Experimental Investigation on the Performance and Emission Characteristics of Simarouba Glauca Oil as an Alternate Fuel in Variable Compression Ignition Engine

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Abstract: **The researchers are attempting to develop the alternative fuel which is economical, environment friendly and a simple technology which is easy to understand and to implement. From the study of many researchers we came to know that, biofuels are having the potential need to serve as a fuel in compression ignition engine. In the present work, Simarouba Glauca oil biodiesel blends with diesel were used as a fuel. Further, the effect of compression ratio on the performance parameters such as brake specific fuel consumption (BSFC), brake thermal efficiency (BTE) and brake power (BP) and emissions were investigated in a constant speed direct injection (DI) diesel engine, with varied compression ratios (14.3:1, 15.6:1 and 16.5:1). The test results shown that the Simarouba biodiesel blends at CR 16.5:1 is having good performance with low emission than at CR of 14.3:1 and 15.6:1, except for emissions of oxides of Nitrogen.**

Keywords: **biodiesel, Simarouba Glauca oil, Honge oil, Diesel, blending, Compression ratio, Performance, emissions.**

I. INTRODUCTION

Nowadays, it is believed that crude oil and petroleum products will become very scarce and costly. Day by day the fuel economy of engines is getting improved and will continue to improve. However, increase in number of vehicles has started dictating the demand for fuel. Gasoline and diesel will become scarce and most costly in the near future. With increased use and the depletion of fossil fuels, alternate fuel technology will become more common in the coming days.

There are several alternative sources of fuel like vegetable oils, biogas, biomass, alcohols which are all renewable in nature. Among these fuels, vegetable oils appear to have an exceptional importance as they are renewable, widely available, biodegradable, non-toxic, and environmental friendly. In a country like India it is observed that biodiesel can be a viable alternative automotive fuel. Biodiesel is a fastest growing alternative fuel and India has better resources for its production.

The vegetables oils cannot be used directly in diesel engines as alternative fuel because of high viscosity of vegetable oils leads to problem in pumping and spray characteristics. The inefficient mixing of vegetable oils with air contributes to incomplete combustion. The best way to use vegetable oils as fuel in diesel engines is to convert it into biodiesel. It is a fact that biodiesel is a safer, more economical and environmentally friendly than the conventional petroleum diesel that the majority of people currently use.

Biodiesel refers to a vegetable oil or animal fat based diesel engine fuel consisting of long chain alkyl (ethyl, methyl, or propyl) esters. Biodiesel is typically produced by chemically reacting lipids (e.g. vegetable oil, animal fat) with an alcohol.

Simarouba Glauca belongs to family Simarubaceae, commonly known as "The Paradise Tree" or "King Oil Seed Tree" or Laxmitaru tree is a multipurpose evergreen tree having a height of 8-15 m with tap root system. It is mainly found in coastal hammocks throughout South Florida. In India, it is mainly observed in Andhra Pradesh, Karnataka and Tamil Nadu etc. It can adapt a wide range of temperature, has the potentiality to produce 2000-2500 kg seed/ha/year. However, in the present context the seeds are economically very important as they contain 60-75% of oil, and can grow well in marginal lands/wastelands with degraded soils and therefore considered as a major forest tree.

II. LITERATURE REVIEW

Shailesh Golabhanvi et al. [1] investigated the performance of single cylinder direct injection diesel engine using Simarouba biodiesel (SOME) as fuel was evaluated for its performance, emission and combustion characteristics. The properties of SOME thus obtained are comparable with ASTM biodiesel standards. The produced SOME was blended with diesel (Simarouba-S20, S40, S60, S80 and S100) were tested for their use as a substitute fuel for diesel engine at an engine speed of 1500 rpm, fixed compression ratio 16.5:1, fixed injection pressure of 200bar and varying brake load. The result shows that the Methyl ester of Simarouba oil (S80) results in a nearly equal in thermal efficiency as compared to that of diesel. The exhaust gas temperature is decreased with the methyl ester of Simarouba oil as compared to diesel. The brake mean effective pressure of all the blends of Simarouba oil as well as diesel increases with brake power. The air fuel ratio of diesel is observed that higher than that of the other blends of Simarouba oil.

