A Review on CNSL Biodiesel as an Alternative fuel for Diesel Engine

Raghavendra Prasada S.A

M. Tech. Student, Thermal Power Engineering,
Alva's Institute of Engineering and Technology, Moodbidri, Karnataka, India,

Abstract: ***The world is confronted with serious problems like depleting reserves of petroleum and environmental issues have led to the search for more environmental friendly and renewable fuels. Biodiesel obtained from various renewable sources has been recognized as one of the alternative fuel due to its biodegradability, high cetane number, no sulphur emissions and low volatility. In this paper Cashew nut oil is used as raw material to produce a biodiesel. This paper reviews the preparation of biodiesel from Cashew nut shell oil (CNSL), properties of oil and Biodiesel, performance and emission of cashew nut oil as biodiesel in Compression Ignition engine. Cashew nut oil is one of the most efficient and high productivity Non-edible oil crops. The cashew nut oil blended in varying proportion like 10%, 20%, 30% etc. with diesel fuel in the CI engine. By varying the Compression ratio, Injection pressure, Speed, Load or by using Additives we can check the performance and emission characteristics of biodiesel-diesel blends and finds the most preferable combination of the blend for diesel engine. Based on various studies, this paper generally found that CNSL biodiesel is considered as offering many advantages, including sustainability, decrease of HC, CO, NO_x gas emissions and many harmful pollutants.***

Keywords: Cashew nut shell oil, Biodiesel, performance, harmful pollutants, Non-edible oil crops.

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. In view of this, vegetable oils like palm oil, cottonseed oil and Neem oil, Pongamia oil are considered as alternate fuels to diesel which are promising alternatives [1]. The world is confronted with a twin crisis of limited supply and the increasing cost of fossil fuels. This issue has led to increased exploration into alternative renewable energy for ensuring energy security and resolving environmental issues [2]. Biomass-based fuel such as alcohol, biogas, biodiesel and vegetable oil are found to be possible substitutes for petroleum based fuels [3]. The consumption of diesel fuels in India was 28.30 million tones which was 43.2% of the consumption of petroleum products. This requirement was met by importing crude petroleum as well as petroleum products [4]. The reserves of crude petroleum are stiffly depleting and the pries of the furnace oil and light diesel oil are constantly increasing [5]. A renewable fuel such as biodiesel, with lesser exhaust emissions, is the need of the day. Hence, researchers and scientific community worldwide have focused on development of biodiesel and the optimization of the processes to meet the standards and specifications needed for the fuel to be used commercially without compromising on the durability of engine parts [6]. In 1970s, Africa was the largest producer of raw cashew nuts accounting for 67.5% of world production. This subsequently declined to 35.6% by 2000, with Nigeria, Tanzania and Mozambique being largest producers. The production in Asia during the same periods increased from 26.8% to 49.5% with the major producers being India, Indonesia and Vietnam. Similarly, the production in South and Central America also rose from 4.5% in 1970 to 14.5% in 2000 with Brazil and El Salvador being the leading producers [7]. India is the largest producer, processor, exporter and Second largest consumer of cashew in the world. Total area in India under cashew cultivation is about 8,54,000 hectare with annual production of 6,20,000 tones giving average productivity 820 kg/ha with highest productivity reported in Maharashtra (1500 kg/ha) from 1,73,601ha under cultivation and produced 1,97,000 tones of raw cashew nut seeds through 2200-3650 cashew processing units. Production of Cashew nut shell in Koknan region is 20,000 metric tons as waste product obtained during deshelling of cashew kernels [8]. As of now cashew nut processing industries are looking for quick disposal of cashew nut shells at reasonable prices. Presently it is burnt in a semi open pit for thermal energy generation for roasting of the nuts and is also picked up by hotels, bakeries at a cheaper rate and fired for cooking applications. In all these applications the efficiency is very low [9]. CNSL is extraction from cashew nut shell (CNS) by using of different methods. The heating process (roasting) can be achieved by open recipients or drums. The cashews can also be heated by CNSL in a process denominated as thermo – mechanic (hot oil process). In the cold, the CNSL can be obtained by extrusion, in solvents or by pressing [10].

1.1. Why CNSL oil?

Biodiesel is a clean burning alternate fuel, produced from renewable resources like virgin or used vegetable oils, both edible and non-edible. It can be used in compression-ignition (diesel) engines with little or no modifications. The use of edible oil to produce bio diesel in India is not feasible in view of big gap in demand and supply of such oil. Indian plants like Jatropha (Jatropha curcas), Mahua (Madhuca Indica), Karanja (Pongamia pinnata) and Neem (Mellia azadirachta) contain 30% or more oil in their seed, fruit or nut. In India, as edible oils are in short supply, non-edible tree borne oilseeds (TBOs) of karanja, Jatropha, Mahua and Neem are being considered as the source of straight vegetable oil (SVO) and biodiesel. Plant species, which have 30% or more fixed oil in their seeds or kernel, have been identified [11]. The mesocarp of cashew nut consists of honey comb network of cells containing a viscous liquid called cashew nut shell liquid (CNSL). It obtained from the shell of a cashew nut. About 30-35% CNSL is present in the shell, which amounts to approximately 6% of the nut [12]. Hence, Cashew nut oil can also be used to produce fuel to run CI (Diesel) engines.

