Performance and Emission Characteristics Studies on Stationary Diesel Engines Operated with Cardanol Biofuel Blends

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Abstract- This work composed with performance and emission studies of three stationary diesel engines operated with 20% cardanol biofuel volumetric blends. A single cylinder diesel engine and VCR engines were used to evaluate the performance and emission characteristics of cardanol biofuel. An extended experimental study was conducted on a double cylinder CI engine, to evaluate the performance and emission characteristics. The cardanol biofuel volumetric blends between 0-25% and base fuel (Petro diesel) were tested at various loads between 0-full load. From the results, brake thermal efficiency, increased with increase in load. The brake specific energy consumption decreased by 30 to 40% with increase in brake power. The HC emissions were nominal up to B20, and more at B25. The NOx emissions (ppm) increased with increased proportion of blends. The carbon monoxide emissions increased with higher blends and decreased slightly at higher loads. From this investigation, it is observed that up to 20% blends of cardanol biofuels may be used in CI engines without any modifications.

Keywords Fossil fuels, Hydrocarbons, Internal combustion engines, Characteristics, Performance, Emissions, Cardanol biofuel

1. Introduction

In today's world majority of automotive and transportation vehicles are powered by compression ignition engines, which use diesel as fuel. Pollution being the main concern today extensive research has proved that exhaust emissions cause considerable environmental pollution, diminished air quality, acidic precipitation, toxic chemical transport, climate change impacts. Petro diesels are not evenly distributed on the globe, which means that they must be transported over greater distances from source to market. This increases potential for soil and water contamination at any point in extraction bulk transport, refining, distribution, storage and supply.

Self-reliance in energy is vital for the economic development of a nation [1]. The needs to search for alternative sources of energy which are renewable and eco-friendly assume top priority in view of the uncertain supplies and frequent price hikes of fossil fuels in the international market. There are many tree species which bear seeds, rich in oil, having properties of an excellent fuel and which can be processed into a diesel substitute. Of these some important varieties are Pongamia, Jatropha, Neem, Mahua, Simarouba, Sal, Undi, Pilu etc.Non-edible oils that can be used to produce bio-fuels are gaining worldwide acceptance as one of the comprehensive solutions for problems of environmental degradation, energy security, restricted imports (import restrictions), rural employment and agricultural economy. "Bio-fuels are fuels produced by a number of chemical / biological processes from biological materials like plants, agricultural wastes etc. Being sourced from trees already existing and to be further propagated, bio-fuel is a source of renewable energy". Bio-diesel can be used as a pure fuel or blended with petroleum diesel depending on the economics and emissions.

1.1 Potential for use of tree based seeds

We, in India, have a well-established collection and marketing network for non-edible oils, going back to the Vedic days, for use as fuel for lighting lamps. There are more than 300 different species of trees, which produce oil-bearing seeds; therefore, we do not have to pursue any monoculture to obtain them. Most of these trees are wild and therefore, once established, will look after themselves. At commonly used densities of more than 100 trees per hectare, many of these trees yield 10 to 15 tons of seeds per hectare on maturing. Since 15 to 20 year old trees use soil to more than 10 meter depth (unlike agricultural crops which use only 0.15 meter of top soil), both the survivability during dry periods and annual output per hectare are better than what could be obtained from many agricultural crops. There is also no possibility of total yield failure with trees in any year. These are well documented [2 and 5].

1.2 Introduction to cashew tree

The forest departments established the first cashew plantations in many countries as an easy way of afforestation. Cashew trees in India were planted for the protection of coastal dunes, sometimes in combination with Casuarina equisitifolia [4] and for wasteland recovery, almost exclusively on poor soils unsuitable for other crops. In Brazil, plantations exist with more than 40,000 hectors. In the countries south of the Sahel with 600-800 mm annual rainfall, cashew is important as a tree to counterbalance desertification.

