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Performance and Emission Characteristics of VCR Engine Fueled with TYRE Oil and Cotton Seed Oil Blends

G. Naga Malleswara Rao, Shaik Chand Mabhu Subhani

***Abstract:** In this paper, the biodiesel from non-edible tyre oil and edible cottonseed oil is prepared using a two-step 'acid-base' process. An experimental investigation has been carried out to analyze the performance and combustion characteristics of a VCR diesel engine fueled with tyre oil & cottonseed oil and its blends for different compression ratios. The blends will be prepared using varying 5% of biofuel with diesel, using cotton seed and tyre and diesel blends at different loads. The results will show that maximum cylinder pressure and maximum heat release rate increased with the increase in biodiesel blends. The carbon monoxide (CO) and smoke emissions may be significantly lower when operating on biodiesel & diesel blends, Nitrogen Oxide (NOx) emissions will be found at full load. This study will reveal that the performance of the engine with these biodiesel blends differs marginally from diesel and its blends. The performance of the individual and mixture of both biofuels will be compared.*

***Keywords:** VCR Engine, Biofuel, Cottonseed Oil, Tyre Oil, Blends, Performance, Emissions*

I. INTRODUCTION

Energy is very important for society as it is used to sustain and improve well-being. It exists in various forms, from many different sources. Historically, with economic development, energy needs grew, utilizing natural resources such as wood, hydro, fossil fuels, and nuclear energy in the preceding century.

The difference between biodiesel and petroleum diesel lies in the name itself. Petroleum diesel is created and is 100% petroleum-based, considered as a fossil fuel. On the other hand, bio-diesel is composed of biological mass. Bio-diesel is created from live feedstock such as vegetable oil, peanut oil, coconut oil, and even algae oil. Bio-diesel can be used as a direct fuel considered B100, or in its unrefined form of Straight Vegetable Oil (S.V.O.). Since many of these S.V.O. (Straight Vegetable Oil) are similar in properties to those of petroleum diesel.

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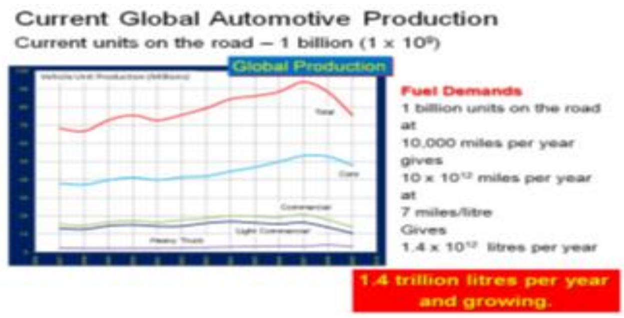

Figure 1: Current Global Automotive Productions and Fuel Usage

First-generation biofuels are produced in two ways. One way is through the fermentation of either a starch-based food product, such as corn kernels, or a sugar-based food product, such as sugar cane, into ethanol, also known as ethyl alcohol, or "gasohol." Another way is by processing vegetable oils, such as soy, rapeseed and palm, into bio-diesel, a nonpetroleum-based diesel fuel.

Second Generation bio-fueLSecond-generation bio-fuels (hydrogenated vegetable oil (HVO), synthetic diesel, bioethanol (more advanced than 1st generation) can be produced from 'plant biomass' which tends to refer to lignocelluloses materials (whole parts of plants). These second-generation, or "advanced," bio-fuels, are made from non-food sources and hold significant promise as a low-carbon, renewable transportation fuel that can complement traditional petroleum-based fuels in meeting the world's future of energy needs. The process of making alcohol from lignocellulose biomass, in principle, is relatively simple: after hydrolysis and subsequent fermentation, the ethanol can be refined by distillation

Recent improvements in the injection systems (common rail system) and the application of supercharged or turbocharged engines satisfy the requirements regarding output power. Moreover, the exhaust gaseous emissions are improved against older engine and injection systems. Unfortunately, the exhaust gaseous emissions of NOx and soot from the compression ignition (CI) engine are still high and limited by the legislation norms.

