Different methods of improving performance of an IC engine fueled with CNSL biodiesel: A Review

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Abstract

Compression ignition (CI) engine is a popular prime mover, because of its high thermal efficiency and load carrying capacity. But, in view of the fast depletion of fossil fuel, the search for alternative fuels has become inevitable. Use of bio fuel as an alternative fuel can contribute significantly towards the twin problem of fuel crises. The main problem with biodiesel is its higher viscosity than diesel. To solve the problems due to high viscosity of oil various techniques are used like fuel blending,Esterification/transesterification, cracking & micro- emulsification. This paper reviews the preparation of biodiesel from Cashew nut shell oil (CNSL) & methods for improving performance of CI engine fueled with CNSL biodiesel. Performance of engine can be improved by using additives, varying injection pressure & compression ratio, by changing blends composition, preheating etc. Results of all methods are then compared with each other in order to select best method which shows improved performance and reduced fuel consumption and emission of the engine. Based on various studies, this paper generally found that CNSL biodiesel is a good alternative fuel for CI engine and if additives like ethanol are used performance of the engine can be further improved.

Keywords

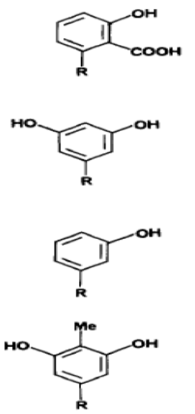
Biodiesel; Cashew nut shell oil; Injection pressure; Fuel consumption; Performance

1. Introduction

Diesel engines are the major source of transportation, power- generation, marine applications etc. But due to gradual depletion of world petroleum reserves and the impact of environmental pollution there is an urgent need for suitable alternate fuels for use in diesel engines [1]. Recently, many developing countries have focused their attention on non-edible oil for renewable fuels in order to reduce the net production from fossil fuel and the combustion process. The advantages of biodiesel are renewability, higher combustion efficiency, lower sulphur aromatic content, higher cetane number, biodegradability, and higher oxygen content [2]. Biodiesel is oxygenated compounds, defined as the mono alkyl esters of long chain fatty acids are also called methyl esters derived from lipid feedstock for example vegetable oils, animal fats or even waste cooking oil. Pure oils are not suitable for diesel engines because they can cause the carbon deposits and pour point problems and they can also cause the problems like engine deposits, injector plugging, or lube oil gelling [3]. The production of cashew nut is large number of shell help groups are enraged in decortications of cashew nuts and huge quantity of nut shells are produced as byproducts. At present these shells are going waste. The waste material deters its polluting the environment. These shells contain nearly more percent of oil. It can be easily extracted and used for various purposes [4]. The combustion efficiency of cashew nut shells for furnace, semi open pit, and for other direct burning applications is quite low. Thus demand is low and availability is in excess at low price. At present, cashew nut shells are sold at the rate of Rs 300-400 per ton at the factory premises where cashew nut processing is carried out [5]. The major producing countries of Cashew are Tanzania, India, Mozambique, Srilanka, Kenya, Madagascar, Thailand, Malaysia, Indonesia, Nigeria, Senegal, Malawi and Angola [6]. Cashew nut is very nutritious with high amount of energy as it contains protein, minerals, fats, carbohydrate, vitamins and fiber, all of which contribute enormously to good health from its consumption. Cashew nut kernel can be eaten raw, fried and sometimes pre-treated with salt or sugar. Other useful products made from cashew are jam, juice, syrup, chutney and beverage [7]. Solvent-extracted CNSL contains anacardic acid (60–65%), cardol (15–20%), cardanol (10%) and traces of methyl cardol. Technical CNSL is obtained by roasting shells and contains mainly cardanol (60–65%), cardol (15–20%), polymeric material (10%), and traces of methyl cardol [8]. India is the largest producer, processor and exporter of cashew in the world. In India cashew cultivation covers a total area of about 0.77 million hectares of land, with annual production over 0.5 million metric tons of raw cashew nuts. CNSL is extracted by various methods such as open pan roasting; drum roasting, hot oil roasting, cold extrusion, etc. [9]. The main components of CNSL are anacardic acid, cardanol, and cardol. These are phenolic compounds that have double bonds in its branched chains. Cardanol compound has chemical structure similar to phenol, so it has the potential to be used as substitute for phenol compound [10].

