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Performance and emission characteristics of double cylinder CI engine operated with cardanol bio fuel blends

Mallikappa D.N. [a,*], Rana Pratap Reddy [b], Ch.S.N. Murthy [c]

[a] Department of Mechanical Engineering, NMAM Institute of Technology, Nitte 574110, Karnataka, India
[b] Reva institute of Technology and Management, Bangalore, Karnataka, India
[c] Department of Mining Engineering, N.I.T.K, Surthkal 575025, Karnataka, India

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ABSTRACT

India imports more than seventy percent of the oil it uses and is looking for alternative fuel to reduce its dependence on imports. In India, bio fuels derived from non-edible oils is considered as a renewable alternative to the fossil diesel. The cost of the biodiesel is higher than diesel and hence in this work, cardanol was used as an alternative renewable fuel for the diesel engine. The engine tests were conducted on a double cylinder, direct injection, compression ignition engine. From the engine tests, it is observed that the brake power increases (by 70% approximately) as load increases. Brake specific energy conversion decreases (by 25–30% approximately) with increase in brake power. Brake thermal efficiency increases with higher brake power and emission levels (HC, $C_{O,}$ NO_X) were nominal up to 20% blends.

1. Introduction

In today's world the majority of automotive and transportation vehicles are powered by compression ignition engines. The compression ignition engine moves a large portion of the world's goods & generates electricity more economically than any other device in their size range. All most all the CI engines use diesel as a fuel, but the diesel is one of the largest contributors to environmental pollution problems. Bio fuel is an alternative to petroleum based fuel, renewable energy source, bio degradable and non-toxic fuel, being beneficial for reservoirs, lakes, marine life and other environmentally sensitive places such as large cities and mines & use of biodiesel in diesel engines generates rural employment opportunities by cultivating such oil producing crops [1–5].

The issue of energy security led governments and researchers to look for alternate means of renewable and environment-friendly fuels. Bio fuel has been one of the promising, and economically viable alternatives. Fuel and energy crisis and the concern of society for depleting world's non-renewable resources initiate various sectors to look for alternative fuels. One of the most promising fuel alternatives is the vegetable oils and their derivatives. Plenty of scientific articles and research activities from around the world were printed and recorded. Oils from coconut, soy bean, sunflower, safflower, peanut, linseed and palm were used depending on what country they grow abundantly. It has been reported that in diesel engines; vegetable oils can be used as fuel, straight as well as in blends with the diesel. It is evident that [2] there are various problems associated with vegetable oils being used as fuel in compression ignition engines, mainly caused by their high viscosity. The high viscosity is due to the molecular mass and chemical structure of vegetable oils, which in turn leads the problems in pumping, combustion and atomization in the injector system of diesel engine. Due to the high viscosity, vegetable oils normally introduce the development of gumming, the formation of injector deposits, ring sticking as well as incompatibility with conventional lubricating oils in long-term operations.

In India Cashew nut cultivation presently covers a total area of 0.70 million hectares of land, producing over 0.40 million tons of raw cashew nuts [6]. The Cashew is a tree in the flowering plant family Anacardiaceae. The plant is native to northeastern Brazil, where it is called by its Portuguese name Caju (the fruit) or Cajueiro (the tree). It is now widely grown in tropical climates for its cashew "nuts" and cashew apples. Fig. 1(1) shows the cashew nut with cross sectional view.

The cashew nut shell is about 0.3 cm thick, having a soft feathery outer skin and a thin hard inner skin. Between these skins is the

* Corresponding author. Tel.: +91 8258281264; fax: +91 8258281265.
E-mail address: mallikappadodderi@gmail.com (Mallikappa D.N.).

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Nomenclature

BSEC	Brake Specific Energy Consumption
B.T.E	Brake Thermal Efficiency
CBF	Cardanol Bio-Fuel
CI	Compression Ignition
CO	Carbon Monoxide
DR-CNSL	Double Refined Cashew nut Shell Liquid
EGT	Exhaust Gas Temperature
HC	Hydro-Carbon
IC	Internal Combustion
NOx	Oxides of Nitrogen
ppm	parts per million

honeycomb structure containing the phenolic material known as CNSL. Inside the shell is the kernel wrapped in a thin skin known as the testa. The nut consists of the following, kernel 20–25%, kernel liquid 20–25%, testa 2%, others rest being the shell. The raw material for the manufacture of CNSL is the Cashew.