1.2.1 Uses: There are many uses of Cashew nut tree, Cashew nut, oil etc. [13].

a) **Food:** Botanically, the nut is the fruit; the cashew apple is the swollen, fleshy fruit stalk. The seeds kernels are extracted by shelling the roasted nuts. In production areas, cashew serves as food. Elsewhere it forms a delicacy. The kernels are nutritious, containing fats, proteins, carbohydrates, vitamins and minerals.
b) **Fodder:** The cake remaining after oil has been extracted from the kernel serves as animal food. Seed coats are used as poultry feed.
c) **Fuel:** The wood is popular for firewood and charcoal. The residue of the shell is often used as fuel in cashew nut shell liquid extraction plants.
d) **Fiber:** Pulp from the wood is used to fabricate corrugated and hardboard boxes.
e) **Gum or resin:** The bark contains an acrid sap of thick brown resin, which becomes black on exposure to air. This is used as indelible ink in marking and printing linens and cottons. The resin is also used as a varnish. The stem also yields an amber-coloured gum, which is partly soluble in water. This gum is used as an adhesive (for woodwork panels, plywood, bookbinding), partly because it has insecticidal properties.
f) **Tannin or dyestuff:** The acrid sap of the bark contains 3-5% tannin and is employed in the tanning industry.
g) **Lipids:** Oil, cashew nut shell liquid, is produced in the large cells of the pericarp; it has industrial applications and is used as a preservative to treat, for instance, wooden structures and fishing nets. It is also in good demand for paints, synthetic resins, laminated products, brake linings and clutch facings.
h) **Alcohol:** In Brazil, Mozambique and Indonesia cashew wine (slightly fermented juice) is enjoyed at harvest time and can be distilled to produce strong alcoholic drinks. In Goa, India, fermenting the juice makes a type of brandy called ‘fenni’.
i) **Poison:** One of the components of the bark gum acts as a vesicant and has insect repellent properties.
j) **Medicine:** Cashew syrup is a good remedy for coughs and colds. Cashew apple juice is said to be effective for the treatment of syphilis. Root infusion is an excellent purgative. Old cashew liquor in small doses cures stomach-ache. The oil obtained from the shell by maceration in spirit is applied to cure cracks on the sole of the feet, common in villagers. Cashew apple is anti-scorbutic, astringent and diuretic, and is used for cholera and kidney troubles. Bark is astringent, counterirritant, rubefacient, vesicant, and used for ulcer.
k) **Timber:** The wood of Anarcardium occidentale (‘white mahogany’ in Latin America) is fairly hard with a density of 500 kg/cm. It finds useful applications in wheel hubs, yoke, fishing boats, furniture, false ceilings and interior decoration. Boxes made from the wood are collapsible but are strong enough to compete with conventional wooden packing cases [13].

1.2. What is CNSL

CNSL: Cashew tree (*Anarcardium Occidentale)* is a native of southern America and was brought to Africa by the Portuguese. The tree produces nuts in a kernel with economic importance. The major producing countries of cashew are Tanzania, India, Mozambique, Sri Lanka, Kenya, Madagascar, Thailand, Malaysia, Indonesia, Nigeria, Senegal, Malawi, and Angola [14]. Cashew nut shell liquid (CNSL) is the byproduct of the cashew industry. Conventionally, CNSL is extracted by various methods such as open pan roasting; drum roasting, hot oil roasting, cold extrusion, etc. [15]. The main product of cashew plant is cashew nuts, while the secondary products are false fruits and cashew nut shell liquid (CNSL). Currently, both the false fruit and CNSL have not been exploited optimally, mostly just as wastes. The production of unshelled cashew nuts in 2002 was 94,439 tons and about 42,498-47,220 tons of CNS were obtained, hence it contained about 7,650-10,861 tons of CNSL. The main components of CNSL are anacardic acid, cardanol, and cardol [16].

1.3. Methods of producing CNSL oil

CNSL is classified into Technical CNSL and natural CNSL depending upon the type of Extraction. Technical CNSL is rich in Cardanol (also known as Decarboxylated CNSL) where as Natural CNSL is rich in Anacardic acid. There are three main methods generally used in extracting cashew nut shell liquid from cashew nuts namely thermal, mechanical and solvent extraction. Subbarao et al. [17] explained these methods.

1.3.1 Thermal extraction

In this there three methods are there, like Roasting method, hot oil bath method or by Using Solar cooker. The roasting process not only removes the corrosive CNSL, but also makes the shell brittle, thereby aiding the cracking process. 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 hot oil bath method cashew nut shells were collected in the cylinder, where steam heating was applied at temperatures around 200-250°C for 2-3 minutes. CNSL was then released from the shells and the process was repeated. This method yields CNSL of around 7-12% by weight. Where as in Solar cooker method Cashew nut shell oil was extracted using concentrating solar cooker of 1.4 kW capacity and a diameter of 1.4m. The focal point diameter of the cooker was 30m and was used to collect the reflected heat from reflector and achieved a temperature of 225-300°C [17].

1.3.2 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. 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 [17].

1.3.3 Solvent extraction

This method gives off most of CNSL compared to other methods. The oil remains in the residue was less than 1% by weight. Extraction solvents fall into two groups; those which are less dense than water and those which are denser. Commonly used extraction solvents which fall into the first group include diethyl ether (the most common extraction solvent of all), ethyl acetate and hydrocarbons, such as light petroleum, hexane or toluene. The second group comprises chlorinated solvents, such as dichloromethane and chloroform, with dichloromethane being the preferred solvent because of its lower toxicity. However, chlorinated solvents do have a greater tendency to form emulsions than non chlorinated solvents [17].

Cashew nut is a high value edible nut. It yields two “Oils” one of these found, between the seed coat (or pericarp) and the nuts, is called the Cashew Nut Shell Liquid (CNSL**)** [18]. Extraction of oil from cashew nut shell is explained by many investigators. Tejas Gandhi et al. [10] explain that, The Cashew nut has a shell of about 1/8 inch thickness, with a soft honeycomb structure inside, containing a dark brown viscous liquid. It is called cashew nut shell liquid (CNSL), which is pericarp fluid of the cashew nut. CNSL is extraction from cashew nut shell (CNS) by using of different methods. 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.

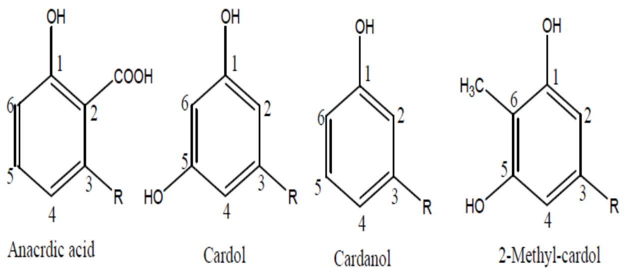

Figure 1: Structure of main components of CNSL [10]

1.4. Methods of producing Biodiesel from CNSL

Studies have revealed that the usage of non-edible oil in neat form is possible but not preferable. The high viscosity of non-edible oils and low volatility affects the atomization and spry patterns of fuel, leading to incomplete combustion and severe carbon deposits, injector choking and piston ring sticking. The methods used to reduce the viscosity are.

- Emulsification.
- Pyrolysis.
- Dilution.
- Transestrification.

Among these, the transesterification is commonly used commercial process to produce clean and environment friendly fuel [19].

1.4.1 Emulsification or micro Emulsification

To solve the problem of high viscosity of vegetable oil, micro emulsions with solvents such as methanol, ethanol and butanol have been used. A micro emulsion is defined as the colloidal equilibrium dispersion of optically isotropic fluid microstructures with dimensions generally in the range of 1–150 nm formed spontaneously from two normally immiscible liquids and one or more ionic or non-ionic amphiphiles. These can improve spray characteristics by explosive vaporization of the low boiling constituents in the micelles. All micro emulsions with butanol, hexanol and octanol will meet the maximum viscosity limitation for diesel engines [20]. The formation of micro emulsions (co-solvency) is one of the potential solutions for solving the problem of vegetable oil viscosity. 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 [21].