II. LITERATURE REVIEW

S. Sinha et al [1] investigated that emissions of carbon monoxide and un-burnt hydrocarbon reduce as the load increases for all the blends of bio-diesel tested on the engine up to 80% of maximum engine load beyond that these emissions further increase.

It has been found that nitrogen oxide emission increases slightly as the engine load increases on the engine up to 80% of the maximum engine load beyond that it further decreases. The fuel samples containing 0%, 10%, 20%, 30%, 40%, 50%, 75% & 100% blends of jatropha biodiesel and conventional diesel, have been tested on a single cylinder, four-stroke, water-cooled, direct injection diesel engine of Kirloskar Make (Rated Power 10 hp at 1500 rpm). It is observed that a blend of 10-20% Jatropha bio-diesel with conventional diesel is found to be the best proportion as far as brake thermal efficiency and brake-specific fuel consumption are concerned. Emission characteristics of the engine show that the use of Jatropha bio-diesel reduces harmful emissions from the exhaust such as un-burnt hydrocarbon, carbon monoxide and smoke. Nitrogen oxide emission is found to be a little bit higher with some blends of bio-diesel for some range of brake power

Bhojraj N. Kale et al [2] investigated the performance of a diesel engine using diesel fuel and cottonseed oil (CSO) biodiesel in terms of brake thermal efficiency and indicated thermal efficiency for conventional diesel, cottonseed oil, as well as for jatropha oil on a Single Cylinder, 4-stroke vertical, water-cooled, self-governed diesel engine developing 5 HP at 1500 rpm (Rope brake dynamometer with spring balances and loading screw).his evaluation of theoretical data showed that the brake thermal efficiency and indicated thermal efficiency of CSO biodiesel was slightly higher than that of diesel fuel and jatropha oil. He finally concluded that the use of cottonseed oil biodiesel improves the performance parameters of CI engines compared to conventional diesel fuel.

Jinang M. Patel et al [3] in their study the oil is obtained from pyrolysis of the waste tyre. He evaluated the use of various tyre pyrolysis oil (TPO) blends with diesel fuel investigated and compared the results of performance and emissions characteristics of TPO blends with diesel on a 4-cylinder direct injection engine .he was maintained A constant speed of 1500rpm throughout the experiment. He blended TPO with diesel fuel at the volumetric ratios of 5% (D5), 10% (D10) and15% (D15) in his study the results showed that the brake thermal efficiency of the engine was maximum, BSFC was also found to be less and no significant increase in exhaust gas temperature for D10 blend than diesel at same loading conditions

Jawalkar et al [4] [15] [16] [17] [18] [19]. investigated and compared the results of performance and emissions characteristics of single-cylinder vertical direct injection Kirloskar diesel engine by using a different blend of mahua and linseed oil. They found that with an increase of injection pressure, the Bth Eff was increased and BSFC was reduced more for mahua biodiesel in comparison to Linseed biodiesel. They observed that as a proportion of blend is increased the brake thermal efficiency was decreased. They observed that the BthEff of M50 was 13.49% lower than that of L50 at 160 bar pressure at full load. They also observed that as the proportion of blend increased the BSFC decreased. They investigated that CO emissions were lower for mahua oil than for linseed oil. They also observed that at 20% load, the HC emission of the engine

Sk. Mohammad Younus et al [5] investigated oil taken as the tyre pyrolysis oil which was obtained by the pyrolysis of the waste automobile tyres. He conducted the test on four four-stroke single-cylinder diesel engines by using diesel. In his investigation the tyre pyrolysis oil was blended with diesel in different proportions such as T10, T20 and T30 with Ethanol and Ethyl Hexyl Nitrate (EHN) as additives to the diesel-biodiesel blends .he did Ethanol was added as 5% and 10% by volume to the diesel-biodiesel blends and Ethyl Hexyl Nitrate (EHN) was added as 0.5% and 1% to the diesel-biodiesel blends. He concluded that the Brake thermal efficiency increased The Brake specific fuel consumption decreased and CO, CO2 and HC emissions decreased significantly with all blends when compared to the conventional diesel fuel.

