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A Comparative Characteristic Study of Jatropha and Cardanol Biodiesel Blends

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Abstract. The demand in fuel needs and the depleting fossil fuels raised the need towards bio-fuels. The emerging trend in research field is highly focused on biodiesel production and their characteristic analysis. Since pollution is a major threat to the environment, emission parameter analyses are much important to be concentrated. As the entire world contains plenty of biofuels, it is necessary to explore them for its efficiency and analyze their parameters. In this experimental work jatropha and cashew nut shell biodiesel (Cardanol) was extracted and they were blended with diesel. The characteristics of jatropha and cardanol biodiesel were studied in the DI diesel engine by varying the load at the same speed. In brief, this experimental analysis is carried out to compare the emission characteristics between Jatropha biodiesel at 20% (B20) and 40% (B40) and Cardanol biodiesel blends at 20% (C20) and 40% (C40).

1. Introduction

In this current era, the consumption and price of hydrocarbon fuels (Petrol, Diesel) have increased progressively. The existing hydrocarbon fuels can be utilized for the next 50 to 60 years only, to fulfill our fuel requirements. In order to meet the demand of these fuels, there is a need to develop alternative energy sources like biodiesel, solar power, natural gas, gasohol etc., which could be an alternative in the future. Dhanasekaran and Mohankumar [1] revealed the importance of the alternative fuel in the current scenario. Biodiesel is described as a fuel comprised of mono-alkyl esters of long chain fatty acids derived from animal fats or vegetable oils. The use of edible oil to produce biodiesel in India is not feasible as the demand is more due to the inadequate supply of such oil for commercial use. In Indian economic condition, the promotion of non-edible biodiesel is essential; it can be grown in even non-cropped marginal lands and waste lands in large scale. India has more than 300 species of trees, seeds, and fruits which produce the oil bearing seeds [2].

The raw biodiesel obtained cannot be used directly, because of its higher density and viscosity when it compared to hydrocarbon fuels. This biodiesel is very poor in atomization and vaporization with air, which leads to poor combustion, lower thermal efficiency, and higher emissions. So the biodiesel and their blends can be used to promote favorable environmental and performance benefits. From the literature survey, there are two main non-edible oil crops are used; among them, the first one is Jatropha curcas. The seed of Jatropha contains 26 - 40% oil, which can be processed to produce a good quality of biodiesel. The other one is Cashew Nut Shell oil (CNSL). It is also one of the most efficient and high productivity Non-edible oil crops The usage of CNSL reduces HC, CO, NOx gasses than the hydrocarbon fuels [3]. In this comparative study, 20% and 40% of the blends of Jatropha curcas and Cashew Nut Shell are used; they are mentioned here as B20, B40 (Jatropha) and C20, C40 (CNSL).

2. Literature survey

Anand et.al. [4] derived the biodiesel by using transesterification process from waste cooking oil in response surface method. The derived biodiesel characteristics were studied in a single cylinder, four-stroke, direct injection diesel engine at a constant speed of 1500 rpm to find the combustion characteristics, the effect of injection pressure, timing of performance and emission. The combined variation of injection pressure and timing increase the injection pressure about 280 bars and injection timing in advance of 25.50 BTDC, which shows the appreciable improvement in brake thermal efficiency, cylinder gas pressure, and heat release rate and it is also reduced the nitric oxide (NO) and smoke emission.

In general, the transesterification process is used to produce the biodiesel, which involves a chemical reaction between an alcohol and the triglycerides. The fatty acids are the suitable catalyst which leads to the formation of fatty acid alkyl esters and glycerol. Alcohol to oil molar ratio, catalyst concentration, reaction temperature, reaction time, free fatty acid (FFA) content and stirring rate are the major factors of affecting the transesterification process. Velmurugan (2011) tested of commercial diesel fuel and bio-fuel from CNSL with ethanol as an additive (BDEB) [5]. Experimental Investigation of CNSL as the alternative was undertaken by V. Palvannan and the first trial run with a maximum of 20% CNSL-diesel blend was successfully conducted on single cylinder CI engine. Engine power output and smoke emissions are found to be satisfactory, then it was decided to proceed further testing. Achten W.M.J., et.al., [8] studied the performance of the biodiesel blends and emission characteristics with 0.5%, 10%, 15%, 20% and 25% blends of Cardanol and Diesel. They reported that up to 20% blends of Cardanol bio-fuels may be used in combustion-ignition engines without any modifications.