1.4.2 Pyrolysis

Pyrolysis strictly defined; is the conversion of one substance into another by means of heat or by heat with the aid of a catalyst. It involves heating in absence of air or oxygen and cleavage of chemical bonds to yield small molecules [22]. The decarboxylated cardanol is termed as CNSL biodiesel. The biodiesel obtained from CNSL not required for further processing like transesterification [23]. It can be obtained by pyrolysis. Risfaheri et al. [16] explain the pyrolysis procedure of CNSL, Heating CNSL decomposed the anacardic acid into cardanol and CO_2. Decarboxylation of CNSL to convert anacardic acid into cardanol could be done by heating, with an optimum heating temperature of 140°C for 1 hour. Cardanol was isolated from the CNSL by vacuum distillation (4-8 mmHg) at high temperature, with an optimum temperature of 280°C, and the rendement 74.22%.

1.4.3 Dilution

The vegetable oil is diluted with petroleum diesel to run the engine. Caterpillar Brazil, in 1980, used pre-combustion chamber engines with the mixture of 10% vegetable oil to maintain total power without any alteration or adjustment to the engine. At that point it was not practical to substitute 100% vegetable oil for diesel fuel, but a blend of 20% vegetable oil and 80% diesel fuel was successful. Some short-term experiments used up to a 50/50 ratio [24].

1.4.4 Transesterification

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. So to use the oils in the diesel engines, they are chemically treated and that chemical process is known as transesterification. The transesterification which is also known as alcoholysis is the reaction of fat or vegetable oil with an alcohol to form esters and glycerol. Mostly a catalyst is also used to improve the rate and yield of the reaction. Since the reaction is reversible in nature, excess alcohol is used to shift the equilibrium towards the product. Hence, for this purpose primary and secondary monohydric aliphatic alcohols having 1-8 carbon atoms are used. The chemical reaction of transesterification processes is shown below in fig.2. where R represents a mixture of various fatty acid chains depending on the specific oil in use. Subscript 3 represents the number of moles needed to satisfy the formation of methyl esters [25].

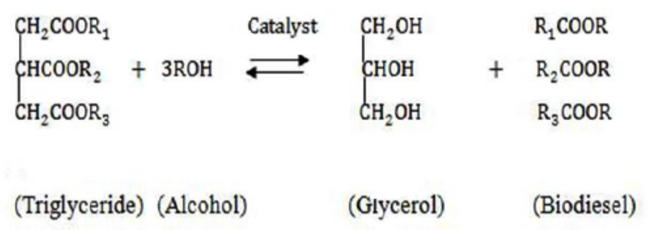

Figure 2: Transesterification Reaction [25]

Linus N. Okoro et al. [26] explains production of Biodiesel from CNSL as, 50ml (36.0g) of cashew nut oil was measured and poured into a conical flask. The oil was preheated to 70°C. Sodium hydroxide (0.225g) was weighed and added to 20ml of methanol in a conical flask. The sodium hydroxide and methanol were properly mixed by stirring till the entire pellet dissolves to form sodium methoxide solution. The sodium methoxide solution was poured into the preheated cashew nut oil. The solution was mixed and stirred properly until homogeneity was achieved. This same procedure was followed while using potassium hydroxide as catalyst. The reaction mixture was maintained at a temperature of 70^{o}C for 1.5hr. The product was poured into a separating funnel and left overnight for proper settling of the glycerin produced. The products of the transesterification reaction Fatty Acid Methyl Esters (FAME) contain some impurities like unreacted methanol, potassium methoxide and the by- product of biodiesel (glycerol) therefore it needs some forms of purification before it can be used in diesel engines. Hence, the following procedure was used in washing the biodiesel: 30ml of water was measured using a measuring cylinder and poured gently on the product sample. The mixture was gently stirred to avoid foam formation. Shaking rigorously is not advised. The mixture of water and biodiesel was left for 5 hrs to settle into two phases which are; water-impurities phase and biodiesel phase. The two phase mixture was then separated using a separating funnel, drying is recommended.

1.5. Properties of CNSL oil

A.P. Chaudhari et al. [27] reported three main properties of cashew nut oil are Moisture content, Specific gravity and viscosity.

Moisture content of CNSL: The moisture content of the samples of Crude CNSL extracted by screw press, heated CNSL extracted by screw press and the CNSL extracted by hot oil bath method were determined and compared as shown in Table 1. The values of moisture contents obtained are less than the standard permissible values.

Table 1: Moisture content of CNSL extracted by screw press and hot oil bath method

Sr. No.	Type of oil	Moisture content, % (wb)
1	Crude CNSL extracted by screw press	0.75± 0.01
2	Heated CNSL extracted by screw press	0.69± 0.01
3	CNSL extracted by hot oil bath method	0.65± 0.01

Specific gravity of CNSL: The specific gravity of the samples of Crude CNSL extracted by screw press, heated CNSL extracted by screw press and the CNSL extracted by hot oil bath method were determined and compared as shown in Table 2.

Table 2: Specific gravity of CNSL extracted by screw press and hot oil bath method

Sr. No.	Type of oil	Specific gravity
1	Crude CNSL extracted by screw press	0.98± 0.01
2	Heated CNSL extracted by screw press	0.96± 0.01
3	CNSL extracted by hot oil bath method	0.96±0.01

Viscosity of CNSL: The oil viscosity is used in assessing the lubricating properties of oil. The viscosity of the samples of Crude CNSL extracted by screw press, heated CNSL extracted by screw press and the CNSL extracted by hot oil bath method were determined and compared as shown in Table 3. It is seen that the viscosity of the Crude CNSL extracted by screw press was higher than the other types of CNSL, followed by the CNSL extracted by hot oil bath method, where as the viscosity of the heated CNSL extracted by screw press was lowest. This may be due to the effect of heating the CNSL at high temperature for longer time.

Table 3: Viscosity of CNSL extracted by screw press method and hot oil bath method

Sr.No	Type of oil	Viscosity(cP)
1	Crude CNSL extracted by screw press	57.43± 0.83
2	Heated CNSLextracted by screw press	28.96± 0.74
3	CNSL extracted by hot oil bath method	37.69± 0.73

Evbuowman B. O et al. [28] reported physical and chemical properties of the oil extracted from the cashew nuts are presented in Table 4 and 5.