According to the invention [6], CNSL is subjected to fractional distillation at 200° to 240 °C under reduced pressure not exceeding 666 Pa in the shortest possible time which gives a distillate containing cardol and the residual tarry matter, for example, in the case of a small quantity of oil, say 200 ml/the distillation period is about 10–15 min. A semi-commercial or commercial scale distillation of CNSL may however take longer times. It has been found that there are certain difficulties of operation with regard to single-stage fractional distillation method due to frothing of the oil which renders difficult the fractionation of cardol and also formation of polymerized resin. These difficulties can be overcome in the two-stage distillation, if care is taken not to prolong the heating; this is to avoid the undue formation of polymerized resins and possible destruction partially or completely of the cardol or anacardol. When CNSL is distilled at a reduced pressure of about 265–333 Pa, the distillate containing anacardol and cardol distils firstly at about 200 °C–240 °C. This first distillate is then subjected to a second distillation under the same identical conditions of temperature and pressure when the anacardol distils over at a temperature of 205 °C–210 °C and the cardol distils over at a temperature of 230 °C–235 °C. In practice it has been found that the preliminary decarboxylation of the oil is essential, since there will be excessive frothing, which renders the distillation procedure unproductive and uneconomical. A specific feature of this invention is that both cardol and anacardol may be obtained by a three-step process. The first step of the process is to get the decarboxylated oil by heating the oil to a temperature of 170 °C–175 °C under reduced pressure of 4000–5333 Pa. The next two steps are the same as above for the production of both cardol or cordanol and anacardol.

DR-CNSL - Double Refined Cashew nut Shell Liquid. The Cashew Nut Shell Liquid (CNSL) obtained by pyrolysis. It mainly consists two naturally produced phenolic compounds: Anacardic acid 90% Cardol or cardanol 10%. Fig. 1(2) shows the chemical structure of CNSL.

Cardanol obtained by pyrolysis from dr-csnl oil was utilized for testing purposes. Cardanol is a naturally occurring phenol manufactured from cnsl. It is a monohydroxyl phenol having a long hydrocarbon chain in the Meta position and is shown in Fig. 1(3).

Cardanol is a renewable, cheaper, easily produced inexpensively in most regions of the world, and hence was used as a substitute for fossil diesel in this work.