Sayin Cenk et al., investigates the influence of compression ratio (CR) and injection parameters such injection timing (IT) and injection pressure (IP) on the performance and emissions of a DI diesel engine for various biodiesel blended with different CRs, ITs and Ips at the speed of 2200 rpm. The study gives the best results for BSFC, BSEC and BTE were observed at increased the CR, IP. The experiments were carried out using DI diesel engine which was operated in a range of 700 kPa brake mean effective pressures with the interval of 100 kPa. The increased IP gave the best results for BSFC, BSEC and BTE compared to the ORG and decreased IP. Finer breakup fuel droplets obtained with increased IP provides more surface area and better mixing with air and this effect improve the combustion. OP, HC, and CO emissions decreased and NOx emissions increased with the increase in IP for the all fuel blend [6].

Narayana Reddy and Ramesh [7] study the performance, emissions and combustion of Jatropha in a single cylinder, constant speed, direct injection diesel engine and results were compared with neat diesel operation. Anand. R., et.al., [4] studied the effect of diestrol fuel on the performance, emission and combustion characteristics of a DI diesel engine for varying injection pressure and timing. From the experimental investigation, the maximum brake thermal efficiency of 31.3% was obtained at an injection pressure of 240 bars and injection timing of 25.5° btdc it reduced the nitric oxide (NO) emission by 4.3%. The unburnt hydrocarbon (UHC) was observed and a minimum ignition delay was observed in 12.7° CA with diestrol fuel.

3. Jatropha curcus

The Jatropha is a shrub type plant that grows to an average height of 3-5 meters. Its fruit contains seed, which is rich in non-edible oil. It can grow in poor soils, but generally, prefer the heat of the tropics and subtropics and doesn't need irrigation. According to favorable natural conditions for the growth of this plant, it can be cultivated throughout India.

3.1: Jatropha oil extraction

Jatropha curcas seeds contain 27% to 40% of the oil that can be helped to produce a high-quality of biodiesel fuel. It can be used in the standard diesel engines, especially if the oil of the seeds is well extracted [9]. Many oil extraction methods are available based on accuracy, cost effectiveness, kind and nature of the feedstock and efficiency. The methods include mechanical pressing, solvent extraction and supercritical fluid extraction [4]. Thananchayan et al. their experiments indicate that the Jatropha gives a higher biodiesel yield than Castor oil by transesterification reaction in first order reversible reaction in this the oil was extracted in excess compared to methanol. The mechanical pressing (expulsion) process involves the use of pieces of equipment like screw press or a piston, extruder expander and mortar. In this process, oil is expelled from a dry feedstock. The main drawbacks of this process are particle size and nature of the feedstock. Also, the moisture content of the seeds has a role to play in the efficiency of the process [10]. In solvent extraction, oil can be extracted chemically using a solvent such as n-hexane, chloroform, and benzene. N-hexane is the most commonly used solvent that mixed with the feedstock paste and then, later, distilled in order to obtain pure oil. This method is not expensive, and it is efficient [12].

3.2: Biodiesel production from jatropha

The extracted oil has to undergo a chemical process known as transesterification to yield biodiesel. The process was carried out by reacting the extracted Jatropha oil with methanol in the presence of potassium hydroxide (which has been reported to give high yield and conversion of the transesterification reaction with minimal side reaction) as a catalyst to produce ester and glycerol. At the end of the reaction, glycerol and biodiesel will be formed in two layers. After settling, the glycerol was at the bottom while the biodiesel was at the top of the container used. The layers were later separated from each other by draining the glycerol from the bottom of the flask containing the mixture.