Table 4: Physical properties of the extracted oil

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 5: Chemical properties of the extracted oil

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

Tables 4 and 5 present the physicochemical properties of oil extracted from cashew nut. The specific gravity is 0.96; this implies that oil is less dense than water. The melting point shows the temperature at which a fat or oil starts to melt. The moisture content was 0.0% for cashew nut oil, which is an indication of its shelf life and nutritive value, hence low moisture content is a requirement for long storage life. High concentrations of free fatty acids are undesirable in crude oils because they result in large losses of the neutral oil during refining. Cashew nut contains FFA of 5.4; hence loss of oil is less during refining. The iodine value is a measure of the unsaturation of fats and oils and it is an indicator of double bindings in the molecular structure in terms of classification of fats and oils. Cashew nut oil is non-drying with an iodine value lower than 100 [28].

1.6. Properties of CNSL Biodiesel

E. I. Bello et al. [29] reported Properties of CNSL oil, Biodiesel and Blends and compared with ASTM standards. Table 6 shows the properties of the oil, Biodiesel and Blends.

Table 6: Properties of cashew nut oil, its biodiesel and blends to ASTM D6751-02 and EN 14214

Property	CNO	B100	B10	B20	Diesel	ASTM Limits	EN 14214
Density kg/m^3 902 at 15°C	874	854	856	850		860-900	
Relative density kg/m^3 at 15°C	0.914	0.875	0.855	0.857	0.852		
Cloud point °C	20	6	7	9	-12		
Pour point °C	13	1	5	5	-20		
Cold filter plug point °C	15	4	6	7	-15		
Flash point °C	167	136	82	89	68	93	120 min
Dynamic viscosity cts at 40°C	49.62	4.21	2.46	2.67	2.23		
Kinematic viscosity mm^2/s 40°C	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 gI2/100g	85.28	82.74	16.24	23.65	8.63		120 max
Peroxide value gI2/100g	21.70	27.00	17.30	16.30	15.00		
Oxidation stability (hours) 110°C	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 °C	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 15°C	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, 50°C)	4	2	1	1		No.3 max	1
Distillation temperature 90% °C	355	350	320	322		360 max	

2. Literature Review

Velmurugan A & Loganathan M 2011 [30] conducted experimental investigation of performance and Emission of a DI Diesel Engine Fuelled with Cashew Nut Shell Liquid (CNSL) and its Blend (B20, B40, B60, B80 and B100) and the results are compared with neat diesel operation. In this study Biodiesel produced by Pyrolysis method and properties are evaluated. The diesel engine was not modified during all the tests. At each engine operating mode, experiments were carried out for the diesel fuel, and each of the Cashew-Diesel (CD) blends. The Author conducted experiments by changing injection timing (18º, 19º, 21º, 23º, 26º, and 28ºbTDC), and injector opening pressure (18 Mpa, 20 Mpa, and 22Mpa) to optimize the best brake thermal efficiency with neat diesel. It was 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, but it can be used as a low cost alternative fuel for diesel engine. The author based on this result finally concluded that, In future the additives and oxygenates can be used with CNSL–Diesel fuel to improve the performance and emission of direct injection diesel engine.

Mallikappa et al. 2011 [31] In this research work, they made the detailed investigation on 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. In this case the author used two-stage distillation method because of certain difficulties of operation with regard to single-stage fractional distillation method to produce cardnol from CNSL. Cardnol produced was used as raw material to produce Biodiesel by using transesterification process. Author 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 brake thermal efficiency increases with higher loads. In all cases, it increased with increase in load. The maximum thermal efficiency for B20 (31%) was higher than that of the diesel. The NO_x emissions (ppm) increases with increased proportion of blends and also with higher EGT. This trend mainly because of presence oxygen in bio fuel, this leads to more oxidation at higher temperature and responsible for more NO_x emissions. The HC emissions are nominal up to B20, and more at B25, the reason for this is the incomplete combustion. The Carbon monoxide emissions increases with higher blends, and increases slightly more after 20% blends. At elevated temperature, performance of the engine improved with relatively better burning of the fuel resulting in decreased CO. From this investigation it has been observed that up to20% blends of cardnol bio fuels may be used in CI engines without any modifications.

D.N.Mallikappa et al.2012 [32] This work composed with performance and emission studies of three stationary diesel engines operated with 20% cardanol bio fuel volumetric blends. Various tests were conducted on a single cylinder diesel engine and VCR engines in order to evaluate the performance and emission characteristics of cardanol bio fuel (CNSL Bio fuel). An extended experimental study was conducted on a double cylinder CI engine to evaluate the performance and emission characteristics. The cardanol bio fuel volumetric blends between 0-25% and base fuel (Petro diesel) were tested at various loads between 0-full load. Here the author used two-stage distillation method to produce cardnol. And then biodiesel produced by transesterification process by using cardnol as raw material. but it was found that the properties like density, viscosity, flash and fire points of cardanol bio fuel volumetric blends under test are higher, and calorific values are lower and are in the range of 94-96% that of diesel. The brake thermal efficiency obtained for single cylinder and VCR at 20% cardanol bio fuel volumetric blends is less than that of twin cylinder diesel engine. The reason for higher brake power in the case of twin cylinder engine could be higher brake mean effective pressure. The BSEC obtained for VCR engine at 18:1 Compression ratio is 25% more compared to twin cylinder engine at no load conditions, and 8-10% higher BSEC in twin cylinder engine compared to other two engines at full load conditions. It is observed that slight variations of NO_x emissions occur in all engines at 0% load and 100% load conditions, the reason for these variations could be malfunctioning of bio fuel mixture. From the results it is observed that lower (30-50%) hydrocarbon emissions occur in the case of VCR engine at 18:1 CR compared to single cylinder and twin cylinder engines. The carbon monoxide emissions at different load conditions in different engines are not uniform. From this work it is proved that, up to 20% Cardnol Bio Fuel (CBF) volumetric blends can be used in the diesel engines without any major hardware modifications.

T. Pushparaj et al. 2012 [23] used Ethanol as additive to CNSL bio diesel to check the possibility of using higher percentage of biodiesel in an unmodified diesel engine. Biodiesel was made by pyrolysis process. CNSL was selected for biodiesel production. Diesel fuel containing 20% biodiesel and 80% diesel fuel, author called it as B20. 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. The effect of test fuels on engine torque, power, brake specific fuel consumption, brake thermal efficiency, exhaust gas temperature, were ascertained by performance tests. The influence of blends on CO, CO2, HC, NO and smoke opacity were investigated by emission tests. Because of addition of ethanol some fuel properties of B20 such as cetane number, Calorific value, sulphur content, flash point, density and the viscosity are improved better than those of diesel fuel. Exhaust gas emission for 10% ethanol blend reduces CO_2 emission by 27%, HC emission by 8% and NO emission by 57% at full load than that of B20. That means, low NO and CO_2 emissions were measured with the 10% ethanol as additive in B20 blend. Author concluded that, 20% CNSL biodiesel and 10% ethanol as additive can effectively be used in diesel engines without any modification.