2. Production of CNSL

Subbarao et al. [11] explained the various methods of extraction of CNSL form cashew nuts. It is given briefly as follows. There are three main methods generally used in extracting cashew nut shell liquid from cashew nuts namely thermal, mechanical and solvent extraction. thermal extraction involves roasting the nut in drums or baths. The roasting process not only removes the corrosive CNSL, but also makes the shell brittle, thereby aiding the cracking process. This method causes the loss of most of CNSL. In order to extract the retained CNSL, the nuts are roasted in baths at a temperature of 180–185ºC. Vents in the equipment dispel the unpleasant fumes. This method recovers 85–90% of the liquid. In Mechanical extraction the raw cashew nut shells are put in the hydraulic press on screw pressing and then exert high pressure in order to release CNSL from shells. This method is rather straightforward and quick among others. By using screw speed of 7-13 rpm and feeding rate of 54-95 kg/h, the percentage of CNSL extracted was 20.65-21.04 percent, the percentage of CNSL purity was 85.53-87.8 wt % and the rate of extraction was 11.93-14.90 kg/h 40. Solvent extraction in turn can be carried out by cold extraction, hot extraction by different solvent using Soxlet extractor, Ultrasonication and super critical carbon dioxide extraction. Cashew nut shell liquid can also extracted using vacuum pyrolysis. In cold solvent extraction, the nuts were placed in liquid nitrogen bath when they cracked. The shells were broken by light hammering and separated from the kernel and testa. In hot solvent extraction the raw cashew nuts were steamed in boiler. The cooking time is varied depending upon the conditions of cashew nut and atmospheric conditions. The steaming expands the shell, softens the nuts due to penetration of steam into the shell. After steaming, the nuts are air-cured by spreading out on the floor in the shade. The cut shells of steam roasting process yield quality Cashew Nut Shell Liquid [C.N.S.L.]. The structure of various components of CNSL is shown in Fig.1 [11].



1: R = 8Z,11Z,14-pentadecatrienyl
2: R = 8Z,11Z-pentadecadienyl
3: R = 8Z-pentadecenyl
4: R = pentadecyl

5: R = 8Z,11Z,14-pentadecatrienyl
6: R = 8Z,11Z-pentadecadienyl
7: R = 8Z-pentadecenyl
8: R = pentadecyl

9: R = 8Z,11Z,14-pentadecatrienyl
10: R = 8Z,11Z-pentadecadienyl
11: R = 8Z-pentadecenyl
12: R = pentadecyl

13: R = 8Z,11Z,14-pentadecatrienyl
14: R = 8Z,11Z-pentadecadienyl
15: R = 8Z-pentadecenyl
16: R = pentadecyl

Figure 1. Structures of the phenolic lipids of CNSL [11]

3. Production of Biodiesel from CNSL

Saroj K. Padhi et al. [12] explained about biodiesel processing. This method can be used for any type oil to convert into biodiesel. There are three ways in which oils and fats can be converted into biodiesel, namely, transesterification, micro emulsions and pyrolysis. Pyrolysis refers to a chemical change caused by application of thermal energy in absence of air or nitrogen. The pyrolised vegetable oils contain acceptable amounts of sulphur, water and sediment with acceptable copper corrosion values but unacceptable ash, carbon residue and pour point. Micro-emulsions are defined as transparent, thermodynamically stable colloidal dispersions. A micro-emulsion can be made of vegetable oils with an ester and dispersant (co-solvent), or of vegetable oils, an alcohol and a surfactant and a cetane improver, with or without diesel fuels. The process of converting the raw vegetable oil into biodiesel, which is fatty acid alkyl ester, is termed as transesterification. There are three basic routes to biodiesel production from oil are such as base catalyzed transesterification of the oil , direct acid catalyzed transesterification of the bio-lipid and Conversion of the bio-lipid to its fatty acids and then to biodiesel. Transesterification being the most commonly used method.

4. Properties of CNSL oil and CNSL biodiesel

The properties of Cardanol bio-fuels obtained by transesterification from crude cardanol oil compared with diesel oil which has been utilized for testing various performance and emission characteristics in compression ignition engines [13]. Tables 1 and 2 present the physicochemical properties of oil extracted from cashew nut. Table 3 present the Properties of cashew nut oil, its biodiesel and blends to ASTM D6751-02 and EN 14214.