Vishwanath Kasturi et al. [2] investigated the Performance and Emission Characteristics of Simarouba Biodiesel and Its Blends on Low heat rejection Engine (LHR). The blends are S20, S40, S100, and diesel. They observe that 20% blend of Simarouba biodiesel in diesel fuel has almost same mechanical efficiency, same specific fuel consumption. They also suggest that S20 with LHR has higher brake thermal efficiency than normal engine D100 this is because of increased combustion rate which provides complete burning of fuel and due to low heat rejection. Fuel consumption is higher in case of LHR engine due to increased temperature and completes combustion. Air fuel ratio decreases with increase in load because air fuel mixing process is affected by the difficulty in atomization of biodiesel due to its higher viscosity. The thermal efficiency of S20 is lower than diesel because the reason is large difference in viscosity, specific gravity and volatility. The thermal efficiency of S20 gives slight increase in brake thermal efficiency which is a positive sign with this blend. So we can conclude that without any modification in engine we can save diesel fuel for certain extent.

Karthikayan.s et al. [3] investigated the effect on combustion and emission in constant pressure heat addition using vegetable oil and hydrogen aspiration using a standard diesel engine. The results of the experiment disclose that the application of hydrogen has improved combustion behavior of Neat Simarouba Glauca oil (NSGO). The results of the experiments showed that a considerable improvement has obtained in combustion and emission characteristics of NSGO. The results of the experiments expose that the performance of NSGO was improved sufficiently by hydrogen combustion enhancer. The superior properties of hydrogen such as higher calorific value, higher flame speed and gaseous nature helps to combust NSGO with higher performance and lower emission. The application of 15 percent hydrogen + NSGO performance compared with diesel fuel. The results shows 5% higher brake thermal efficiency, the highest BTE produced by 15H NSGO is 33.2 %. This is 5 % higher than diesel fuel and 13 % higher than NSGO. The addition of Hydrogen increase BTE of NSGO from 28.8 % to 33.2 %.

Sharun Mendonca et al. [4] investigated the performance and emission characteristics of Simarouba oil and Jatropha oil at 20% blend with diesel have been studied. Tests were carried out for analyzing various parameters such as thermal efficiency, brake specific fuel consumption (BSFC), emission of CO, HC and NOx gases in exhaust. S20 is more suitable biodiesel compare to J20. The brake thermal efficiency of S20 is decreases about 6% and J20 decreases by about 12.5% compare to diesel at IP200 bar, IT 20.50BTDC. The reason for this is poor atomization of biodiesel due to higher viscosity. In all injection pressure BTE of biodiesel is decreased. S20 as better BTE compare to J20. The BSFC of S20 is increased about 8.2% and J20 increased about 15.8% compare to diesel. The reason for this is lower calorific value of biodiesel. S20 has 11% less BSFC compare to J20. The final results shows that the while using S20 and J20 the BTE is decreased and BSFC is increased.

III. METHODOLOGY

3.1 Production of Simarouba biodiesel

Raw oil extracted from the dry seed of Simarouba Glauca has higher viscosity and poor combustion quality due to the presence of free fatty acid. Simarouba oil undergone trans-esterification process for reducing the viscosity and make it has combustible. The process for the production of the biodiesel is based on the presence of the FFA. Since the FFA value of Simarouba oil was found to be 2.57% single stage (alkaline catalyzed trans-esterification) process was used. 1 liter of Simarouba oil is taken and transferred into a 3-neck flask. This 3-neck flask is placed on a magnetic stirrer which has a magnetic pellet inside it. Now the reflux condenser is fixed to the central neck of 3-neck flask. Water pipeline is connected to the condenser and checked for water circulation from tap to condenser and outlet. The magnetic stirrer is then switched on, the heating control is set to 60^0C and the speed of the stirrer is adjusted between 600-800 rpm to get a homogeneous heating of the oil. Now add some oil into the thermo-well and insert it into the side neck of the 3-neck flask. Place the thermometer into the thermo-well and check the temperature. Now take 300ml methanol per liter of oil in a 500ml capacity beaker. Weigh the 6 grams of NaOH (based on the FFA% determined earlier for the raw oil) and add to methanol. Stir well and this mixture is called Methoxide mixture. When the temperature reaches 63^0C, the Methoxide mixture slowly added to the hot oil inside the 3-neck flask through the loading opening neck and the speed is maintained at 600rpm. Now the opening neck is closed with a stopper. The temperature is maintained at 60^0C to 63^0C using condenser and the process is run for 2hours. It is observed that the color of the mixture turns to transparent chilly red. Switch off the power and remove the reflux condenser. Transfer the mixture into a separating funnel and allow settling for 2-hours. After 2 hours the glycerin is settled down at the bottom and the biodiesel separates as top layer. Glycerin is drained from the bottom of the separating funnel carefully and stored.