Alp Tekin ERGENC et al [6] analyzed that Conventional diesel and soybean-based biodiesel blends and tests were conducted on an air-cooled single-cylinder DI diesel engine. He found that by using soybean ester–diesel blends, the engine operated smoothly without any notable problems. He finally concluded that the maximum torque generated by the soybean ester blends (B20, B50) and CO, NOx, and CO2 emissions were very similar or lower than those of diesel fuel. He found that the rate and maximum value of heat release decreased with the higher percentage of soybean ester in the blends

K.Naveen et al [7] examined the Ziziphus jujuba(Indian jujube), which is edible, first time introduced as fuel to run single-cylinder, four-stroke, variable compression ratio diesel engines. His Experimental investigation of a diesel engine was made with 20% (B20),40% (B40) and 60% (B60) blending of Ziziphus jujuba oil with diesel for compression ratio from 15:1 to 18:1 his investigation finally concluded that SFC decreases with increasing load for the compression ratio from 15:1 to 18:1 and increases with increasing percentage blending of bio fuel, BTE and EGT increases with increasing the load for all the compression ratio (18:1 to 15:1) and all the blending (B20, B40 & B60).B20 register higher BTE when compared to B40 & B60 except the compression ratio of 17:1. And EGT decreases with increasing the compression ratio and blending percentage. B60 register lower EGT at all compression ratios compared with B20 & B40 as well as Diesel. Miqdam Tariq Chauhan et al https://doi.org/10.1016/j.egypro.2012.05.149 investigated the effect of the biodiesel produced from restaurant waste feedstocks on the engine [8]. Biodiesel blends were prepared from restaurants' waste yellow grease of different vegetable oils. The neat fuels and their 20% blends with diesel fuel were studied at steady-state engine operating conditions in a four-cylinder direct injection. In his investigation he found that Brake specific fuel consumption was found to have minimal, the brake thermal efficiency was found to increase with the increase in load when compared with neat diesel and he examined that biodiesel fuels provided significant reductions in carbon monoxide, unburned hydrocarbons and particulate matters, oxides of nitrogen increased by 7 and 11% for the yellow grease B20 and B100 respectively.

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Dr Hiregoudar Yerrennagoudaru et al [9] in his investigation he highlighted the usage of Methanol (30%) blended with Cottonseed oil (70%) for a twin-cylinder compression ignition engine and the performance characteristics of this blended fuel. He found that Methanol Blends with vegetable oils emit fewer pollutants compared to diesel, he examined that The HC, CO emissions are measured in exhaust gases using a gas analyzer and it is observed that HC, CO emissions in Methanol Blend with vegetable oil are less compared to diesel.

M.Harinatha Reddy et al [10] his paper give a brief line about the worldwide production of cottonseed & its oil, Cotton Seed Oil (CSO) properties, its comparison with diesel and Jatropha biodiesel he investigated the performance of a diesel engine using diesel fuel and cottonseed oil (CSO) biodiesel in terms of brake thermal efficiency and indicated thermal efficiency for conventional diesel, cottonseed oil, as well as for Jatropha oil. The test is conducted on A Single Cylinder, 4-stroke vertical, water-cooled, self-governed diesel engine developing 5 HP at 1500 rpm (Rope brake dynamometer with spring balances and loading screw. Brake drum diameter = 0.400 m.). His evaluation of theoretical data showed that the brake thermal efficiency and indicated thermal efficiency of CSO biodiesel was slightly higher than that of diesel fuel and Jatropha oil. This study reveals that the use of cottonseed oil biodiesel improves the performance parameters of CI engines compared to conventional diesel fuel.