A. Velmurugan et al. 2012 [33] In this study, bio fuel, diesel and ethanol blends (BDEB) were tested in a single cylinder direct-injection diesel engine to investigate the engine combustion, performance and emission characteristics of the engine under five engine loads at the speed of 1500 rpm. Here the ethanol is used as an additive to enhance the engine combustion. The mixture of Commercial diesel fuel, bio fuel from CNSL and ethanol mixture is named as BDEB is used to run the direct injection diesel engine. The different combination of BDEB as BDEB 5 (Diesel 75%,Cnsl 20% and Ethanol 5%) , BDEB 10 (Diesel 70%,Cnsl 20% and Ethanol 10%) and BDEB 15(Diesel 65%,Cnsl 20% and Ethanol 15%), were tested in the engine. The results are compared with neat diesel fuel. Compared with diesel fuel, the heat release rate of all BDE blends is lower than that of diesel fuel. It decreases from 99 MJ/m3deg to 61 MJ/m3 deg. This is due to the poor pre mixed combustion of BDE blends. The brake thermal efficiency is increased with increase of ethanol percentage. The brake thermal efficiency is 34.98%, 35.1%, 36.1% for the fuel BDEB 5, BBE10, and BDEB 15 at full load, but for Diesel and B20 were 34.52% and 29.95% respectively. The brake thermal efficiency of BDEB was higher compared to diesel, B20 fuels. The BSFC was increased for the BDEB 5, BDEB 10, and BDEB 15 fuel compared to diesel fuel. Brake specific fuel consumption for BDEB 15 was 25% higher than that of diesel fuel at full load. The CO and HC emissions were reduced with the use BDEB fuel with respect to neat diesel fuel for all load condition. The exhaust gas temperature was increased for BDEB15, at all loads compared to diesel, B20 and BDEB fuels. The NO_x emissions were increased with the use of both B20 and BDEB fuel compared to neat diesel fuel. The NO_x emissions were found to be for B20, BDEB5, BDEB10 and BDEB15 at full load. The percentage of increase of NO_x is 3.05%, 5.05%, 7.07% and 12.12% for full load compare to diesel. Author finally concludes that On the whole the blends diesel, CNSL oil and ethanol fuel can be used as alternative fuels in conventional diesel engines without any major change in the engine. Besides, the exhaust emissions for BDEB5, BDEB10 and BDEB15 were fairly reduced.

S. Radhakrrishnan et al. 2014 [34] In this research work, they made the detailed investigation on performance and emission characteristics of four stroke single cylinder engine run by CNSL as a fuel in order to check whether CNSL diesel blends can be used as alternative fuel or not. A single cylinder, four-stroke direct injection compression ignition engine with a compression ratio of 17.5: 1 was used for conducting the experiment. The experiments were done at different static injection timing 18°, 19°, 21°, 23°, 26°, and 28° bTDC at the rated injector opening pressure 200 kg/cm^2. And the author found that the brake thermal efficiency is increasing when the injection timing is advance from 18° to 19° bTDC. The variation of smoke density also decrease with the advancing the injection timing and for CNSL oil blends it is noticed to be generally higher than that of the diesel oil. HC emission is lowest with the best injection timing namely 19°bTDC, this is due to more amount fuel taking part in the premixed phase of combustion as that injection timing advance due to an increase in ignition delay period. But, NO_x emission level increase as the advance that injection timing 19° bTDC expect due to increase cylinder gas temperature. Blends of CNSL oil shows lower NO_x emission compared to neat diesel fuel. The thermal efficiency of all blends of CNSL oil is found to be lower than that of neat diesel. This is due to poor mixture formation as a result of low volatility, higher viscosity and higher density of CNSL oil. And also The thermal efficiency of B20 blends gives the higher efficiency compared to other blends namely B40, B60, B80 this is because of more blends gives the high viscosity of fuel and poor atomization and hence poor combustion. The specific fuel consumption of CNSL oil is noted to be higher than that of diesel for all loads. This is caused due to the effect of higher viscosity and poor mixture formation of CNSL oil. The unburned hydrocarbon emission of blends of CNSL oil is more compared to that for neat diesel for all loads. The carbon monoxide emission is higher than that of diesel blends. The exhaust temperature of CNS oil is decreased because of poor combustion takes place compare to neat diesel. Author Based on the experimental investigations carried out on the single cylinder diesel engine concludes that with diesel CNSL oil blends can be used as alternative fuels in diesel engine and with further experiments of adding additives emissions can be reduced.

3. Experimental Set-Up Description

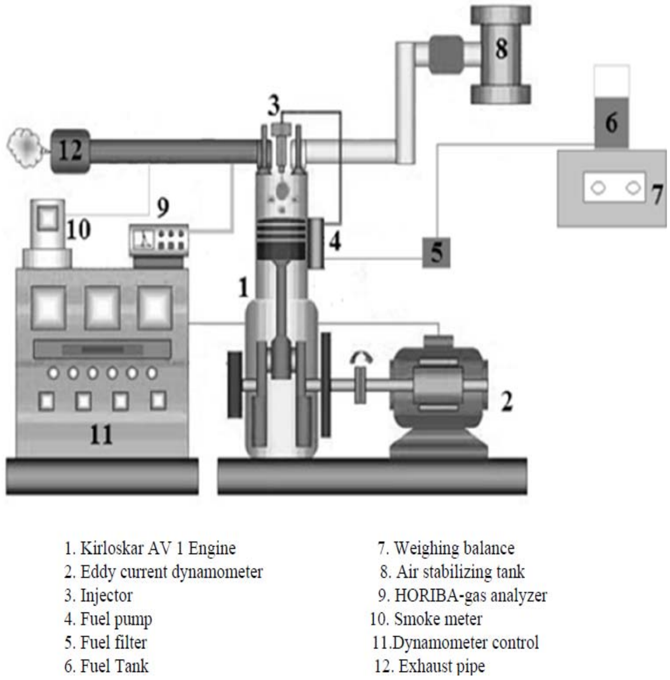

Figure 3: Experimental Setup [33]