3.2 Recovery of methanol from biodiesel

Transfer the biodiesel into the reaction vessel, make the necessary arrangement for the distillation setup like heating, stirring and fixing the double wall condenser along with the recovery flask, maintain the rpm speed at 1000RPM and the temperature at70^{0}C, methanol starts evaporating. Collect the methanol condensate, measure the quantity and record it. Switch off the system when the methanol condensation stops.

3.3 Washing of biodiesel

Transfer the biodiesel after methanol recovery into the plastic washing funnel specially assembled for this purpose, spray 300ml of warm water slowly into the biodiesel without any agitation. Allow to settle for 15 minutes. A bottom layer of soap water will slowly start to form, drain the bottom layer carefully. Repeat the above procedure (300ml water) for third time and shake vigorously and allow it to settle for 1 hour and drain the soap water. Check up the pH value of the third drained soap water using the pH paper. Continue washing with the warm water till the biodiesel reaches 7pH.

3.4 Drying of biodiesel

Transfer the washed biodiesel from the washing funnel to the 1 liter beaker, add the magnetic pellet and adjust rpm to suitable speed. Heat the biodiesel to a temperature of 100^{0}C, allow the biodiesel to cool gradually, measure the final finished biodiesel. Record the quantity and store it in a clean, dry container.

IV. PREPARATION AND PROPERTIES OF DIESEL AND BLENDS

4.1 Preparation of blends

The blends are done with the help of clean measuring jars. Based on the blend percentage the required quantity of Simarouba biodiesel and diesel are calculated and taken. It is then mixed together to form the blend.

Table 4.1: various properties of selected fuels

Properties	Diesel	S20+D80	S40+D60	S60+D40
Density (kg/m^3)	840	847	854	861
Calorific value (kJ/kg)	42500	41960	41420	40880
Kinematic viscosity (Cst @ 40^{0}C)	2.54	3.00	3.44	3.89
Specific gravity	0.840	0.847	0.854	0.861
Flash Point (^{0}C)	54	76	98	120

V. EXPERIMENTAL PROCEDURE

The engine tests were conducted on a computerized single cylinder, 4-stroke water cooled CI engine test rig. It was directly coupled to an Eddy current dynamometer that permitted the engine motoring either fully or partially loaded. The engine and Dynamometer were interfaced to a control panel which is connected to a digital computer used for recording the test parameters such as fuel flow rate, temperature, air flow rate, load etc, and calculating the engine performance characteristics such as Brake Power, BSFC and Brake Thermal efficiency. The calorific value and density of the particular fuel was fed to the software for calculating the above said performance parameters for different pressures. At the same time the exhaust gas analyzer is used to measure the emission parameters such as HC, CO and NO_x.

Fig 5.1: photographic view of 4-stroke single cylinder engine

Table 5.1: engine specifications

ENGINE		
SI.NO	Parameters	Specification
1	Engine type	Four stroke (AV1)
2	Speed	1500 RPM
3	Aspiration type	Natural
4	Bore	80mm
5	Stroke	110mm
6	Connecting rod length	235mm
7	HP	5 HP
8	Starting	Crank shaft
9	Injection pressure	200 bar
10	Area of piston head	0.005 m^2
11	Number of cylinder	1
12	Injection angle	23^{0}CA

VI. RESULTS AND DISCUSSION

In this work the performance and emission characteristics are studied and experiment is carried out by testing the Kirloskar AV1, single cylinder, 4-stroke CI engine fuelled with Diesel (D100) and with Simarouba biodiesel blends namely S20+D80, S40+D60 and S60+D40. The tests were made at different loads that are 0%, 20%, 40%, 60%, 80% and 100% of full load. The experiment was conducted at three different compression ratios of 14.3:1, 15.6:1 and 16.5:1. The corresponding BP, BSFC, BTE and emissions HC, CO and NO_x were recorded. The results are compared at different compression ratios for different performance and emission parameters.

