

# Performance and Emission Characteristics of Stationary CI Engine with Cardnol Bio Fuel Blends

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**Abstract**— The compression ignition engine is the most popularly used prime mover. The compression ignition (CI) engine moves a large portion of the world's goods & generates electricity more economically than any other device in their size range [1]. All most all the CI engines use diesel as a fuel, but the diesel is one of the largest contributors to environmental pollution problems. The application of bio diesel as a substitute for conventional petroleum fuel in diesel engine gain ever increasing demand throughout the world wide, because it is produced from renewable resources, bio degradable and potential to exhaust emissions & use of bio diesel in diesel engines generates rural employment opportunities by cultivating such oil producing crops[1-5]. In this research work 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. The results indicate that brake power increases (by 76% approximately) as load increases. Brake specific energy conversion decreases (by 30-40 % approximately) with increase in load. Brake thermal efficiency increases with higher loads and emission levels (HC, CO, NOX) were nominal up to 20% blends.

**Key words:** Compression Ignition, characteristics, cardnol bio fuel, Performance, Emissions

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## Nomenclature

BSEC	: Brake Specific Energy Consumption
B.T.E	: Brake thermal efficiency
B10	: Blend with 10%bio fuel
CBF	: Cardnol Bio Fuel
CI	: Compression Ignition
CO	: Carbon Monoxide
DR-CNSL	: Double Refined Cashew nut Shell Liquid
EGT	: Exhaust Gas Temperature
HC	: Hydro Carbons
IC	: Internal Combustion
NOx	: Nitrogen oxide
ppm	: Parts per million
Cs	: Centistokes

## 1 INTRODUCTION

I N 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 bio diesel 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.

India is the largest producer, processor and exporter of Cashews, *Anarcadium Occidentale* Linn, in the world [6]. It was brought to India during the 1400 by Portuguese missionary. Cashew came conquered and took deep root

in the entire coastal region of India. While the tree is native to central and Southern America it is now widely distributed throughout the tropics, particularly in many parts of Africa and Asia. In India Cashew nut cultivation now covers a total area of 0.70 million hectares of land, producing over 0.40 million metric tons of raw Cashew nuts. The Cashew (*Anacardium Occidentale*) 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.

### 1.1 Specification of Cashew nut shell

The shell is about 0.3 cm thick, having a soft feathery outer skin and a thin hard inner skin. Between these skins is the honeycomb structure containing the phenolic material known as CNSL. Inside the shell is the kernel wrapped in a thin skin known as the testa.

### 1.2 Composition of cashew nut

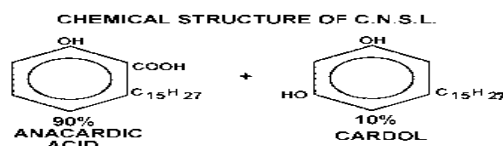
The shell is about 0.3 cm thick, having a soft feathery outer skin and a thin hard inner skin. Between these skins is the honeycomb structure containing the phenolic material known as CNSL. Inside the shell is the kernel wrapped in a thin skin known as the testa. The nut consists of the following kernel 20 to 25%, kernel liquid 20 to 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 5mm. mercury 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 to 15 minutes. 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, i.e. frothing of the oil which renders difficult the fractionation of cardol and also formation of polymerised 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 polymerised resins and possible destruction partially or completely of the cardol or anacardol. When CNSL is distilled at a reduced pressure of about 2 to 2.5 mm. mercury, the distillate containing anacardol and cardol distils firstly at about 200°C to 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 to 210°C and the cardol distils over at a temperature of 230°C to 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 de-

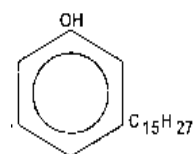
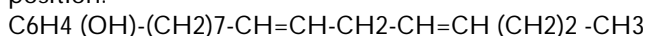
carboxylated oil by heating the oil to a temperature of 170°C to 175°C under reduced pressure of 30-40 mm. mercury. The next two steps are the same as above for the production of both cardol or cordnol and anacardol.

#### 1.2.1 Cardnol

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 cardnol 10%.



Cardnol obtained by pyrolysis from dr-csnl oil was utilized for testing purposes. Cardnol is a naturally occurring phenol manufactured from cnsl. It is a monohydroxyl phenol having a long hydrocarbon chain in the Meta position.