S/no	Properties	Cashew nut oil
1.	Colour(5 1/4)cell	24.6Y,4.7R, 0.7B
2.	Specific gravity	0.96
3.	Moisture Contents (%)	0.00
4.	Melting point (%)	32

Table 1. Physical properties of the extracted oil [14]

S/no	Properties	Cashew nut oil
1.	Acid value	10.70
2.	Peroxide value (meg peroxide/kg)	7.95
3.	Saponification value (mgKOH/g oil)	137
4.	Iodine value (mg iodine/100g)	41.30
5.	Free fatty acid	5.4

Table 2. Chemical properties of the extracted oil [14]

Property	CNO	B100	B10	B20	Diesel	ASTM Limits	EN 14214
Density kg/m³ 902 at 15ºC	874	854	856	850		860-900	
Relative density kg/m³ at 15ºC	0.914	0.875	0.855	0.857	0.852		
Cloud point ºC	20	6	7	9	-12		
Pour point ºC	13	1	5	5	-20		
Cold filter plug point ºC	15	4	6	7	-15		
Flash point ºC	167	136	82	89	68	93	120 min
Dynamic viscosity cts at 40ºC	49.62	4.21	2.46	2.67	2.23		
Kinematic viscosity mm²/s 40ºC	54.92	4.81	2.88	3.12	2.62	1.9-6.0	3.5-5.0
Lower heating Value KJ/kg	37.30	37.20	42.80	42.20	43.40		
Higher heating value KJ/kg	40	40.40	45.30	44.85	45.90		
Calculated cetane number (ASTM D4737)	49.28	60.83	46.22	47.75		47 min	51 min
Free fatty acid %2.29	0.188	0.188	0.225				
Acid value mgKOH/g	4.56	0.374	0.45	0.37		0.80 max	0.05 max
Iodine value gl2/100g	85.28	82.74	16.24	23.65	8.63		120 max
Peroxide value gl2/100g	21.70	27.00	17.30	16.30	15.00		
Oxidation stability (hours) 110ºC	19	9	27	18		3 min	6 min
Saponification value mgKOH/g	117.11	187.94	162.69	165.50	159.89	120 max	159.89 max
Soap content %	0	4	0.5	1.0			
Cold soak filtration ºC	310	230	77	95			
Water and sediments % (vol/vol)	10.00	0.02	0.002	0.004			500 max
Moisture content ppm	3420.	221.0	24	48			
Refractive index at 15ºC	1.47	1.34	1.48	1.48	1.48		
Sulfated ash % (mol/mol)	0.60	0.03	0.01	0.01		0.020 max	0.02 max
Carbon residue 0.17 (mol/mol)	0.07	0.03	0.02		0.050 max	0.30 max %	
Copper strip corrosion test (3h, 50ºC)	4	2	1	1		No.3 max	1
Distillation temperature 90% ºC	355	350	320	322		360 max	

Table 3. Properties of cashew nut oil, its biodiesel and blends to ASTM D6751-02 and EN 14214 [15]

5. METHODS OF IMPROVING PERFORMANCE

5. 1. Varying blends proportion and Compression ratio

Compression ratio is the ratio of the total volume of the combustion chamber when the piston is at the bottom dead centre to the total volume of the combustion chamber when piston is at the top dead center. Theoretically, increasing the compression ratio of an engine can improve the thermal efficiency of the engine by producing more power output. The ideal theoretical cycle, the Otto cycle, upon which spark ignition (SI) engines are based, has a thermal efficiency, which increases with compression ratio. Changing the compression ratio has effects on the actual engine for example, the combustion rate. Also over the load and speed range, the relative impact on brake power and thermal efficiency varies. Therefore, only testing on real engines can show the overall effect of the compression ratio. Knocking, however, is a limitation for increasing the compression ratio [16]. Variable compression technologies in IC engines are used to increase fuel efficiency under variable loads [17]. Mallikappa et al 2011 [18] in this study *"Performance and Emission Characteristics of Stationary CI Engine with Cardnol Bio Fuel Blends"* performance and emission characteristics of four stroke single cylinder engine with variable loads were studied, cardnol bio fuel volumetric blends like 0, 10, 15, 20%, and 25% were used. The tests were conducted up to 25% blends, because the viscosity of above 25% blends exceeds the international standard limits (i.e. more than 5 Cs). The load test was conducted for different loads i.e. no load, 25%load, 50% load, 75%load and full load conditions. The Orotech exhaust gas analyzer used for emission measurements. Compression ratio varied from 12:1 to 17.5:1. It was found that the brake specific energy consumption decreases by 30 to 40% approximately with increases in load conditions. This reverse trend was observed due to lower calorific value with increase in bio fuel percentage in the blends. The break thermal efficiency increases with higher loads. The maximum thermal efficiency for B20 (31%) was higher than that of the diesel. The brake thermal efficiency obtained for B25 was less than that of diesel. The No_x emissions (ppm) increases with increased proportion of blends and also with higher EGT. The HC emissions are nominal up to B20, and more at B25, the reason for this is the incomplete combustion. The CO emissions increases with higher blends, and increases slightly more after 20% blends. From this investigation it has been observed that up to20% blends of cardnol bio fuels may be used in CI engines without any modifications.