4. Result

Many researchers worked on the CNSL oil and they found some result as shown in following graph [32]. When the pyrolysis method was used for producing Biodiesel, the Brake thermal efficiency found to be lower and specific fuel consumption more than that with diesel. Unburned hydrocarbon, Carbon monoxide and smoke density increases, but because of low exhaust temperature NO_x emission decreases with blends of CNSL-Diesel as compared to neat diesel. Investigators based on this result concluded that, the additives and oxygenates can be used with CNSL–Diesel fuel to improve the performance and emission of direct injection diesel engine [30]. Some investigators used 2-stage distillation method to produce cardnol from CNSL oil and then Biodiesel produced by Transesterification method. And it was found that brake specific energy consumption decreases where as brake thermal efficiency noted to be 31%. And for B20 (20% bio fuel & 80% diesel) blend HC, CO & NO_x emission are less compared to higher blends [31]- [32]. But, when 2-stage distillation method used to produce cardnol from CNSL oil and then Biodiesel produced by Transesterification method with Ethanol used as additive to CNSL bio fuel the result was totally different from previous results. For B20 blend and 10% ethanol CO_2 reduced by 27%, HC reduced by 8% and NO_x reduced by 57% at full load than that of B20 blend alone [23]. Whereas brake thermal efficiency for 10% ethanol and B20 blend found to be 35.1% which is more than diesel (34.52%) and B20 (29.95%) with Improved performance of Engine [33].

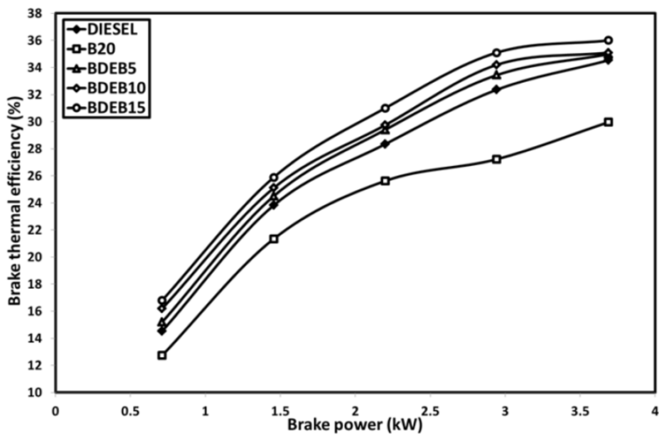

Figure 4: Comparison of Brake thermal efficiency [33]

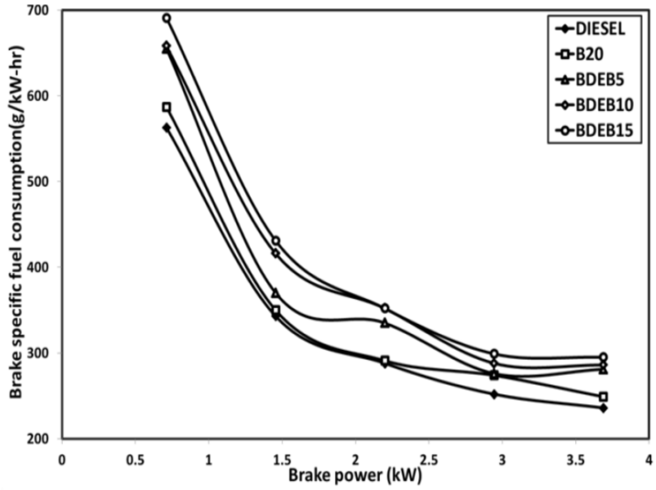

Figure 5: Comparison of specific fuel Consumption [33**]**

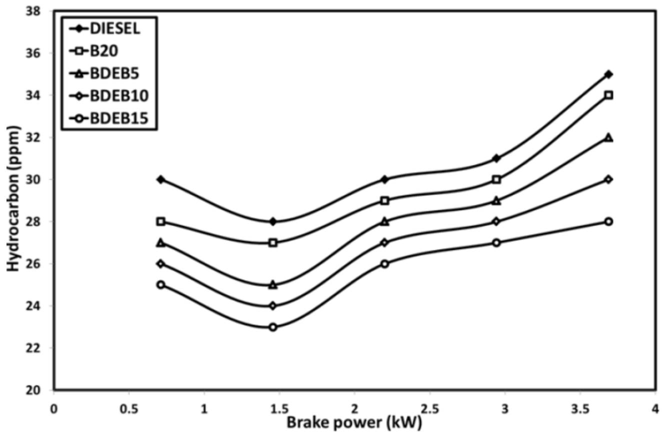

Figure 6: Comparison of HC emissions [33]

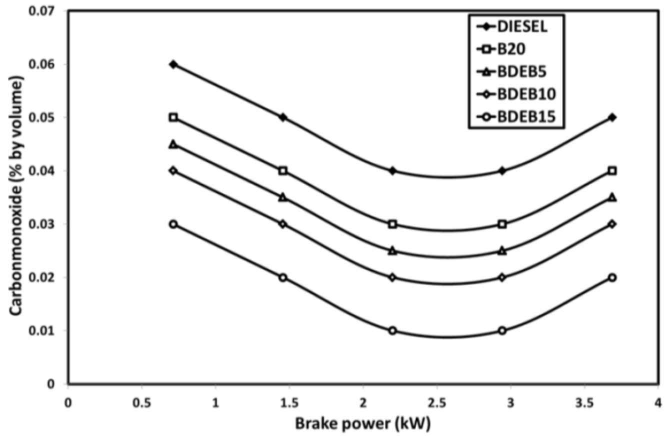

Figure 7: Comparison of CO emissions [33]

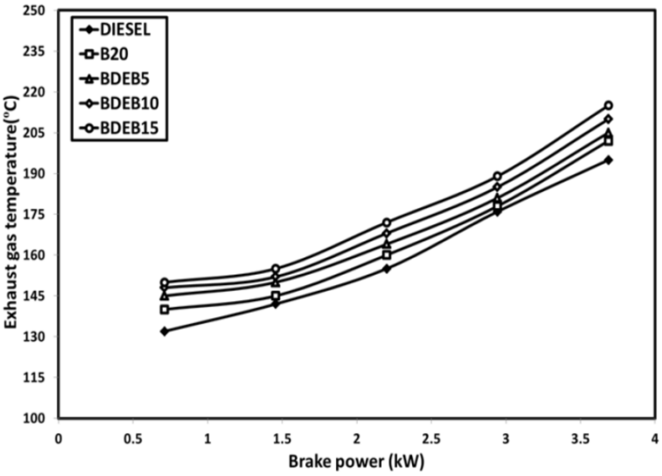

Figure 8: Comparison of exhaust gas temperature [33]