Aydin et al. [11] described the effects of different blends like 5% (B5), 20% (B20), and 50% (B50) of cottonseed oil methyl ester in a single cylinder, direct injection, air-cooled diesel engine at partial and full load condition. They investigated the effects of the blend on the engine fuel consumption and exhaust emissions at 2000 rpm of engine speed. They observed that for both, half-load engine conditions and easy-loaded engine operation, at 2000 rpm engine speed the BSFCS of B5 were lower than those of other fuels. According to them at partial loads, for diesel and B5 fuels the exhaust gas temperatures were found to be higher than those of B20 and B50 as a result of higher thermal efficiencies of B5 and diesel fuels. They observed that the lowest CO emissions were obtained for biodiesel blends, at 50% load due to their rich oxygen content and optimal air-fuel ratio. They stated that the NOx emissions were decreased with the use of B20 and B50 blends. They observed that SO2 emissions were decreased with an increase in biodiesel content in the blend. The lowest SO2 values were found for B50 usage for all loads

Adaileh et al. [12] measured the performance of a diesel engine fuelled by biodiesel extracted from waste cooking oil for a four-stroke single-cylinder diesel engine loaded at variable engine speed between 1200-2600 rpm. According to them, B20 produced significant reductions in the CO, HC, and smoke emissions compared with standard diesel and B5. They observed that biodiesel had more volumetric consumption than diesel due to its higher oxygen content. They investigated that exhaust emissions were reduced and performance was improved with biodiesel as fuel. They also observed that biodiesel can be safely used in engines up to a lower amount of blending up to 20%. According to them treatment of the engine was required for the reduction of particulate emissions. They observed that NOx emissions were increased with the amount of blending and with the use of EGR, these emissions could be reduced. They evaluated that with the increase in engine speed fuel consumption rate, brake thermal efficiency, equivalence ratio, and exhaust gas temperature were increased while at the same time the BSFCs, emission of CO2, CO and NOx were reduced with the engine speed.

Sharma et al. [13] discussed the latest aspects of the development of biodiesel. The effects of molar ratio, moisture content, reaction temperature, specific gravity, and stirring have been discussed in this research paper. Apart from this biodegradability and stability of biodiesel have also been discussed. According to their observation methanol being cheaper was the commonly used alcohol during the transesterification reaction. They observed that among the catalysts, homogeneous catalysts such as sulphuric acid, sodium hydroxide, and potassium hydroxide are commonly used at the industrial level production of biodiesel. They also investigated the use of heterogeneous catalysts such as calcium oxide, magnesium oxide and others to decrease the catalyst amount and production cost of biodiesel. According to them, the transesterification reaction can be completed even without a catalyst by using supercritical methanol but it would increase the production cost of biodiesel as it was energy intensive. They observed that the molar ratio of alcohol to oil required for acid transesterification was from 6:1 and 18:1 for alkaline transesterification it ranged from 5:1 and 12:1. They observed that the temperature ranged between 45^0 C and 65^0 C as the boiling point of methanol is 64.7OC and heating beyond this temperature would burn methanol. However, they observed that a higher temperature was employed while using supercritical methanol (200OC–300OC). They described that a balance had to be maintained between the composition of saturated and unsaturated fatty acids in the biodiesel fuel. According to them, high saturated fatty acid content would increase the oxidative stability but the pour point and cloud point were increased which is not desirable on the other hand higher un saturation content increased the pour point and cloud point but decreased the oxidative stability. Jawalkar et al. [14] investigated and compared the results of performance and emissions characteristics of single-cylinder vertical direct injection Kirloskar diesel engine by using a different blend of mahua and linseed oil. They found that with an increase of injection pressure, the BthEff was increased and BSFC was reduced more for mahua biodiesel in comparison to Linseed biodiesel. They observed that as a proportion of blend is increased the brake thermal efficiency was decreased. They observed that the BthEff of M50 was 13.49% lower than that of L50 at 160 bar pressure at full load. They also observed that as the proportion of blend increased the BSFC decreased. They investigated that CO emissions were lower for mahua oil than for linseed oil. They also observed that at 20% load, the HC emission of the engine was higher for mahua oil in comparison with linseed oil.

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III. EXPERIMENTAL SETUP AND METHODOLOGY

A. Production of Tyre Pyrolysis Oil

i. Availability and Composition of Tyres

Since the number of automobiles used in India is less than the developed countries, the problems related to the disposal of waste tyres are not seriously realized as of today. But it is supposed to become a serious problem shortly. Hence, proper treatment methods for waste tyres have to be put in place in advance.