5. 2. Varying injection pressure and injection timing

The performance and emission characteristics of diesel engines depends on various factors like fuel quantity injected, fuel injection timing, fuel injection pressure, shape of combustion chamber, position and size of injection nozzle hole, fuel spray pattern, air swirl etc. The fuel injection system in a direct injection diesel engine is to achieve a high degree of atomization for better penetration of fuel in order to utilize the full air charge and to promote the evaporation in a very short time and to achieve higher combustion efficiency. The fuel injection pressure in a standard diesel engine is in the range of 200 to 1700 atm depending on the engine size and type of combustion system employed [19]. Velmurugan. A et al. 2011 [20] in this work *"Performance and Emission Characteristics of a DI Diesel Engine Fuelled with Cashew Nut Shell Liquid (CNSL)-Diesel Blends"* the pyrolysis Cashew Nut Shell Liquid (CNSL)-Diesel Blends (CDB) was used to run the Direct Injection (DI) diesel engine. The experiments were conducted with various blends of CNSL and Diesel namely B20, B40, B60, B80 and B100. The different injection timing (18º, 19º, 21º, 23º, 26º, and 28ºbTDC), and different injector opening pressure (18 Mpa, 20 Mpa, and 22Mpa) were tried to optimize the best brake thermal efficiency with neat diesel. The results are compared with neat diesel operation. It is found that the optimized injection timing and optimized injection pressure is 19° BTDC and 22 Mpa respectively for diesel operation. The brake thermal efficiency is decreased with higher blends of CNSL oil (B40, B60, B80 and B100) compared to neat diesel operation. But in the case of lower blend B20 the brake thermal efficiency is closer to diesel operation. The specific fuel consumption is increased in the case of CNSL-Diesel blends compared to neat diesel. The unburned hydrocarbon and carbon monoxide emissions are increased with blends of CNSL-Diesel as compared to neat diesel. The smoke density also increases for the blends of CNSL-Diesel compared to neat diesel operation. The Oxides of Nitrogen (NO_x) emission level is decreased with the blends of CNSL oil compared to neat diesel. The exhaust gas temperature decrease with the blends CNSL-Diesel compared to neat diesel. In general the performance and emission level of CNSL Diesel blends does not improve.

5. 3. Preheating

The use of the biodiesel is being restricted due to variation of its injection, ignition and emission characteristics from that of the diesel. The direct use of vegetable oils is generally considered to be unsatisfactory and impractical for diesel engines. The high viscosity, density of vegetable oil interferes with the injection process and leads to poor fuel atomization. The studies were carried on transesterification process, which decreases effect on the viscosity of vegetable oil, biodiesel still has higher viscosity and density when compared with diesel fuel. Investigations have shown that B20 blend has good performance and emission characteristics on CI engines. Thus it is preheated at different temperature as at 30°C, 60°C, 90°C, and

120°C. Further increase of biodiesel fraction in the blends will increase the viscosity and decrease performance. To increase the fraction of biodiesel in blends, it is required to reduce the viscosity by preheating. Preheating of biodiesel is the easy, less economical and efficient way for mentioned problem evaluation. The preheating of the vegetable oil improves the injection characteristics by decreasing the kinematic viscosity, surface tension and the density of biodiesel [21]. The viscosity of fuels has important effects on fuel droplet formation, atomization, vaporization and fuel–air mixing process, thus influencing the exhaust emissions and performance parameters of the engine. It has been also revealed that the use of biodiesel leads to a slight reduction in the engine break power and torque, and a slight increase in the fuel consumption and brake specific fuel consumption compared to diesel fuel [22]. J.H. Solanki et al. 2012 [23] in this work *"Cashew Nut Shell Liquid Fuel An Substitute For Diesel Fuel To Be Used In C.I. Engine"* CNSL biodiesel was preheated by selecting 25 blends and constant values of 200 kg/cm^2 Injection Pressure and 28° Injection Timing are used during experimentation. Author did the experiment at 25° and 31° BTDC and at 28° BTDC the brake thermal efficiency was maximum value of 33.8% & specific fuel consumption was 278.4 g/kw.hr for preheated period of 119 sec. and at 31° BTDC the brake thermal efficiency was maximum value of 30.33% & specific fuel consumption was 286.02 g/kw.hr for preheated period of 116 sec. Author finally concluded that 28° Injection Timing is optimum. And if we are using preheated CNSL biodiesel the performance of engine with CNSL is for 25% blend is good with minimum fuel consumption.