**Reason for using the cardnol as alternative fuel:** - it is renewable, it is cost effective, easily produced inexpensively in most regions of the world, results in reduced [up to certain extent] emissions compared with petro-diesels, results in no detrimental effects to the engine, non edible and it is extracted from the cashew nut shell not from the seed.

## 2 EXPERIMENTAL

The main objective was to study the performance and emission characteristics of the CI engine when Cardnol 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 cardnol bio fuel volumetric blends like 0, 10, 15, 20%, and 25%, because the viscosities (refer table 1 for properties of cardnol bio fuel blends) of higher blends are more than the international standard limits [ASTM-allowable limits only up to 4-5 centistokes].

Properties	Diesel	B10	B15	B20	B25	B30
Flash point (C)	50	53	55	56	58	61
Density(Kg/m <sup>3</sup> )	817	823	829	836	841	846
Viscosity at 40°C (Centistokes)	2	2.5	3.1	3.5	4.2	5.5
Calorific value (KJ/Kg)	40000	40130	40196	40261	40326	40392

## 2.2 Properties

Following table 1 indicates the properties of cardnol bio fuel blends. Lower Calorific value of the diesel has been considered for calculations. **Table 1 Properties**

## 2.3 Transesterification

Selection of raw materials: cardnol oil sample, anhydrous methyl alcohol 99% grade laboratory reagent type, Sodium Hydroxide was selected as the catalyst.

### 2.3.1 Procedure

About 4 grams of Naoh (catalyst) is 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 twenty minutes. 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 cardnol oil. Stirring of the mixture is continued for 90 minutes at a temperature between 60-65 degrees. The round bottom flask was connected to a reactor condenser and the mixture was heated for approximately three hours.

### 2.3.2 Inference and observation

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 cardnol oil slightly changed from dark brown to light brown color and an average of 95% recovery of bio fuel was possible.

## 2.4 Experimental procedure

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 and for blends such as 0%, 10%, 15%, 20%&25%of Cardnol. The Orotech exhaust gas analyzer used for emission mea-

surements.



**Fig 1 Experimental setup**

In this investigation the various performance and emission tests were conducted on four strokes single cylinder engine manufactured by M/s Kirloskar (as shown in fig 1) Company limited. The parameter involved in performance analysis has been measured using the engine software supplied by the manufacturer.

### 2.4.1 Specifications of the engine

Name of the engine: KIRLOSKAR, TV1

General details: 4 stroke, C.I, Vertical

Type of cooling: Water cooled

Number of cylinders: 1

Bore: 87.5 mm

Stroke: 110mm

Rated power: 5.2 B.H.P at 1500 rpm

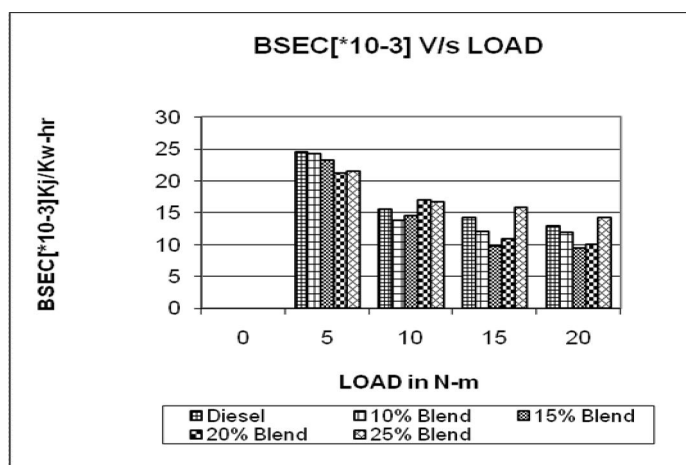
Dynamometer: Eddy current dynamometer

Compression ratio: 12:1 to 17.5:1

## 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.

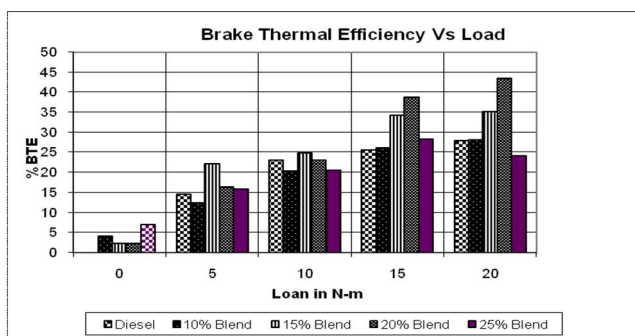
### 3.1 Brake specific Energy consumption



**Fig 2.Brake specific Energy consumption (\*103Kj/Kw-hr) v/s load**

Fig2.Depicts 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.