Table 1: Input Tyres to Finished Products Output Ratio

Input Material	Input Quantity	Output Quantity
Waste mixed plastic scrap	10,000kgs	- 6,500 to 9,000 lit of Pyrolysis Oil - 500 to 1,000 Kg of Hydrocarbon Gas - 500 to 700 Kg of Carbon Black
Nylon Scrap tyres	10,000kgs	- 4,500 to 5,000 lit of Pyrolysis Oil - 1,000 to 1,200 Kg of Hydrocarbon Gas - 3,000 to 3,500 Kg of Carbon Black
Radial Scrap tyres	10,000kgs	- 4,000 to 4,500 lit of Pyrolysis Oil - 800 to 1,000 Kg of Hydrocarbon Gas - 2,750 to 3,250 Kg of Carbon Black - 800 to 1,000 kgs of Mild steel wire scrap

A tyre is artificially engineered by the human mind. It contains chemicals, rubber, steel and fabric. Approximately 80% of the original constituents remain at the end of its service. The theory to reduce, reuse and recycle is difficult to implement with tyres owing to their complex nature, durability, varying size, numbers involved and different dimensions

ii. Pyrolysis of Tyres

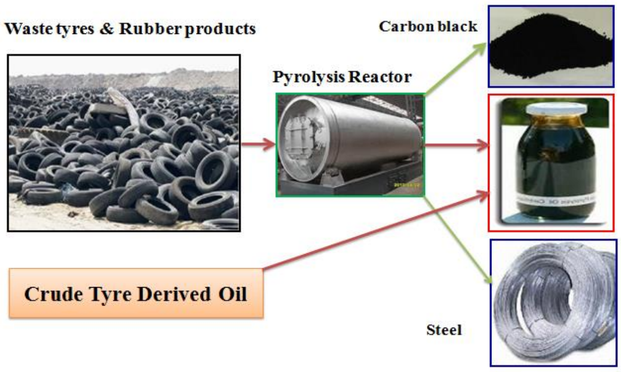

Figure 2: Products from Waste Tyres after Pyrolysis

A car tyre has a mass of about 8.5 kg, whereas the mass of a tyre of a passenger or light-duty vehicle is around 11 kg. The constituents of truck tyres are given in Table 1. The various parts of an automobile tyre include bead, bundle, body, belt, cap sidewall and tread.

The raw materials used in tyres include synthetic and natural rubber, nylon, polyester cord, carbon black, sulphur, oil resin and other chemicals. These constituents provide the tyre with good strength and flexibility to ensure adequate road-holding properties under all conditions. About 80% of the mass of car tyres and 75% of the mass of truck tyres are rubber compounds. The components of tyres manufactured by different manufacturers are very similar. The tread portion of a tyre is primarily used for energy recovery to obtain TPO, pyro gas and carbon black.

Table 2: Components of Truck Tyre

Component	Proportion (%)
Carbon Black	40
Oil	43.5
Steel Wire	16.5

B. Preparation of Blends

The different types of blended bio-fuels used in these projects are

1. DIESEL: 100% PURE DIESEL
2. C0T10N90: 0%CSO 10%TYREOIL 90% DIESEL
3. C0T20N80: 0%CSO 20%TYREOIL 80% DIESEL
4. C10T0N80: 10%CSO 0%TYREOIL 80% DIESEL
5. C20T0N80: 20%CSO 0%TYREOIL 80% DIESEL
6. C10T10N80: 10%CSO 10%TYREOIL 80% DIESEL
7. C10T20N70: 10%CSO 20%TYREOIL 70% DIESEL
8. C20T10N70: 20%CSO 10%TYREOIL 70% DIESEL

Figure 3: Blended Fuels

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Table 3: Properties of the Biodiesel