Das P. et al 2002 [24] in this work "*Bio-oil from pyrolysis of cashew nut shell a near fuel"* author preheated the CNSL biodiesel and found increment in calorific value of 40MJ/kg and reduced ash content of about 0.01% during combustion.

5. 4. Additives

The main purpose of blending ethanol with biodiesel, as a solvent additive, is to research the possibility to use blended fuels with high percentages of bio-fuel in an unmodified diesel engine. Some of the properties of the diesel, bio-fuel, and ethanol are presented in Table 4 [25].

Properties	Diesel	CNSL	Ethanol
Density (kg/m^3)	0.8/0.84	0.9326	0.789
Kinematic Viscosity(cSt)	2 to 5	17.2	1.19
Calorific value (kJ/kg)	42000	41600	30000
Flash Point (°C)	62	198	16
Auto ignition temperature(°C)	210	206	362

Table 4: fuel properties [25]

Since 19th century, ethanol has been used as a fuel for diesel engines. Ethanol is a low cost oxygenated compound with high oxygen content (34.8%). Ethanol is an alcohol, most often chosen because of the ease of production, can be obtained from various kinds of biomass such as maize, sugarcane, sugar beet, corn, cassava, and red seaweed etc., relatively low-cost and low toxicity. Diesel-ethanol blends are a more viable alternative and require little or no change in diesel engines. The use of diesel-ethanol blends can significantly reduce the emission of toxic gases and particulate matters when compared to pure diesel [26]. Di ethyl ether (DEE) is a promising renewable oxygenated fuel and additive for engines and many experimental studies has shown reduction in exhaust emission using DEE as a blend in the fuel [27]. DEE is volatile, so it mixes easily with biodiesel. It improves the combustion efficiency of the fuel. Cetane number is high for the additive. It reduces the ignition delay during exhaust stroke of the engine. High oxygen content leads to complete combustion of the fuel. DEE reduces the viscosity of the fuel. So fuel can be atomized easily. Calorific value of the fuel increases with additive. It improves the brake thermal efficiency of the fuel. Increase in population has made increase in utilization of fossil fuel. But the amount of fossil fuel is decreasing. An Alternative fuel is needed for the use. This fuel should not affect the environment [28]. T. Pushparaj et al. 2012 [29] in this work *"Influence of CNSL biodiesel with Ethanol additive on Diesel engine performance and exhaust emission"* biodiesel was made by pyrolysis process and Ethanol was used as additive to improve performance of the engine. The effects of ethanol, blended with B20 in 5, 10, 15 % by volume were used in a single cylinder, four strokes direct injection diesel engine. Some fuel properties of B20 such as cetane number, Calorific value, sulphur content, and flash point are better than those of diesel fuel. In addition, ethanol as additive improves the density and the viscosity. Exhaust gas emission for 10% ethanol blend reduces CO_2 emission by 27%, HC emission by 8% and NO_x emission by 57% at full load than that of B20. The smoke opacity slightly decreases while comparing with diesel and slightly increases compared with B20. In general, low NO_x and CO_2 emissions were measured with the 10% ethanol as additive in B20 blend. Hence CNSL can be alternately used as fuel for diesel engine. Consequently 20% CNSL biodiesel and 10% ethanol as additive can effectively be used in diesel engines without any modification.

6. CONCLUSION

The CNSL bio oil is cheaper than any other kinds of vegetable oils, which is an important advantage for biodiesel production. B20 (20% CNSL biodiesel and 80% diesel) can be used as optimum blend since it gives good result compared to any other blends. If blends less than B20 are used it results in increased HC, CO and brake thermal efficiency because improper combustion and if blend of more than B20 is used, we can observe reduced engine performance. If B20 is mixed with 10% Ethanol it will improve engine performance. And if the CNSL biodiesel is preheated before introducing in to the cylinder then, B25 gives good result compared to B20 because of reduced density and increased calorific Value. Hence, the final conclusion about this study is by preheating & using ethanol as additive performance of the CI engine fueled with CNSL can be improved. 200 bar injection pressure, 17.5:1 Compression ratio and 28° injection timing can be taken as optimum values.

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