The initial triglyceride content of the oil was determined by titrimetric analysis. Keeping the reaction temperature and stirring rate constant at 65ºC and 460 rpm respectively, three different biodiesel production conditions were varied. Initially, the transesterification was done by varying the reaction time and keeping the oil to methanol molar ratio of 4:1 and 2.5% catalyst. The first set of biodiesel was produced. Secondly, the reaction time was kept at 75 minutes, molar ratio was 4:1 and the catalyst load was varied. Thus yields the second set of biodiesel. Finally, the methanol to oil molar ratio was varied, keeping constant reaction time at 75 min and the catalyst concentration at 2.5%. Thereafter, third biodiesel production was carried out using the obtained optimum parameters from the investigations carried out before, and the yield of that was determined by titrimetric analysis and appropriate calculations. The general equation for transesterification of vegetable oils containing triglycerides is shown in figure 1.

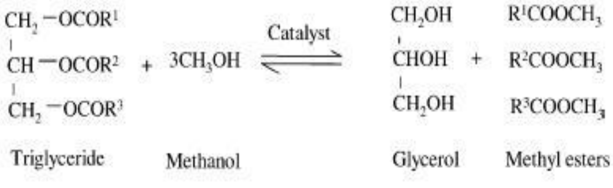

Figure1. Transesterification process

Finally, 880ml of Jatropha biodiesel (i.e. 88% yield) and 120ml of glycerol was obtained from one liter of jatropha curcas oil.

4. Cashew Nut Shell Liquid (CNSL)

The cashew processing industries produce CNSL as a byproduct and nearly 30 – 35 % of CNSL oil is available in the cashew nut shell. There are three main methods generally used in extracting cashew nut shell liquid from cashew nuts, namely thermal, mechanical and solvent extraction [11]. At first, the heating process which leads to decarboxylation of anacardic acid to form Cardanol, this comprises of 10% cardanol and 30% polymeric material and the remaining percentage is made up of substances. After the heating process, distillation is done at a reduced pressure in order to remove the polymeric material. Now, the distilled CNSL consists of 78% Cardanol, 8% cardanol, 2% polymeric material and remaining other substances. At present, the commercial extraction process is carried out by boiling or heating CNSL up to 108^0 to obtain Cardanol rich oil. The cardanol is obtained from cashew Nutshell Liquid (CNSL), the Mono hydroxyl phenol having hydrocarbon chain in the Meta position which was shown in figure 2.

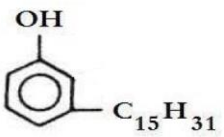

Figure 2. Structure of Cardanol

4.1. Biodiesel from CNSL

The phenomenon of the high and low volatility of non-edible oils affect the atomization of the fuel, Which leads to improper combustion and severe carbon deposits, injector choking and piston ring sticking, etc., The following methods are used to reduce the viscosity of the biodiesel,
1.Emulsification,
2. Pyrolysis,
3. Dilution and
4. Transesterification.

Among these, the transesterification is most commonly used the successful process to produce good biodiesel. The CNL biodiesel is one of the clean and environment-friendly fuel. A 50ml of extracted cashew nut oil measured and poured into a conical flask and which was preheated up to 70°C. In another conical flask, a 0.225 gram of sodium hydroxide and 20ml of methanol are mixture taken and it is mixed in gently and properly, it was mixed by stirring till the entire pellet dissolves to form sodium methoxide solution. The same procedure was followed while using potassium hydroxide as catalyst. The mixture was kept at 70ºC for a period of 1.5 hours and then it was kept overnight for proper setting of the glycerin produced.

Even after the transesterification process some impurities i.e enriched methanol, potassium methoxide, and glycerol are present in the Fatty Acid Methyl Esters (FAME). The extracted biodiesel needs some purification process before it can be used in diesel engines. The water is used as a washing agent of the biodiesel; a 30ml of water is supplied with the product gently and mixed it to avoid foam formation. This biodiesel and water mixture is permitted 5 hours of settling, they were settled in two phases in the form of biodiesel and water impurities, then they separated and used [12].

4.2. Properties of diesel and various biodiesel blends

Table 1. Properties of Biodiesel vs Neat Diesel

FUEL PROPERTY	DIESEL	JATROPHA		CARDANOL	
		B20	B40	C20	C40
Density@ 15^0 C	825	836.5	846.8	910.01	932.6
Kinematic viscosity @ 40^0C	3.52	2.88	3.16	3.12	3.98
Gross calorific value (MJ/kg)	45000	44635	43119	44850	43090
Flash point (ºC)	48	58	52	89	92

5. Engine Test Bed

The performance of the jatropha and Cardanol blends were tested with different loads on Kirloskar make water-cooled, direct injection system was used and compression ratio 20:1 was maintained. Tests were conducted at different loads, with diesel, Jatropha blends and Cardanol blends for comparative analysis and the experimental setup of the engine is shown in figure 3.