S. No	Blend	Viscosity (Stokes)	CALORIFIC VALUE (KJ/Kg K)	Flash Point(^{0}C)	Fire Point(^{0}C)	Density 45 ^{0}C (Kg/m^3)
1	DIESEL	2.65	46000	55	61	640
2	C0T10N90	2.43	45750	54	59	650
3	C0T20N80	2.32	45670	52	57	660
4	C10T0N90	3.59	45730	54	60	660
5	C10T10N80	3.42	45520	53	57	670
6	C10T20N70	3.31	45360	51	55	680
7	C20T0N80	4.53	45600	57	63	660
8	C20T10N70	4.23	45330	56	62	680
9	TYRE OIL	1.64	41320	46	49	780
10	COTTON SEED OIL	6.92	40200	134	146	780

i. *Test Rig Specification*

Engine: 4 - stroke 1- cylinder water cooled Diesel engine
Make: Kirloskar
Rated power: 3.7KW (5 HP)
Bore diameter: 80mm
Stroke length: 110mm
Connecting rod length: 234mm
Swept volume: 562cc
Compression ratio: 16.5: 1
Rated Speed: 1500 rpm

ii. *Dynamometer*

Dynamometer: Eddy current dynamometer

Make: POWER MAG
Rated torque: 24N-m
Arm length: 150mm

iii. *Indus 5 Gas Analyser: it is used to Measure the Concentration of Exhaust Gases*

Figure 3: Indus 5 Gas Analyser

IV. RESULTS AND DISCUSSIONS

A. Performance Parameters

i. *Brake Power (kW) Vs Compression Ratio*

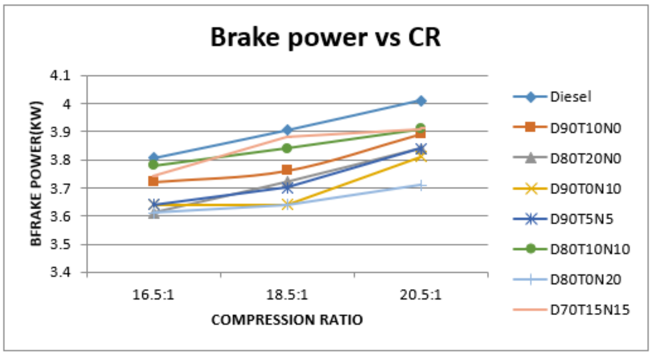

Figure 4: Brake power (kW) Vs Compression Ratio at a Maximum Torque of 24 Nm

ii. *Brake Thermal Efficiency (%) Vs Compression Ratio*

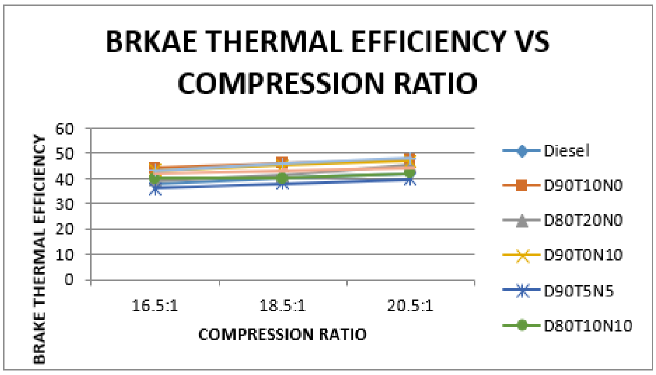

Figure 5: Brake Thermal Efficiency (%) Vs Compression Ratio at Maximum Torque of 24 Nm

iii. *Volumetric Efficiency (%) Vs Compression Ratio*

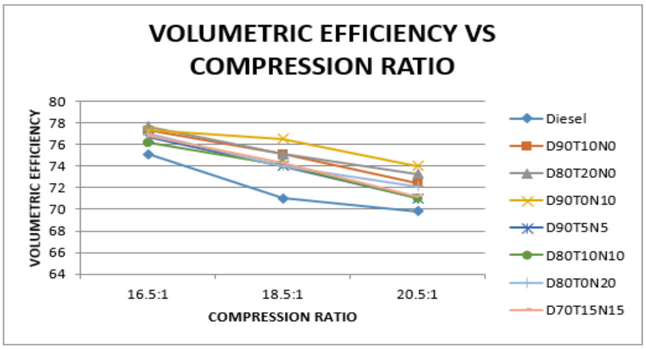

Figure 6: Volumetric Efficiency (%) Vs Compression Ratio at Maximum Torque of 24 Nm

