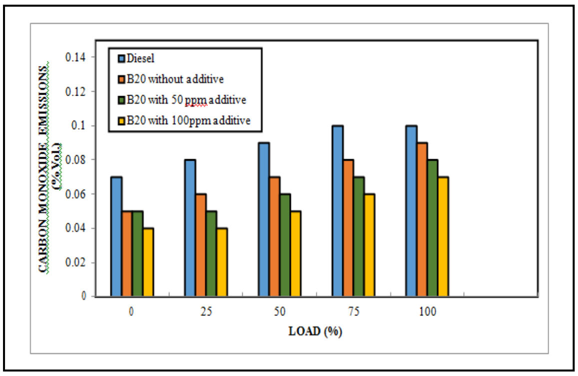

Fig 5.13. Variation of CO with engine load for B20 additive

The variation of CO for various engine loads for the B20 additive is represented in Figure 5.13. The CO emissions were initially high for B20 with 50 ppm additive but it decreased at higher loads. The 100 ppm additive B20 blend had lower emissions at low loads but the emission gradually increased at higher loads. So after adding additive the emission of CO was reduced 0.04% vol. at 50 ppm and 0.06% vol. at 100 ppm additive at higher loads.

4) Nitrous oxide emissions

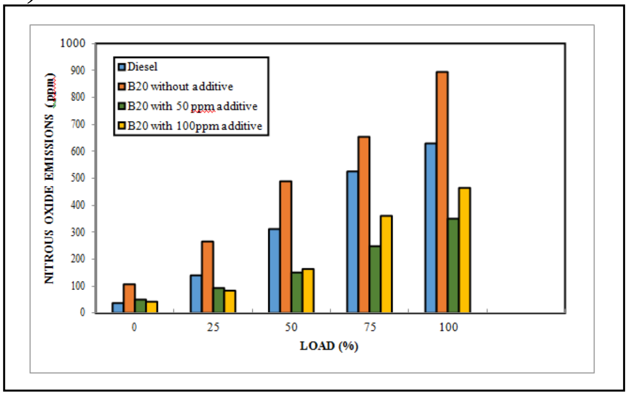

Fig 5.14. Variation of NO_x with engine load for B20 additive

The variation of nitrous oxide emissions for various engine loads of B20 with additive is shown in figure 5.14. The nitrous oxide emission is much reduced for B20 with additives than B20 without additive. Without additive, the NO_X emission for all the blends is higher than diesel. After the addition of Aluminium oxide additive, the emission is reduced. For 100 ppm additive, the emission is slightly higher than 50 ppm additive at higher loads.

D. Effect of adding nanoparticles in biodiesel

Biodiesel usually gives lower hydrocarbon, carbon monoxide and particulate matter emissions. Hydrocarbon is usually formed due to incomplete combustion of the fuel. But in the case of biodiesel, there is more amount of oxygen than normal fossil fuels and also it has a higher cetane number. So it reduces the possibility of incomplete combustion and reduces the emission rates of unburned hydrocarbon. When nano additives are added it further increases the oxygen content and thereby reduces the unburned hydrocarbon emissions. Carbon monoxide is also formed due to incomplete combustion due to the unavailability of the oxygen. Similarly, biodiesel avoids this problem and also with the addition of nanoparticles further reduces the emissions.

The nanoparticles added to the biodiesel reduces the ignition delay during the combustion process which results in improved thermal efficiency. These additives also improve the brake specific fuel consumption. Nitrous oxide is formed only at higher temperatures. Nitrogen reacts with oxygen to form oxides of nitrogen at a higher temperature. The addition of nano additives reduces the ignition delay period to increase the combustion process. It also increases the heat exchange rate and reduces engine temperature. Since the surface area is more for nanoparticles, it is also a reason for the reduction in emission. It also acts as an antioxidant to prevent the oxidation process. This reduces the formation of nitrous oxide at a higher temperature and reduces the emission.

VI. CONCLUSION

The performance, emission and combustion characteristics of aloe vera biodiesel with and without adding aluminum oxide nano additive are studied. From the experimental studies performed, the following conclusions are obtained.

Specific fuel consumption was increased for biodiesel blends of B10, B20, and B30 without additive than pure diesel. But B10 had better fuel consumption results than other blends. The Brake thermal efficiency was more for normal diesel than biodiesel blends without additive. B20 had increased brake thermal efficiency among all the biodiesel. The combustion pressure was maximum for diesel than all other biodiesel blends. But B20 was better than the remaining blends. The Hydrocarbon emission was better for all the biodiesel blends than diesel. B20 had lower emissions comparatively among the other blends. Diesel had lower carbon dioxide emissions. Among the biodiesel blends, B20 had better emissions.B20 and B10 emitted lower carbon monoxide than diesel at all the loads. But the nitrous oxide emission was more for all the biodiesel blends than diesel.

From all the results, it was concluded that B20 was better than all the blends and Al_2O_3 additive was added to eliminate the drawbacks of the biodiesel. After adding aluminum oxide additive at 50 ppm and 100 ppm volume to B20 blend, the Specific fuel consumption was reduced for B20 blend at both 50 ppm and 100 ppm additive but at 100 ppm volume, the result was better. The hydrocarbon, carbon dioxide, nitrous oxide, and carbon monoxide emissions were reduced better than diesel and B20 without additive for both 50 ppm and 100 ppm additive. But at 50 ppm volume, the result was better. The B20 blend without additive had a significant amount of nitrous oxide, hydrocarbon and carbon monoxide emissions. The B20 blend with additive reduced hydrocarbon, nitrous oxide and carbon dioxide emissions by improving the thermal efficiency. The specific fuel consumption of the biodiesel had also reduced for B20 blend with additive than the B20 blend without additive.

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