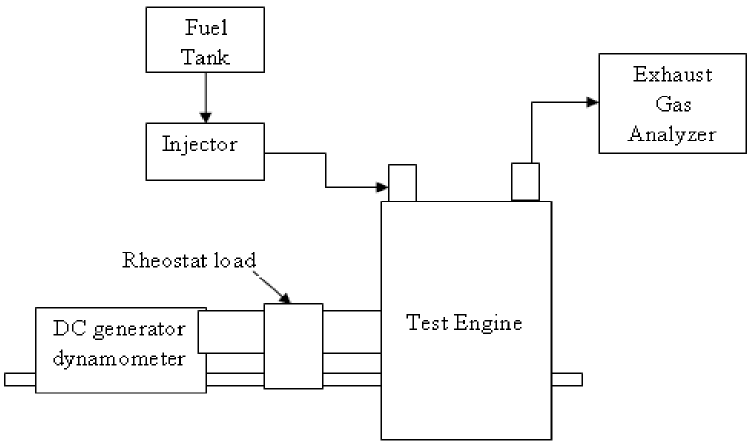

Figure 3. Experimental Setup

The dynamometer was used to find then load measurement and the engine speed was sensed, which indicates the inductive pickup on the flywheel it consists the digital output. The Chromel-alumel thermocouple was used for finding the exhaust gas temperature and a smoke meter used to find the smoke measurement. The Carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbon (HC), nitrogen oxides (NOx) was measured by emission monitoring systems. To measure the accurate value of the fuel consumed a burette place with two sensors apart from the two markings of measure 20cc.

5.1: Engine specification

The engine test bed's engine specification is shown in table 2.

Table 2. Specification of the Engine

S.No.	Details	Specification
1	MAKE AND MODEL	Kirloskar oil engine TAF1
2	Bore diameter and StrokeLenth	87.5 mm X 110 mm
3	Engine Compression Ratio	17.5 : 1
4	Engine Rated Speed	1500 rpm
5	Cubic Capacity	0.661 liter
6	Injection timing	26 Btdc
7	Injector opening pressure	200 r

5.2: Operating parameter

Badal Dev Roy. et.al. (2016), discussed the various operating parameters of the engine test bed [13], Table 3 shows the best operating range of parameters which was tried in the present testing.

Table 3. Operating Parameter

S.No	Parameters	Range
1	Percentage of Load	20%, 40%, 60%, 80% and 100%
2	Engine Speed	Constant speed (1500 rpm)
3	Engine Compression ratio	17.5:1
4	Injection Timing ^{o} Btdc	26^{o}Btdc
5	Injection Pressure	200 bars

5.3: Test procedure

1. The engine tests were conducted at 26° btdc injection timing and the injection pressures of 200bar.
2. The engine started on diesel (Hydrocarbon fuel) and it warmed up to the engine cooling water temperature to be stabilized.
3. The fuel consumption, exhaust temperature, exhaust emissions such as NO_X, CO_2, CO and exhaust gas opacity were measured and recorded in different loads.
4. The tests were repeated for 20%, 40%, 60%and 80% loading conditions.
5. To find the best value of three readings was taken from each load and an average value is calculated.

6. Results & Discussion

The engine test results of both jatropha and cardanol biodiesel's performance and emission characteristics were compared with the diesel and they are tabulated from the following table's which is also being represented in the graphs. Table 4 shows the comparison of brake specific fuel consumption.

Table 4. Comparison of brake specific fuel consumption

BMEP (BAR)	BFSC Kg/kW hr				
	DIESEL	B20	B40	C20	C40
0	0	0	0	0	0
0.89	1.08	0.484	0.512	0.673	0.646
1.78	0.6	0.39	0.468	0.385	0.373
3.57	0.45	0.338	0.421	0.252	0.247
4.46	0.39	0.303	0.357	0.231	0.225

In Figure 4, the BFSC for diesel is initially increasing with BMEP and a further increase in BMEP decreases the BSFC. This is same for the cases with B20, B40, and C20, C40 blends. The Jatropha blends have lower BFSC values than CNSL blends. In brake, specific fuel consumption C20 performs very well than diesel. B20 and C40 also perform well. The brake specific fuel consumption for C20 is around 50% relatively less of biodiesel.