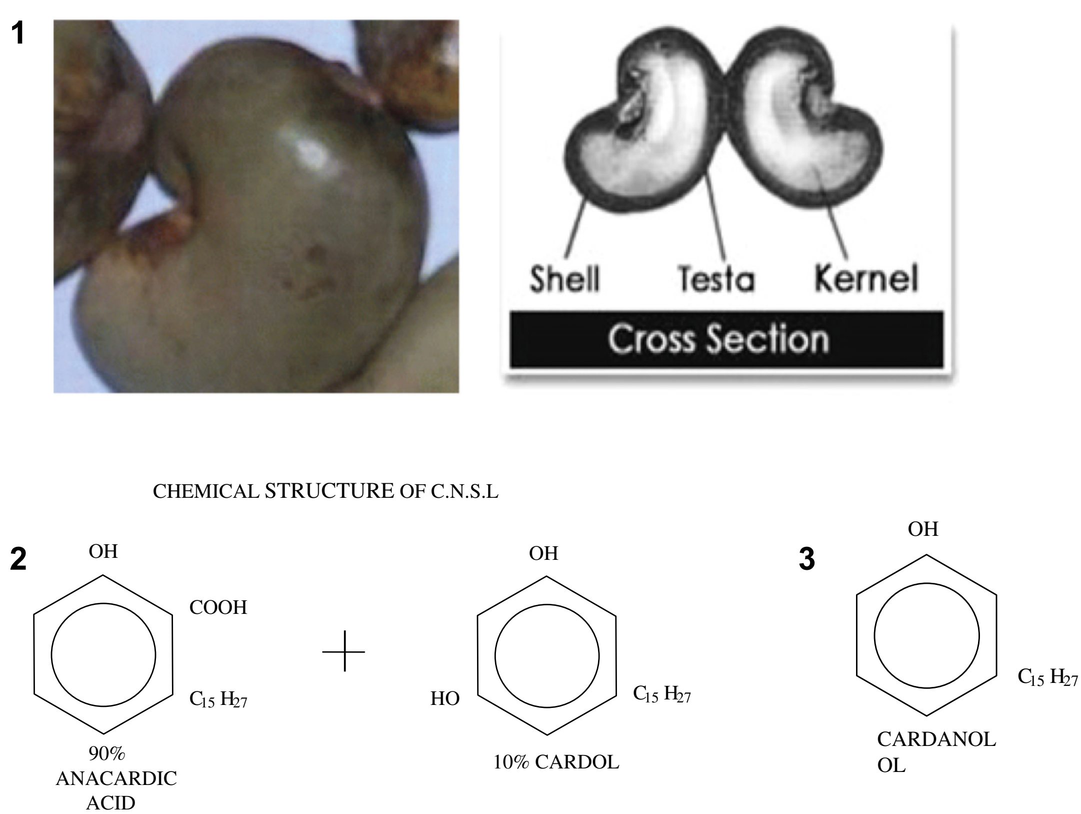

Fig. 1. (1) Cashew nut with cross sectional view, (2) Chemical structure of CNSL, (3) Chemical structure of Cardanol.

Table 1
Properties of the fuel blends.

Properties	Diesel	B10	B15	B20	B25	B30
Flash point (°C)	50	53	55	56	58	61
Density (kg/m^3)	817	823	829	836	841	846
Viscosity (mm^2/sec) at 40° C	2.00	2.50	3.10	3.50	4.20	5.50
Calorific value (kJ/kg)	40,000	40,130	40,196	40,261	40,326	40,392

2. Experimental methods

The following materials were used for the production of biodiesel. The cardanol oil and anhydrous methyl alcohol were used a reactants and sodium hydroxide was used as the catalyst. Researchers generally agrees that NaoH catalyst reacts quickly during transterification [7].For the production of biodiesel using transesterification, about 4 g of NaOH (catalyst) was dissolved in 200 ml methanol to prepare alkoxide, which is required to activate the alcohol. Then stirring is done vigorously in a covered container until the alkali is dissolved completely for 20 min. Then the mixture is protected from atmosphere carbon dioxide and moisture as both destroy the catalyst. The alcohol catalyst (NaOH) mixture is then transferred to the reactor containing 700 ml moisture free crude cardanol oil and stirring of the mixture was continued for 90 min at a temperature between 60 and 65°. The round bottom flask was connected to a reactor condenser and the mixture was heated for approximately 3 h.

The mixture was distilling and condensing within the reactor condenser, no glycerin, because CNSL is extracted from honeycomb structure (shell) of a cashew nut. The color of cardanol oil slightly changed from dark brown to light brown color and an average of 95% recovery of bio fuel was possible.

The main objective was to study the performance and emission characteristics of the CI engine when Cardanol and pure diesel volumetric blends were used and also to investigate which combination of fuel blend is suitable for diesel engine at all load conditions from both performance and emission point of view. Experimentation has been conducted up to CBF volumetric blends 0, 10, 15, 20%, and 25%. The various properties of CBF volumetric blends as shown in the Table 1.

In this investigation the various performance and emission tests were conducted on four strokes twin cylinder engine manufactured by M/s Kirloskar (as shown in Fig. 2(1)) Company limited. The tests were conducted up to 25% blends, because the viscosity of above 25% blends exceeds more than 5 Cs. The parameter involved in performance analysis has been measured using the various equipments supplied by the engine manufacturer (Refer, Table 2 for specifications of the engine).The load test was conducted for different loads i.e. no load, 25%load, 50%load, 75% load and full load conditions.

A DELTA 1600-L of MRU make Exhaust gas analyzer is used to find the NOx (ppm), UBHC (ppm), and CO (%), CO emissions in the exhaust. The AVL437C smoke meter used to measure the opacity of the exhaust gases. Opacity is the extinction of light between light sources and receiver. Opacity is measured in percentage.

3. Results and discussions

The experiments were conducted on a direct injection compression ignition engine for various loads with an intention of studying the behavior of the engine in regard to various emissions, and performance characteristics when it was run on different volumetric blends and the results of the performance test and the emission studies conducted on the engine are plotted in the following (Characteristics graphs) figures.

Following figures (From Fig. 3(1–6)) depicts the various performance and emissions characteristics.

Fig. 3(1), depicts that, the brake specific energy consumption decreases by 25–30% approximately with increases in brake power. This reverse trend was observed due to lower calorific value with increase in bio fuel percentage in the blends.

The variation of brake thermal efficiency with brake power for different volumetric blends is presented in Fig. 3(2). In all cases, it increased with increase in brake power. This was due to reduction in heat losses and increase in brake power with increase in load.