6.1 Performance Parameters:

The performance parameters namely BP, BSFC and Brake thermal efficiency for Diesel and Simarouba blends at three compression ratios as shown below:

6.1.1 Brake Power:

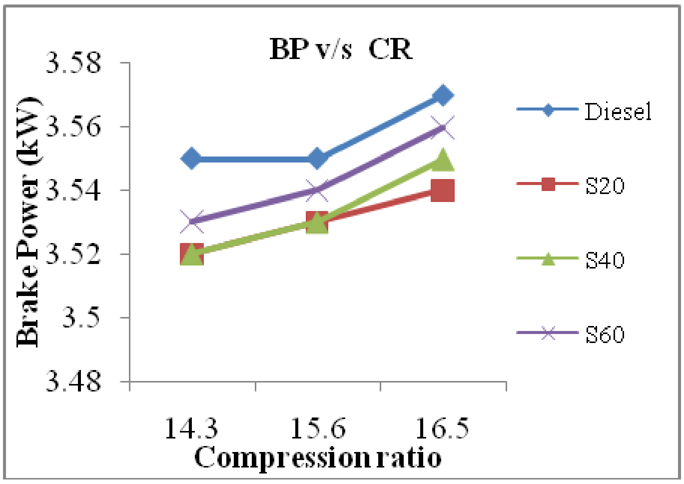

Fig 6.1: variation of BP with CR for Diesel and Simarouba blends

It can be seen from the above figure that pure Diesel (D100) shows higher value of brake power (BP) at higher compression ratio (CR) 16.5:1 compared to other two compression ratios (CR) 14.3:1 and 15.6:1 at full load condition. This is due to the fact that, as the load on the engine increases more fuel is injected and temperature also increases, hence better combustion. Brake power value decreases due to increase in the delay period at lower compression ratio. Hence D100 at CR 16.5:1, which is having best brake power (BP) output is compared with all other biodiesel blends at different compression ratio. The BP values of all biodiesel blends are near to that of pure diesel (D100) at almost all compression ratios. Hence it can be noted that the brake power value is not much varied at the compression ratio of 14.3:1, 15.6:1 and16.5:1 for diesel and biodiesel blends.

From the above figure it can be observed that S60+D40 is having better brake power output at compression ratio 16.5:1 compared to all other blends. It can be noted that as the Simarouba biodiesel percentage increases the blends are showing better brake power output at higher compression ratios. This is due to the fact that as the Simarouba methyl ester percentage increases the viscosity of the blend increases and also Due to shorter ignition delay, the combustion starts earlier and hence resulting in higher brake power output. Overall among all the blends best brake power value is found for S60+D40 at CR 16.5:1.

6.1.2 Brake Specific Fuel Consumption:

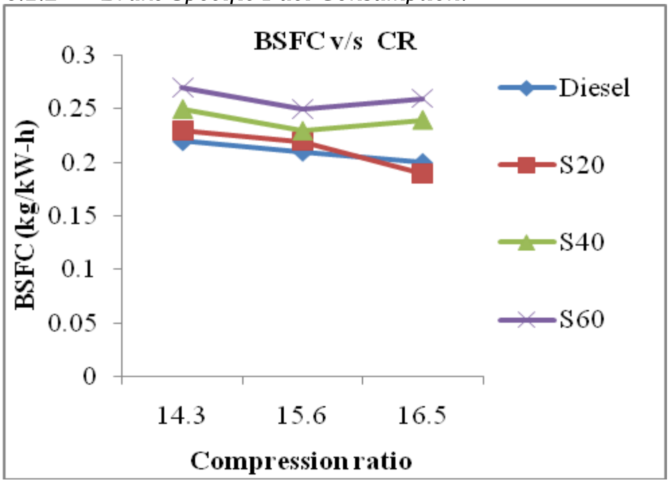

Fig 6.2: variation of BSFC with CR for Diesel and Simarouba blends

The above figure shows the variations of brake specific fuel consumption (BSFC) at maximum load condition for Diesel, S20, S40 and S60 blends for different compression ratios. As the compression ratio increases the brake specific fuel consumption for all Diesel and biodiesel blends decreases. The main reason for this is the brake power developed was higher than the fuel consumption at higher compression ratio. There is also increase in the temperature at higher compression ratios. Specific fuel consumption increases with increasing the percentage of blend from 20% to 60%. Specific fuel consumption decreases with increasing the compression ratio in consequences of higher temp.