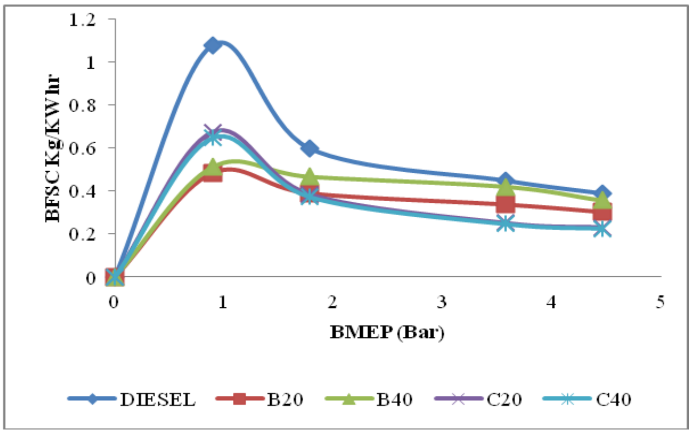

Figure 4. Comparison on brake specific fuel consumption

Table 5. Comparison on brake thermal efficiency

BMEP (BAR)	BTE (%)				
	DIESEL	B20	B40	C20	C40
0	0	0	0.00	0	0
0.89	7.2	8.03	10.12	12.45	12.953
1.78	13.07	14.73	16.77	21.761	22.452
3.57	17.3	19.88	20.98	33.199	33.85
4.46	19.95	23.21	26.04	36.268	37.131

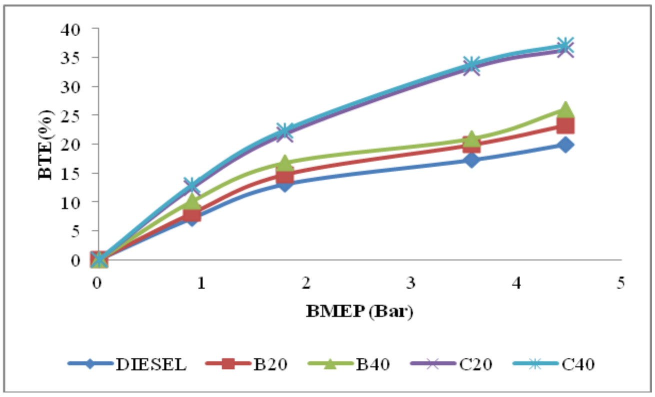

Figure 5. Comparison on brake thermal efficiency

Figure 5, shows that for CNSL blends have little higher BTE than Jatropha blends. In brake thermal efficiency C20 and C40 performs very well than diesel and B20.

Table 6. Comparison on CO emission

BMEP (BAR)	CO EMISSION (%)				
	DIESEL	B20	B40	C20	C40
0	0.03	0.01	0.02	0.095	0.14
0.89	0.04	0.02	0.02	0.09	0.12
1.78	0.05	0.02	0.02	0.087	0.11
3.57	0.06	0.02	0.02	0.081	0.098
4.46	0.06	0.04	0.05	0.079	0.097

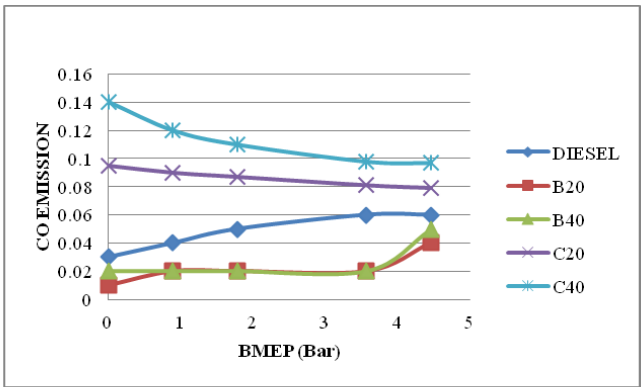

Figure 6. Comparison on CO Emission

Figure 6 illustrates that the CO emission for Jatropha blends which are lower than that of CNSL blends. In CO emission B20 and B40 performs very well than diesel, C20 and C40; C20 is relatively lesser in CO emission than C40.