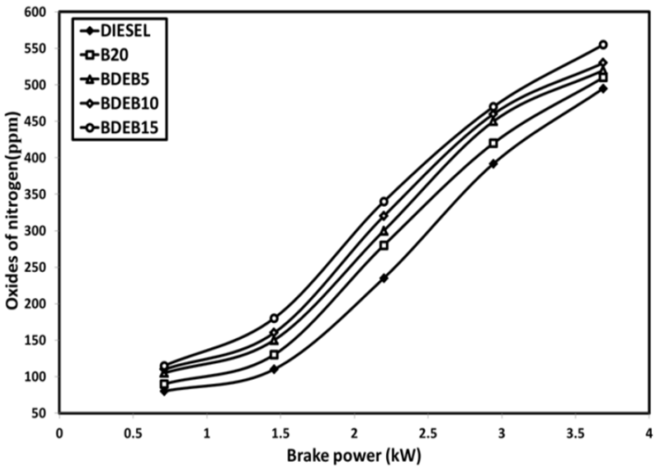

Figure 9: Comparison of oxides of nitrogen [33**]**

5. Conclusion

Combustion of petroleum based fuels in internal combustion engines results in Environmental pollution, global warming, and also effects human health. Whereas on combustion of biodiesel produced from various edible / Non-edible oils produce very less amount of HC, CO and oxides of NO compared to Hydro carbons and this will mitigate the above mentioned issues. But for using Biodiesel in pure form engine modification required. But, if we are using blends of diesel and biodiesel as fuel in engine modifications not required. Depending on the properties, engine running conditions like speed and load etc. performance of engine varies. Keeping that in mind we should select correct blend of biodiesel and diesel. Brazil is using Ethanol as fuel for most of the vehicles. In USA gasoline-Ethanol blend used as fuel in petrol engine vehicles. But, in India because of market monopoly still dependent on Petrol and diesel fuels for vehicles. If we use Biodiesel which are produce locally, decreases the nation's dependence upon foreign energy and Fuel crisis like problems will not occurs. In this paper we study the properties of CNSL oil, transesterification process, properties and result of CNSL Biodiesel as an alternative fuel for CI engine. Based on this study on CNSL biodiesel, we can conclude that the CNSL oil can be used as an alternative fuel for diesel engine.

6. Future scope

Biodiesel derived from CNSL oil is reported to be feasible choices for developing countries including India where consumption of fuel is very high. CNSL oil is relatively an inexpensive and available raw material for biodiesel production as India is one of the largest producers of cashew nut in the world. The following points may be considered before introducing the fuel in India:

- The study of long term stability of blends should be done.
- Further research required to check whether CNSL fuel or blends will affect properties of engine material & parts like cylinders, valves, piston, crank etc.
- The optimization of CNSL oil based on the effect of parameters like. Molar ratio, catalyst concentration, reaction time, reaction temperature, different catalyst, stirring rate should also be studied.
- The performance and emission parameters of CNSL biodiesel in various diesel engines were evaluated on load, compression ratio, injection timing, injection pressure & speed basis. The effect of other parameters like preheating of Biodiesel & ignition delay on the performance of engine may be studied.
- CNSL biodiesel and its blends have strong beneficial effect on HC, CO and Smoke density but adverse effect on NO_x formation. NO_x emissions were found to be increased with CNSL oil in comparison to diesel fuel therefore use of NO_x reduction techniques such as EGR (exhaust gas recirculation) is recommended. Further research is needed to reduce the NO_x emissions like water injection methods.

References

[1] A.S. Kumari, Ch. Penchalayya, A.V.S. Raju & P.R Kumar, "Experimental investigations of IC engine with Pongamia diesel blends", *International Journal of Advanced Engineering Technology (IJAET)*, Vol. 2, Issue 4, pp. 54-58, 2011.

[2] H.C. Ong, H.H. Masjuki, T.M.I. Mahlia, A.S. Silitonga, W.T. Chong & Talal Yusaf, "Engine performance and emissions using Jatropha curcas, Ceiba pentandra and Calophyllum inophyllum biodiesel in a CI diesel engine", *Energy*, 69 (2014) 427-445.

[3] L.A. Chandrashekar, N.S. Mahesh, B. Gowda & William Hall, "Life cycle assessment of biodiesel production from Pongamia oil in rural Karnataka", *CIGR Journal*, Vol. 14, No.3, pp. 67-77, 2012.

[4] J. Alku, P.S. Patil & O. Hebbal, "Experimental investigation of performance and combustion characteristics of Pongamia biodiesel and its blends on diesel engine and LHR engine", *International Journal of Research in Engineering and Technology*, Vol. 2, Issue 7, pp. 202-206, 2013.

[5] Shobha S. B, "Replacement of Furnace oil and light diesel oil (LDO) by Cashew nut Shells oil", *Archives of Applied Science Research*, vol. 3, issue 2, pp. 520-524, 2011.

[6] Y.C. Sharma & B. Singh, S.N. Upadhyay, "Advancements in development and characterization of biodiesel: A review", *Fuel*, 2008.