### 3.2 Brake thermal efficiency

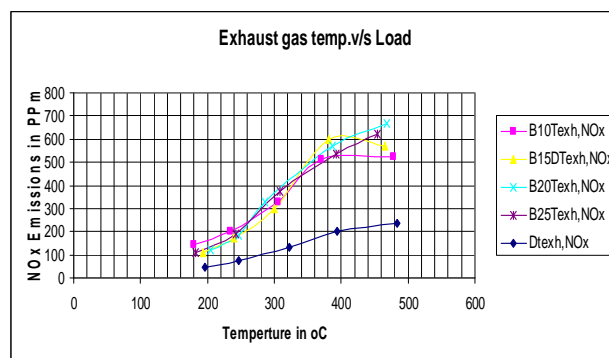


**Fig 3.Brake thermal efficiency v/s Load**

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

esel. This lower brake thermal efficiency obtained could be due to lower calorific value and increase in fuel consumption as compared to B20.

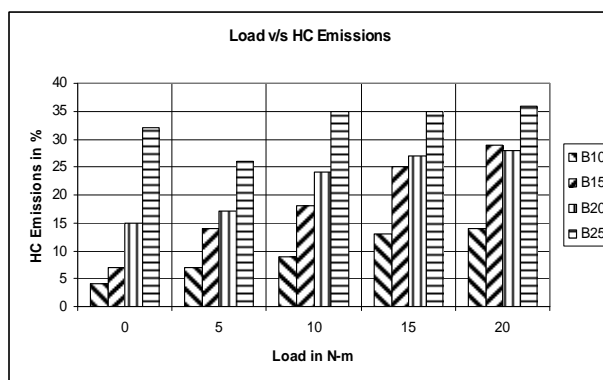
### 3.3 .Exhaust gas temperature & NOx Emissions



**Fig 4.Exhaust gas temp. v/s NOx Emissions**

The variations of exhaust gas temperature and Nox emissions with respect to engine loading are presented in the in fig.4.The exhaust gas temperature increases linearly form 180o C at no load to 480 o C at full load conditions. This increasing trend of EGT is mainly because of generating more power and consumptions of more fuel at higher loads.

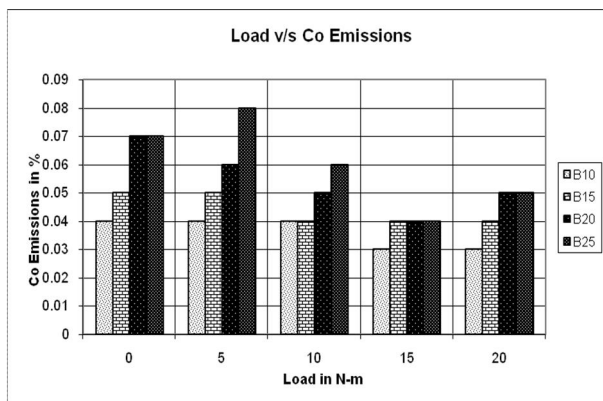
### 3.4 HC Emissions



**Fig 5. HC Emissions**

From the figure 5 it has been observed that HC emissions are nominal up to B20, and more at B25, the reason for this may be incomplete combustion.

### 3.5 Carbon Monoxide Emissions



**Fig 6. Carbon Monoxide Emissions**

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.

## CONCLUSIONS

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.

The significant factor of cardanol bio fuel is its low cost, its abundance and it is a byproduct of cashew nut industries.

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. This was due to reduction in heat losses and increase in brake power with increase in load. 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. This lower brake thermal efficiency obtained could be due to lower calorific value and increase in fuel consumption as compared to B20.

The NOx 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 NOx 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. 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.

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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