From the figure it can be found that brake specific fuel consumption of S20+D80 gives lesser fuel consumption at higher compression ratio 16.5:1 when compared to all other blends. This decrease in BSFC can be attributed to the more efficient utilization of the fuel at higher compression ratio, as the temperature and pressure of the cylinder increases due to the effect of charge dilution. The brake specific fuel consumption is higher in S60+D40 blend for all the compression ratios. This is because of combined effect of lower calorific value and higher density with respect to increasing the blend. Lower calorific value causes higher fuel consumption for the same power development. Overall among all the blends the best (less) brake specific fuel consumption value is found for S20+D80 blend at CR 16.5:1.

6.1.3 Brake Thermal Efficiency

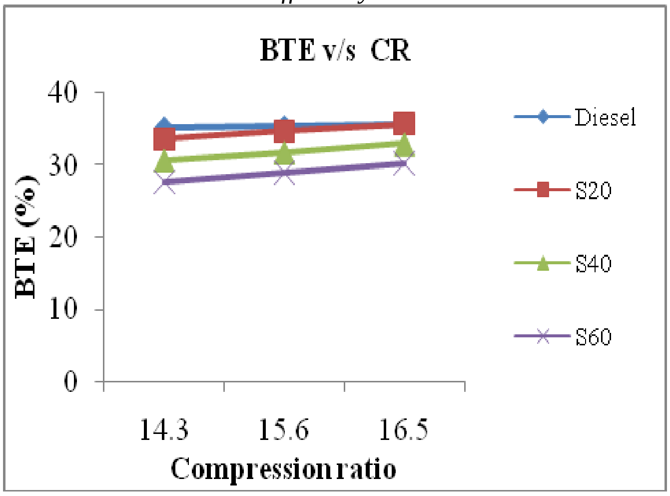

Fig 6.3: variation of BTE with CR for Diesel and Simarouba blends

From the above figure it can be observed that pure diesel (D100) is having almost same brake thermal efficiency at all the three compression ratios considered, however the brake thermal efficiency was highest at CR 16.5:1, since it is having higher brake power output at CR 16.5:1. The brake thermal efficiency of 20% blending of Simarouba oil with 80% blending of diesel having higher brake thermal efficiency at full load condition among the three different blends for all the compression ratios selected from 14.3:1 to 16.5:1, because as the load on the engine increases the brake power also increases, hence brake thermal efficiency also increases.

The brake thermal efficiency of S20+D80 is having 0.17% greater than that of diesel and its value is found to be 35.71%. This may be due to the fact that the oxygen contained in the Simarouba Glauca oil biodiesel takes part in the complete combustion, which in turn enhances the combustion process, hence resulting in higher brake thermal efficiency. For S40+D60 and S60+D40 blends the brake thermal efficiency was lesser than that of S20+D80 for the entire compression ratio's as show in the above figure. When the percentage of blending is increased then the brake thermal efficiency is reduced for the entire compression ratios, because this is due to increasing viscosity and density with increase of blending from 20% to 60%. The brake thermal efficiency values also decreases for higher blend percentages, this may be due to the lower heating value of the Simarouba methyl ester.

6.2 Emission Characteristics

The emission parameters namely HC, CO and NO_x for Diesel and Simarouba blends at three compression ratios as shown below:

6.2.1 Unburned hydrocarbon emission (HC)

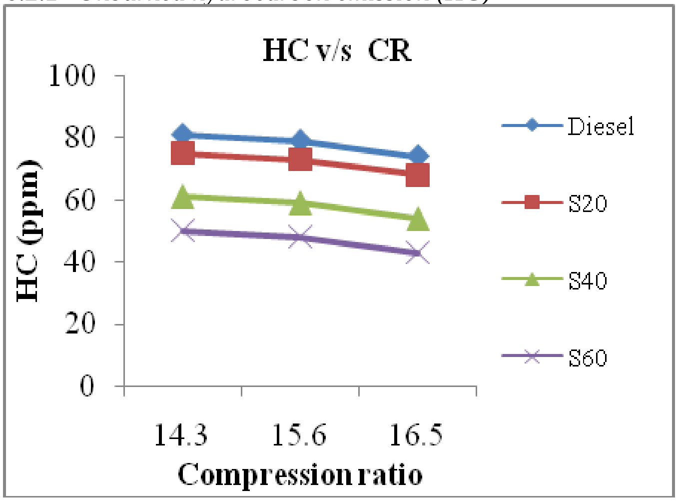

Fig 6.4: variation of HC emission with CR for Diesel and Simarouba blends

The main exhaust emission is the unburnt hydrocarbons. The unburnt hydrocarbon consists of fuel that is completely unburned or only partially burned. The amount of unburnt hydrocarbon emissions (UBHC) depending on the original fuel components, combustion chamber geometry and engine operating parameters.