Table 7. Comparison on HC emission

BMEP (BAR)	HC EMISSION (%)				
	DIESEL	B20	B40	C20	C40
0	12	10	11	8	11
0.89	10	12	11	8	9
1.78	9	9	10	6	9
3.57	11	9	10	5	10
4.46	13	10	11	5	7

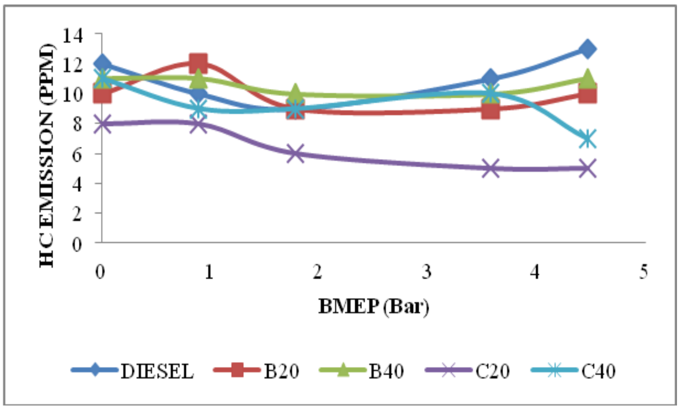

Figure 7. Comparison on HC Emission

Figure 7, Shows that the C20 blend has a low HC emission than any Jatropha blends and C40. In hydrocarbon emission, C20 is relatively very less than all other biodiesel blends as well as diesel. The hydrocarbon emission for C20 gradually reduced with an increase in pressure.

Table 8. Comparison on NO_X emission

BMEP (BAR)	NO_X EMISSION (ppm)				
	DIESEL	B20	B40	C20	C40
0	40	110	115	16	24
0.89	61	206	217	36	52
1.78	78	314	328	73	106
3.57	210	674	692	254	250
4.46	330	1075	1104	312	326

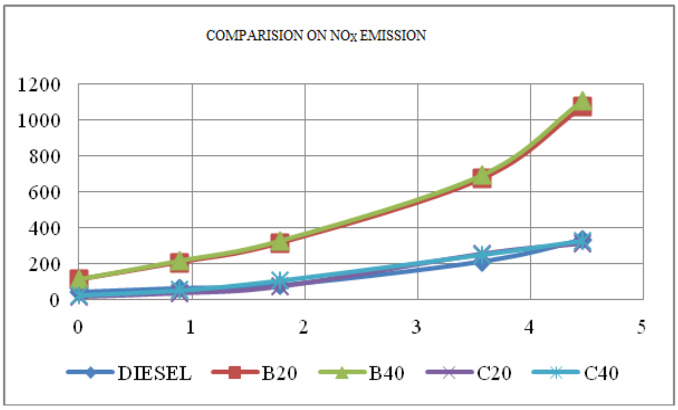

Figure 8. Comparison on NOX emission

Figure 8, illustrates that the NO_X emissions are lower for CNSL blends. In NOX emission C20 and C40 are relatively lesser than the diesel, B20 and B40**.**

6. Conclusion

The characteristics of Jatropha and CNSL biodiesel blends are studied and compared with diesel by varying the pressure, C20 performs very well with respect to brake specific fuel consumption. C20 and C40 perform very well with respect to brake thermal efficiency. C20 performs very well in reducing the hydrocarbon emission. C20 and C40 perform very well by reducing the NOX emission. The reduction of CO emissions was not found to be satisfactory for C20 and C40, whereas B20 and B40 were relatively efficient in reducing the CO emissions.

7. Future work

The comparative character study of the performance and emission characteristic on Jatropha and CNSL revealed that C20 and C40 are not effective in reducing the CO emission when compared to B20 and B40. Hence the future work was targeted in the study of substances to be added with C20 and it has to be effectively reducing the CO emissions, thereby reducing the greenhouse effect.

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