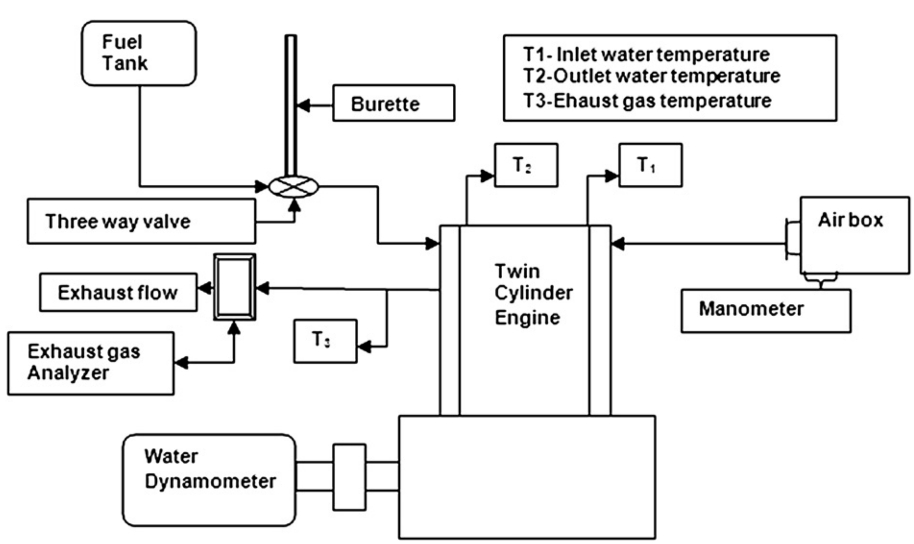

Fig. 2. Engine test rig.

Table 2
Engine specifications.

Engine specifications	
Engine type	Kirloskar, AV 2, Double Cylinder, Water cooled, and Four Stroke CI engine.
Rated power Output	10 HP
Speed	1500 RPM
Stroke length	110 mm
Bore Diameter	102 mm
Loading type	Hydraulic Dynamometer Load - Coupled to the engine through flexible coupling
Exhaust Gas Calorimeter	It consist of shell and pipe type vertical condenser with water inlet and outlet Connections and control valve.
Air Intake Measurement	It consists of air tank size 0.5 × 0.5 × 0.5m fitted with baffle orifice plate 0.02 m diameter. A 'U' tube manometer to measure differential pressure.
Fuel Intake Measurement	Using fuel tank, 3 way cock and burette.
Temperature Measurement	Using thermocouple sensor with a multipoint digital temperature ind

The brake thermal efficiency obtained for CBF blends was less than that of diesel. This lower brake thermal efficiency obtained could be due to lower calorific value and increase in fuel consumption as compared to diesel.

The variations of NO_x emissions with respect to brake power are presented in the in Fig. 3(3). From the figure, it has been observed that NOx emissions (ppm) increases with increased proportion of blends and also with higher EGT (This increasing trend of EGT is mainly because of generating more power and consumptions of more fuel at higher loads). 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.

From the Fig. 3(4), it has been observed that HC emissions are nominal up to B20, and more at B25, the reason for this is the incomplete combustion.

From Fig. 3(5), it is observed that the carbon monoxide emissions increases with higher blends, and increases slightly more after 20% blends. The minimum and maximum CO produced was 0.03–0.08%. At higher loads Co emissions slightly decreased. At elevated temperature, performance of the engine improved with relatively better burning of the fuel resulting in decreased Co.

There is a reduction in smoke density for CBF volumetric blends at higher brake power, this trend mainly due to the presence of internal availability of oxygen content in the CBF and neat burning of fuel at elevated temperature (As the oxygen content in the fuel increases, smoke content in the exhaust is reduced).

4. Conclusion

The cnsl and its extracts showed promising results in terms of engine performance in par with conventional CI engine fuels. Based on the results of the study the following conclusions were drawn.

1. The significant factor of cardanol bio fuel is its low cost, its abundance and it is a byproduct of cashew nut industries.
2. The brake specific energy consumption decreases by 30–40% approximately with increases in brake power. This reverse trend was observed due to lower calorific value with increase in bio fuel percentage in the blends.