The above figure shows the HC emissions of different blends with respect to different compression ratio at full load condition. It can be observed that hydrocarbon emissions (HC) were low at higher compression ratios. As it can be seen that pure diesel shows lower HC emissions at CR 16.5:1 and highest HC emission at CR 14.3:1. This is because at higher compression ratio higher temperature of burnt gases in combustion chamber helps in preventing condensation of higher hydrocarbon reducing unburnt hydrocarbons. The heavier hydrocarbon particles those are present in diesel fuel increases HC emissions at lower compression ratios.

From the above figure it can be seen that S60+D40 is having low HC emission at higher compression ratio 16.5:1 compared to pure diesel (D100) and 3 different biodiesel blends. This is due to the fact that as the Simarouba biodiesel percentage increases the blends are showing lower HC emissions at higher compression ratios. This is because of due to the inbuilt oxygen content in the biodiesel may be responsible for complete combustion and thus reducing the HC emissions or HC levels. Overall among all the blends S60+D40 is having a low HC emission at CR 16.5:1.

6.3 Carbon Monoxide (CO)

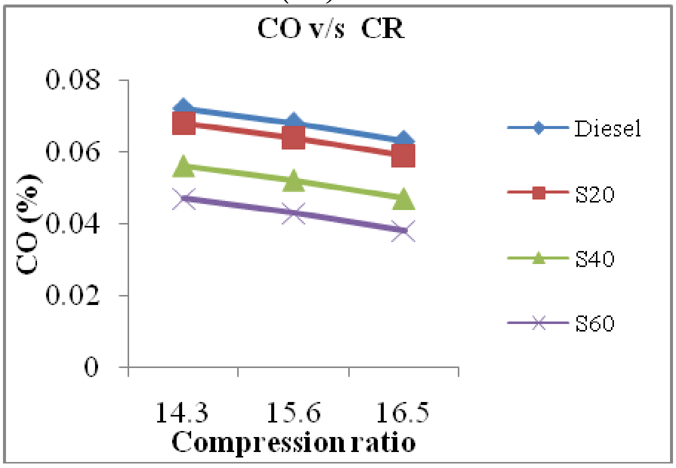

Fig 6.5: variation of CO emission with CR for Diesel and Simarouba blends

Carbon monoxide is a colourless and odourless but a poisonous gas. It is generated in an engine when it is operated with a fuel-rich mixture. When there is not enough oxygen to convert all carbon to CO_2, some fuel does not get burned and some carbon ends up as CO. Maximum CO is generated when an engine runs rich mixture. Rich mixture is required during starting or when accelerating under load. Even when the intake air-fuel mixture is stoichiometric or lean, some CO will be generated in the engine. Poor mixing, local rich regions and incomplete combustion will also be the source for CO emissions.

From the above figure it is clear that all the biodiesel blends are showing low CO emissions at CR 16.5:1 compared to pure diesel. This is due to the fact that at higher compression ratio, the temperature rise inside the combustion chamber will be very high resulting in complete combustion and thus reducing the CO emission. It can also be seen from the above figure that CO emissions will be very low at CR 16.5:1 for the blend S60+D40 compared to pure diesel and all other blends. This is because of due to oxygen content which is inherently present in the biodiesel, helps in the more complete combustion of the fuel. Overall among all the blends S60+D40 is having a low CO emission at CR 16.5:1.