iv. *Exhaust Gas Temperature (0C) Vs Compression Ratio*

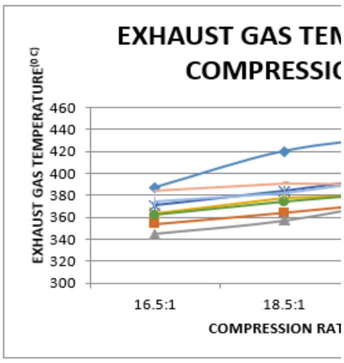

Figure 7: Exhaust Gas Temperature (^{0}C) Vs

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Compression Ratio at Maximum Torque of 24 Nm

v. Brake Specific Fuel Consumption (Kg/Kw Hr) Vs Compression Ratio

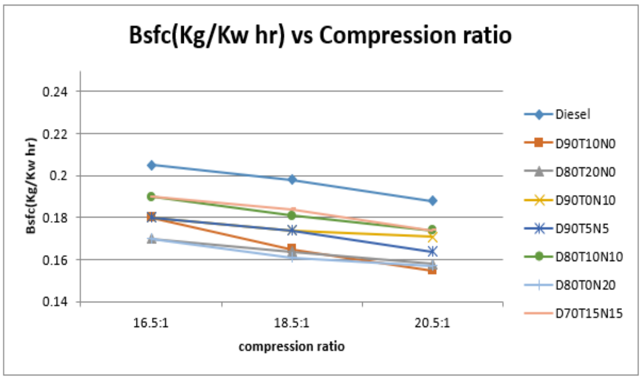

Figure 8: Brake Specific Fuel Consumption (Kg/Kw Hr) Vs Compression Ratio at Maximum Torque of 24 Nm

B. Emission Analysis

i. Hydro Carbon Emission (Ppm) Vs Compression Ratio

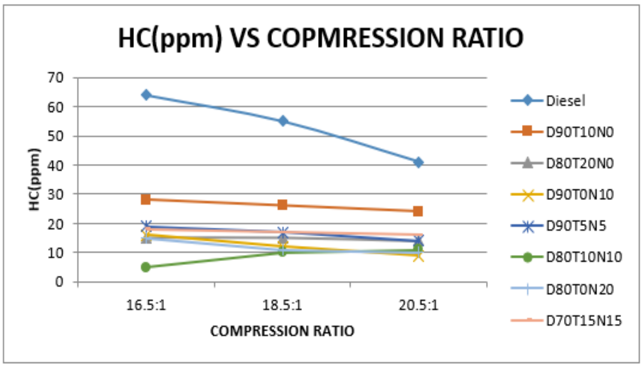

Figure 9: Hydro Carbon Emission (ppm) Vs Compression Ratio at Maximum Torque of 24 Nm

ii. Nitrogen Oxide Emission (Ppm) Vs Compression Ratio

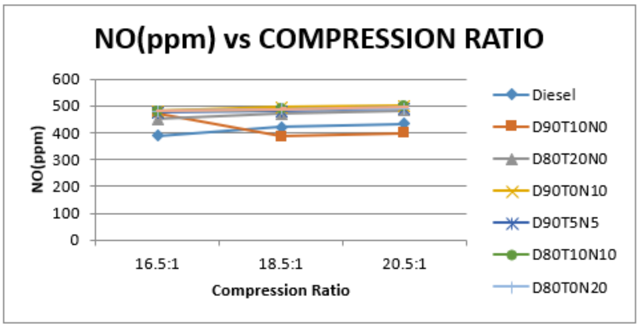

Figure 10: Nitrogen Oxide Emission (ppm) Vs Compression Ratio at Maximum Torque of 24 Nm