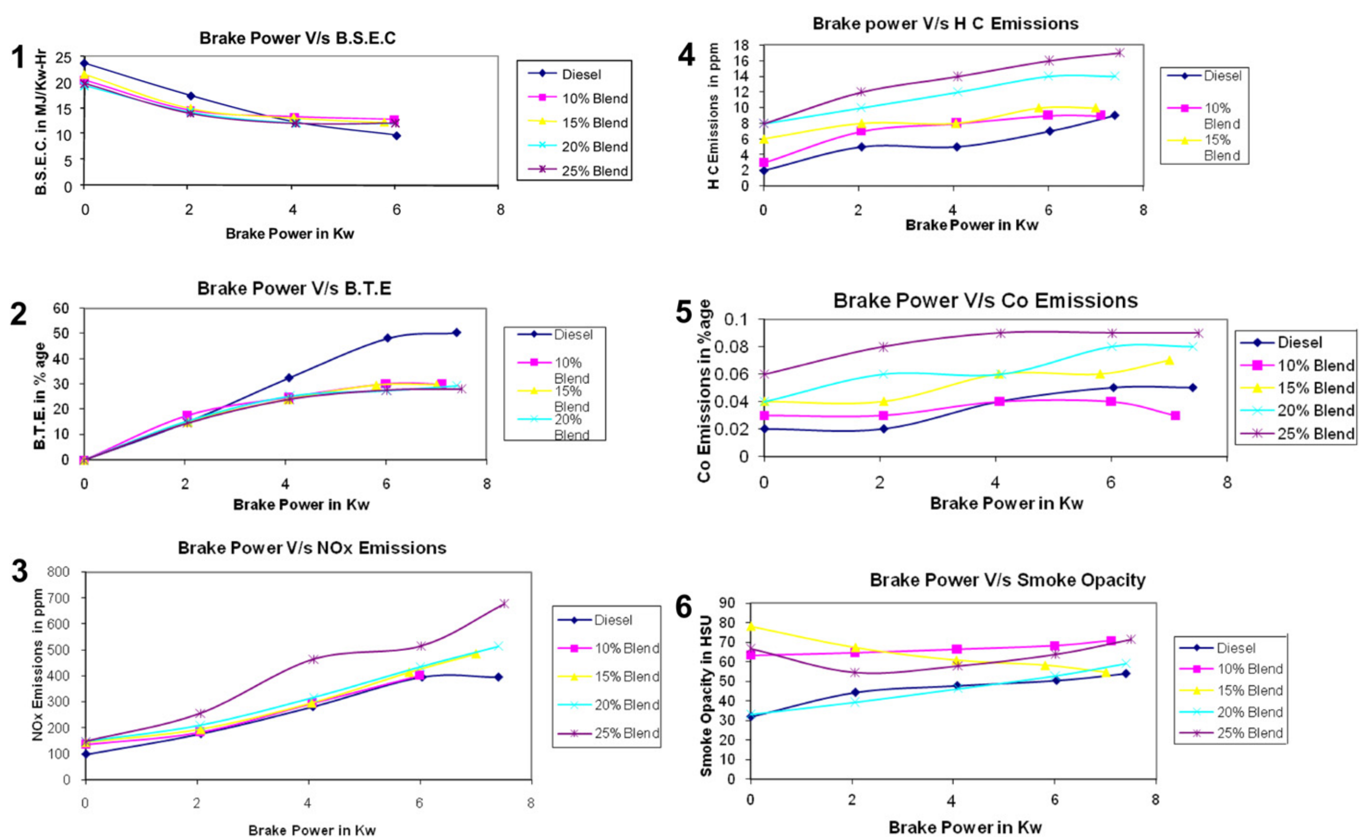

Fig. 3. (1) Brake specific Energy consumption V/s Brake Power, (2) B.T.E V/s Brake Power, (3) Brake Power V/s NOx Emissions, (4) Brake Power V/s HC Emissions, (5) Brake Power V/s CO Emissions, (6) Brake Power V/s Smoke Opacity.

3. The brake thermal efficiency increases with higher loads. In all cases, it increases with increase in load. This was due to reduction in heat losses and increase in brake power with increase in load. The brake thermal efficiency obtained for Cardanol bio fuel volumetric blends was less than that of diesel. This lower brake thermal efficiency obtained could be due to lower calorific value and increase in fuel consumption as compared to diesel.
4. 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.
5. The HC emissions are nominal up to B20, and more at B25, the reason for this is the incomplete combustion.
6. The Carbon monoxide emissions increases with higher blends, and increases slightly more after 20% blends. At higher loads CO emissions slightly decreased may be due to at higher temperatures the performance of the engine improved with relatively better burning of the fuel resulting in decreased Co.
7. From this investigation it has been observed that up to 20% blends of cardanol bio fuels may be used in CI engines without any modifications.

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