1.3 Cashew nut shell liquid (CNSL) and its extraction [4,7,8]

Cashew nut shell liquid (CNSL) is a by-product of cashew industry in India, which is a major earner of foreign exchange. CNSL is contained in the soft honeycomb structure between the outer shell and the kernel of the cashew nut. The cashew nut tree (Anacardium accidenate in Latin; Kaju in Hindi) belongs to the natural order Anacardiaceae, even as Bhilawan tree and grows at altitudes below 1000 ft. along the West and Eastern Coasts of India. It is extensively cultivated in Brazil, East Africa, Tanzania, Mozambique, Madagascar, Philippines and other tropical regions. In India it is grown in the states of Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra, Orissa, West Bengal, Assam and Goa.

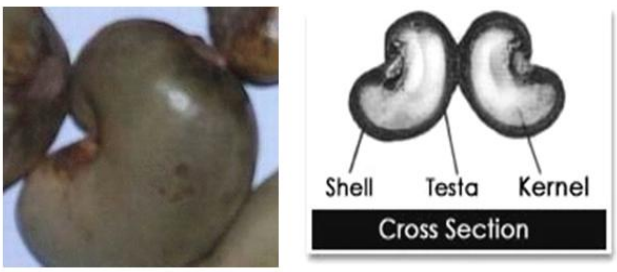

Fig. 1. Cashew nut with cross sectional view

The cashew fruit has a kidney-shaped nut 1 to 1.5 inches long (Figure 1 depicts the cross section of cashew nut shell). The nut is attached to the end of fleshy receptacle or enlarged peduncle of the fruit, which is commonly known as cashew apple. This is pear shaped or rhomboid-to-oval shaped, having 2-41/2 inches length and is bright yellow to red with a waxy skin. Pericarp of the nut consists of coriaceous epicarp, spongy mesocarp and stony endocarp. The mesocarp consists of a honeycomb network of cells which gives cashew nut shell liquid.

1.4 Cardanol production

According to the invention [5], 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.

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. The first step of the process is to get the decarboxylated oil by heating the oil to a temperature of 170°C to 175°C under reduced pressure of 3999-5330 Pa. The next two steps are the same as above for the production of both cardol or cordanol and anacardol.

1.4.1 Transesterification

Cardanol oil sample, unhydrous methyl alcohol 99% grade laboratory reagent type and sodium hydroxide was selected as the catalyst. About 4 grams of catalyst was dissolved in 200 ml methanol to prepare alkoxide, which is required to activate the alcohol. The solution was stirred vigorously for 20 minutes in a covered container until the alkali was dissolved completely. Mixture was protected from atmosphere carbon dioxide and moisture as both destroy the catalyst. The alcohol catalyst (NaOH) mixture was then transferred to the reactor containing 700 ml moisture free crude CNSL oil. Stirring of the mixture was continued for 90 minutes at a temperature between 60-65 degrees. The round bottom flask was connected to a refractor condenser and the mixture was heated for approximately three hours.

1.4.2 Inference and observation

The mixture was distilling and condensing within the reactor condenser. Viscosity was reduced to half its normal value mainly due to dilution with methanol. No glycerin, because CNSL was extracted from honeycomb structure of the cashew nut shell.

2. Experimental Investigation

Three different test engines test equipments (measuring instruments) were employed during this test program, as summarized below in Table 1. These engines /equipments represented a wide range of potential applications for biodiesel fuel.

Table 1. Details of test engines & emission measuring instruments

Test NO.	Engine Type	Rated Power HP	Test equipments (Emission measuring instruments)
1	Single cylinder, four stroke CI engine, constant speed, water-cooled [Computerized].	5.2	Automotive emission analyzers QRO– 402 of QROTECH CO. LTD
2	Single cylinder 4 stroke CI engine water-cooled. Modified to VCR Engine [CR:12-18],	3.7kW	DELTA 1600-L of MRU make Exhaust gas analyzer
3	Double cylinder, Four Stroke CI engine. Water-cooled.	10	DELTA 1600-L of MRU make Exhaust gas analyzer with AVL437C smoke meter

2.1. Specifications of the engines used

The various performance and emission characteristics tests were conducted on four stroke single cylinder CI engine,VCR CI engine and twin cylinder CI engines manufactured by Kirloskar company limited.