6.3.1 Oxides of Nitrogen (NO_x)

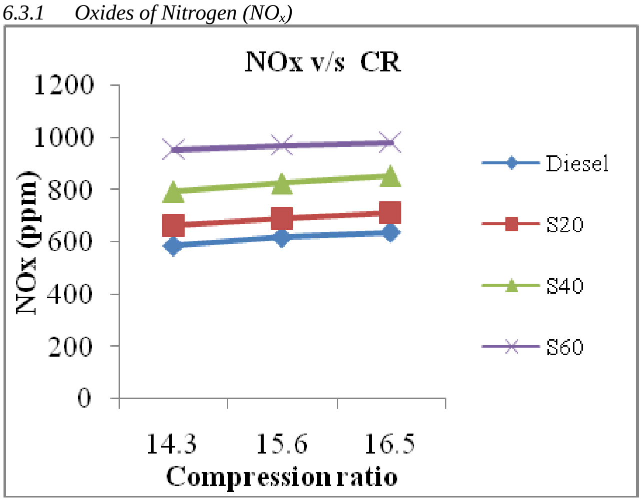

Fig 6.6: variation of NO_x emission with CR for Diesel and Simarouba blends

The above figure shows the variations of NO_x emissions of different blends with respect to different compression ratio at full load condition. It is observed from the figure that NO_x emissions increase with increasing the compression ratio at full load condition. The formation of NO_x is highly dependent on cylinder temperature, oxygen concentration and residence time for the reaction to take place. The NO_x emission for diesel was found to be high at CR 16.5:1. Also it is observed that the oxygen content is less in lower compression ratio i.e. 14.3:1, hence NO_x formation is lowered.

From the above figure it can be seen that all the biodiesel blends are showing NO_x higher than that of diesel at all compression ratios. This higher NO_x emission is due to higher temperature of combustion and the presence of oxygen with biodiesel. The NO_x emission also increases with the increase of engine load; this is because of due to the increase in combustion temperature. From the above figure it can also be observed that S20+D80 are having low NO_x emission at all the compression ratio compared to all other biodiesel blends. Overall among all the biodiesel blends the lowest NO_x emission value is found for S20+D80 blend at lowest CR 14.3:1 compared to all other compression ratios.

VII. CONCLUSIONS

1. The properties of Simarouba biodiesel and their blends are found nearer to that of Diesel.
2. The direct injection Diesel engine runs smoothly for all the Simarouba and Honge biodiesel blends used in the experiment.
3. The BP values of all biodiesel blends are near to that of pure diesel (D100) at almost all compression ratios. Overall among all the blends best (high) brake power value is found for S60+D40 at CR 16.5:1.
4. The brake specific fuel consumption of S20 blend is almost equal to diesel at lower compression ratios but at higher compression ratio the brake specific fuel consumption value of S20 blend is equal to diesel.
5. The brake thermal efficiency of S20+D80 is having 0.17% greater than that of diesel and its value is found to be 35.71%. This may be due to the fact that the oxygen contained in the Simarouba Glauca oil biodiesel takes part in the complete combustion, which in turn enhances the combustion process, hence resulting in higher brake thermal efficiency.
6. Methyl ester of Simarouba S60 is having low HC emission at higher compression ratio 16.5:1 compared to pure diesel (D100) and 3 different biodiesel blends.
7. Methyl ester of Simarouba S60 is having low CO emission at higher compression ratio 16.5:1 compared to pure diesel (D100) and 3 different biodiesel blends.
8. The Simarouba biodiesel blends are showing NO_x emissions higher than that of diesel at all compression ratios. Overall among all the biodiesel blends the lowest NO_x emission value is found for S20+D80 blend at lowest CR 14.3:1 compared to all other compression ratios.
9. Finally it is concluded that by using Simarouba biodiesel blends main emissions like HC and CO emissions decreases, where as NO_x emissions increases, this is one drawback.

VIII. FUTURE SCOPE

1. A detailed study can be made on biodiesel from the combination of Simarouba Glauca oil and Honge oil using different catalyst like MgO, CaO, and $CaTiO_3$, etc.
2. Performance of bio-fuelled engines can be improved by adding oxygenated fuel additives.
3. By varying the number of spray holes and orifice diameter of nozzle by correct combination and optimizing the engine parameters an attempt can be made to increase the efficiency.
4. Preheated biofuels can be used to study the effect of preheating the fuel before injection on the performance and emission characteristics of direct injection CI engine using biofuel as fuel.
5. Further investigations can be done to explore the knowledge of dynamics combustion with biodiesel as fuel for the better optimization.

NOMENCLATURE

B.P.- Brake Power, BSFC- Brake Specific fuel consumption, BTE- Brake Thermal Efficiency, HC- Hydro Carbons, CO- carbon monoxide, NO_X- oxides of nitrogen, ppm- parts per million.

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