[7] L.A. Hammed, J.C. Anikwe & A.R. Adedeji, "Cashew Nuts and Production Development in Nigeria", *American-Eurasian Journal of Scientific Research*, Vol.3, No. 1, pp. 54-61, 2008.
[8] Sanger S.H., Mohod A.G., Khandetode Y.P., Shrirame H.Y & Deshmukh A.S., "Study of Carbonization for Cashew Nut Shell", *Research Journal of Chemical Sciences*, Vol. 1, No. 2, pp.43-55, 2011.
[9] R.N. Singh, U. Jena, J.B. Patel & A.M. Sharma, "Feasibility study of cashew nut shells as an open core Gasifier feedstock", *Renewable Energy*, 31 (2006) 481–487.
[10] T. Gandhi, M. Patel & B.K. Dholakiya, "Studies on effect of various solvents on extraction of cashew nut shell liquid (CNSL) and Isolation of major phenolic constituents from extracted CNSL", *J. Nat. Prod. Plant Resour.*, Vol. 2, No. 1, pp. 135-142, 2012.
[11] S.K. Padhi & R.K. Singh, "Non-edible oils as the potential source for the production of biodiesel in India: A review", *Journal of Chemical and Pharmaceutical Research*, Vol.3, No.2, pp. 39-49, 2011.
[12] T. Rajeswari, B. Padmapriya, K. Teesha & P.K. Kumari, "Degradation of Cashew Nut Shell Liquid by Pseudomonas sp Isolated from Soil", *International Journal of Microbiological Research*, Vol.2, No.2 , pp. 172-175, 2011.
[13] Orwa C, Mutua A., Kindt R., Jamnadass R, & Simons A, "Agroforestree Database:a tree reference and selection guide" Version 4.0, 2009.
[14] Bart Plange A., Mohammed K.A.P., Addo A. & Teye E. "Some physical and mechanical properties of Cashew nut and kernel grown in Ghana", Internati*onal journal of science and nature*, Vol. 3, No. 2, pp 406-415, 2012.
[15] R.N. Patel., S. Bandyopadhyay & A. Ganesh, "Selective Extraction of Cardanol and Phenols from Cashew Nut Shell Liquid Obtained through Pyrolysis of Cashew Nut Shells", chemcon – 05, New Delhi, India.
[16] Risfaheri, T.T. Irawadi, M. Anwar Nur, & Illah Sailah, "Isolation of cardanol from cashew nut shell liquid using the vacuum distillation method", *Indonesian journal of agriculture*, Vol. 2, No. 1, pp. 11-20, 2009.
[17] Subbarao, Ch. N.V, K. Prasad, K.M.M & Prasad, V.S.R.K, "Review on Applications, Extraction, Isolation and Analysis of Cashew Nut Shell Liquid (CNSL)", *The Pharma Research Journal*, Vol. 6, Issue 1, pp. 21-41, 2011.
[18] Akinhanmi T.F., Atasie V.N. & Akintokun P.O., "Chemical Composition and Physicochemical Properties Of Cashew nut (Anacardium occidentale) Oil and Cashew nut Shell Liquid", *Journal of Agricultural, food and environmental science*, Vol.2, Issue 1, pp. 1-10, 2008.
[19] C. V. Mahesh, E. T. & Puttaiah, "Studies on performance and emission characteristics of non-edible oil (honge oil) as alternate fuel in CI engine", *International Journal of Engineering Research and Applications*, Vol. 2, Issue 3 , pp. 2288-2293, 2012.
[20] Mr. S.V. Channapattana & Dr. R.R. Kulkarni, "Bio-diesel as a fuel in I.C. engines – A review", *International Journal of Computer Science and Applications*, Vol. 2, No. 1, pp. 22-26, 2009.
[21] K. Shikha & C.Y. Rita, "Biodiesel production from non edible-oils: A Review", *Journal of Chemical and Pharmaceutical Research*, Vol. 4, No.9, pp. 4219-4230, 2012.
[22] S. Kumar, A. K. Gupta & S N Naik, "Conversion of Non-edible into Biodiesel", *journal of scientific & industrial research*, Vol.6, No.2, pp 124-132, 2003.
[23] T. Pushparaj & S. Ramabalan, "Influence of CNSL biodiesel with Ethanol additive on diesel engine performance and exhaust emission", *International journal of mechanical engineering and technology*, Vol. 3, Issue 2, pp. 665-674, 2012.
[24] S.P. Singh & D. Singh, "Biodiesel production through the use of different sources and characterization of oils and their esters as the substitute of diesel: A review", *Renewable and Sustainable Energy Reviews*, 14 (2010) 200–216.
[25] K. Singh, M.Y Sheikh & Dr. Y.B. Mathur, "Performance Study of a VCR Diesel Engine Fueled With Diesel and Low Concentration Blend of Linseed Oil Biodiesel", *International Journal of Emerging Technology and Advanced Engineering*, Vol. 4, Issue 4, pp. 295-299, 2014.
[26] L.N. Okoro, F.I. Sambo, M. Lawal & C. Nwaeburu, "Thermodynamic and Viscometric Evaluation of Biodiesel and Blends from Olive Oil and Cashew Nut Oil", *Research Journal of Chemical Sciences*, Vol. 1, No.4, pp.90-97, 2011.
[27] A.P. Chaudhari1, N.J. Thakor, D.M. Mahale, P.M. Haldankar & S.P. Sonawane, "Physical Properties of Cashew Nut Shell Liquid", *International Journal of Application or Innovation in Engineering & Management*, Vol. 1, Issue 2, pp. 172-175, 2012.
[28] Evbuowman B.O., Lawson J.N. & Atuka M.M., " Some Physicochemical Properties of Cashew Nut (Anacardium Occidentale) and Palm Kernel (Elaeis Guineensis) Oil using Straight Run Gasoline", *International Journal of Science and Engineering Investigations*, Vol. 2, issue 20, pp. 82-84, 2013.
[29] E.I. Bello, A.O. Akinola1, F. Otu1 & T. J. Owoyemi, "Fuel and Physiochemical Properties of Cashew (Anarcardium occidentale) Nut Oil, Its Biodiesel and Blends with Diesel", *British Journal of Applied Science & Technology*, Vol.3, No.4, pp. 1055-1069, 2013.
[30] Velmurugan A. & Loganathan M, "Performance and Emission Characteristics of a DI Diesel Engine Fuelled with Cashew Nut Shell Liquid (CNSL)-Diesel Blends", *World Academy of Science, Engineering and Technology*, Vol.5, pp.10-28, 2011.
[31] Mallikappa, R.P. Reddy & Ch. S.N. Muthy, "Performance and Emission Characteristics of Stationary CI Engine with Cardnol Bio Fuel Blends", *International Journal of Scientific & Engineering Research*, Vol. 2, Issue 4, pp. 1-6, 2011.
[32] D.N. Mallikappa, R.P. Reddy & S. N. Murthy, "Performance and Emission Characteristics Studies on Stationary Diesel Engines Operated with Cardanol Bio fuel Blends", *International journal of renewable energy research*, Vol.2, No.2, pp. 295-299, 2012.
[33] A. Velmurugan & M. Loganathan, "Effect of ethanol addition with cashew nut shell liquid on engine combustion and exhaust emission in a DI diesel engine",

International Journal of Engineering Science and Technology, Vol. 4, No.7, pp. 3316-3328, 2012.

[34] S. Radhakrrishnan, C. Thamodharan & N. Senthilnathan, "Evaluating Performance and Emission Characteristics Of C.I. Engine Run By Cashew Nut Shell Liquid (CNSL) As a Fuel", *International journal of scientific & technology research*, Vol. 3, Issue 4, pp. 13-18, 2014.

Author Profile

Raghavendra Prasada S.A received the B.E. degree in Mechanical Engineering from Shree Devi Institute of Technology, Mangalore in 2012. He is now M. Tech. (Thermal Engineering) final year Student in Alva's Institute of Engineering and Technology, Moodbidri, Karnataka, India.