Specifications of the Single cylinder engine: Engine:- four stroke, single cylinder diesel, Rated power-5.2 kW, Bore & stroke (mm)- 87.5&110.0, Nominal compression ratio-17.5:1, Dynamometer type-eddy current175 mm lever arm at load cell load dynamometer, Fuel flow measurement-fuel measurement with DPT, Air flow measurement-orifice meter with monometer and DP Orifice diameter 20 mm, Water flow measurement-rotometer,Temperature measurement-RTD PT-100 sensors, Cylinder pressure measurements- by piezo sensor, Analysis- through computer software.

Specifications of the Variable Compression Ratio engine:- Single cylinder 4 stroke Kirloskar diesel engine water cooled [computerized] modified to VCR Engine [CR: 12-18] 3.7kW, 1500rpm, Dynamometer-eddy current water cooled, Air box- MS fabricated with orifice meter and manometer, Calorimeter- type pipe in pipe, Piezo sensor-range 5000 PSI, with low noise cable,Temperature sensor-type RTD,Software-“EnginesoftLV” engine performance analysis software.

Engine specifications of the twin cylinder engine:- Engine type- Kirloskar, AV2, 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- shell and pipe type vertical condenser with water inlet and outlet connections and control valve, Air Intake measurement- air tank size 0.5 x 0.5 x 0.5m fitted with baffle orifice plate 0.02 m diameter and '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 indicator for jacket water and exhaust calorimeter temperatures.

Table 2. Properties of the CBF 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 degree C	2.00	2.50	3.10	3.50	4.20	5.50
Calorific value (kJ/kg)	40000	40130	40196	40261	40326	40392

The properties of Cardanol biofuels obtained by transesterification from crude cardanol oil compared with diesel oil which have been utilized for testing various performance and emission characteristics in compression ignition engines. The various properties like flash point, density, viscosity and calorific values are depicted in the table 2.

3. Results and Discussions

A single cylinder diesel engine and VCR engines were used to evaluate the performance and emission characteristics of cardanol biofuel. An extended experimental study was conducted on a Kirloskar double cylinder CI engine, to evaluate the performance and emission characteristics. The cardanol biofuel volumetric blends between 0-25% and base fuel (Petro diesel) were tested at various loads between 0-full loads.

3.1. Brake thermal efficiency v/s load

Figure 2 depicts that the brake thermal efficiency increases with higher loads. In all cases, it increases with increase in load. This is due to reduction in heat losses and increase in brake power with increase in load. The brake thermal efficiency obtained for single cylinder and VCR at 20% Cardanol biofuel volumetric blends is less than that of twin cylinder diesel engine. This lower brake thermal efficiency obtained could be due to lower [both in single cylinder and VCR engines] brake power and increase in fuel

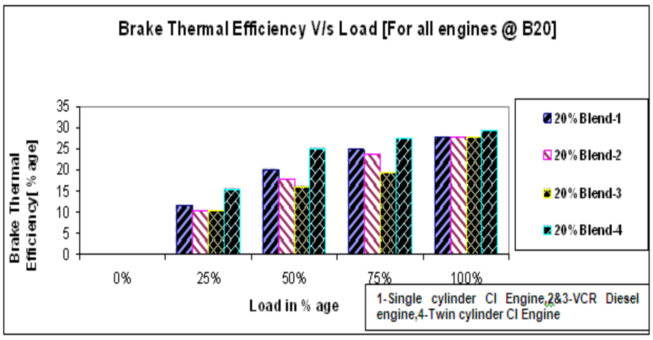

Fig. 2. B.T.E v/s load at 20% blends

consumption as compared to other two diesel engines. Another reason for higher brake power in the case of twin cylinder engine may be due to higher brake mean effective pressure.