iii. Carbon Monoxide (%) Vs Compression Ratio

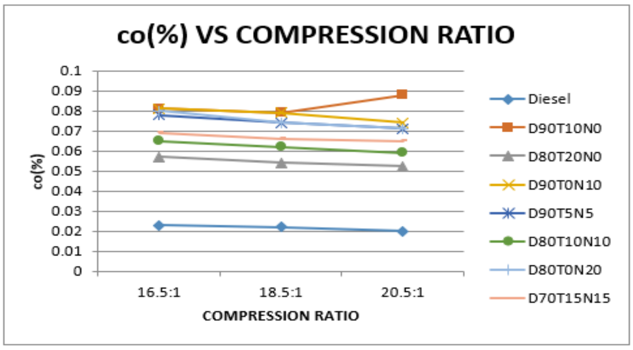

Figure 11: Carbon Monoxide (%) Vs Compression Ratio at Maximum Torque of 24 Nm

iv. Carbon Dioxide (%) Vs Compression Ratio

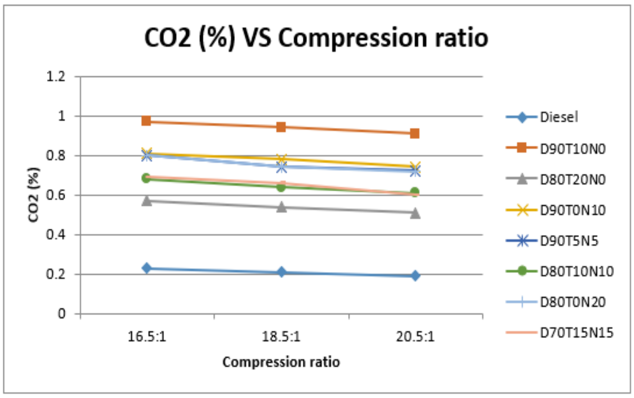

Figure 12: Carbon Dioxide (%) Vs Compression Ratio at Maximum Torque of 24 Nm

V. CONCLUSIONS

The experimental results shown in this paper that engine performance and emissions of all blends were run on the diesel engine and compared with standard diesel fuel

1. Properties of all blends are nearly equal to the diesel fuel. The brake power for C20T10N70 is 1.183% more than the diesel and for C0T20N80 is 5.125 % less than diesel. The highest is recorded with and C20T10N70 lowest with C0T20N80 at higher compression ratio
2. Ø As the applied torque is maximum at 24 KN m, the brake thermal efficiency of the fuel blends also increases at all compression ratios. The maximum brake thermal efficiency at full torque of 24Nm is 45.36% for C10T0N90
3. The brake-specific fuel consumption for C0T20N80, C10T0N90 and C20T0N80 is 0.17Kg/Kw Hr and diesel has 0.205 Kg/Kw Hr the specific fuel consumption only increases for higher percentages of blends at higher compression ratios.
4. The volumetric efficiency decreases for the blend. The decrease in volumetric efficiency is due to an increase in the compression ratio
5. The increasing compression ratio at maximum Torque the exhaust gas temperature is also increased. The exhaust temperature is highest for C10T20N70 and lowest for C10T10N80 at a 20.5:1 compression ratio
6. It can be observed from the figure that there was a gradual increase in NOx emission with an

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increase in the blend concentration but less than that of diesel fuel. Due to higher heat release rates, there is an increase in cylinder temperature increasing NOx emissions

7. Due to incomplete combustion and inadequate supply of oxygen carbon dioxide emission of the fuel blends C0T10N90 low at full load decreases.
8. The carbon monoxide emission of the blend C10T10N80 is found to be higher for low and medium torque and closer to that of standard diesel at high Torque.

The blends of C10T20N70 and C20T0N80 have carbon monoxide lower than that of diesel Cotton seed oil and tyre oil promising as the best alternative fuel source for diesel engines because of their high heat content. It can be directly used as diesel fuel but a major problem was cottonseed oil having high viscosity. From this investigation, test results showed that 20% cottonseed oil 10% tyre oil and 70% diesel (C20T10N70) and for suitable to be used as diesel fuel without any modification of the engine

DECLARATION STATEMENT

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Conflicts of Interest	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material	Not relevant.
Authors Contributions	All authors have equal participation in this article.

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