3.2. Brake specific energy consumption v/s load at 20% blends

From figure 3, the brake specific energy consumption decreases by 30 to 40% approximately with increase in load conditions. This reverse trend is observed due to lower calorific value and higher viscosity with increase in biofuel percentage in the blends. The brake specific energy consumption decreases by 30 to 40% approximately at higher CR and 25 to 30% at lower CR with increase in brake power.

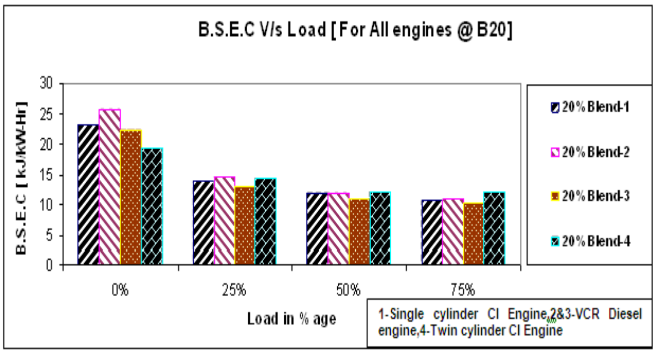

Fig. 3. BSEC v/s load at 20% blends

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.

3.3. NOx emissions v/s load at 20% blends

From the figure 4, it is observed that slight variations of NOx emissions occur in all engines at 0% load and 100% load conditions; the reason for these variations may be due to malfunctioning of biofuel mixture. NOx emissions are sensitive to the spry characteristics, temperature and oxygen. The spry characteristics of a fuel depend on droplet size, penetration rate, evaporation rate, degree of mixing with the air etc. A change in any of these properties may change NOx production.

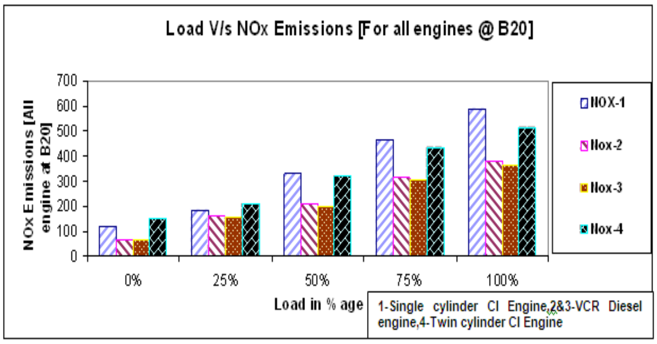

Fig. 4. NOx Emissions v/s load at 20% blends

3.4. HC Emissions v/s load at 20% blends

From the figure 5 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 reason for this may be due to proper burning of fuel at higher compression ratio. Another reason for this could be incomplete combustion and physical properties of the CBF.

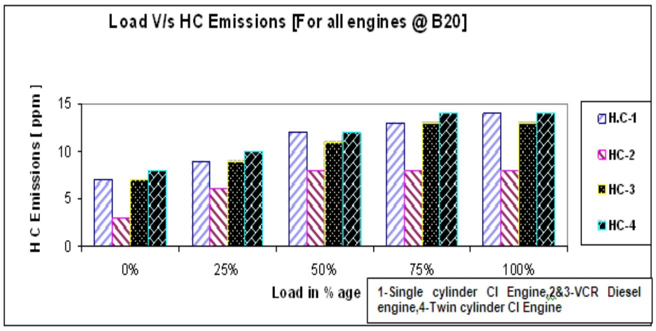

Fig. 5. HC Emissions v/s load at 20% blends

3.5. CO emissions v/s load at 20% blends

From the figure 6, it is observed that the minimum and maximum CO produced is 0.03-0.08%.The carbon monoxide emissions at different load conditions in different engines are not uniform. The reason for this could be malfunctioning of CBF(Cardanal biofuel) volumetric blends in different injection systems and may be due to change of operating parameters in CI engines.

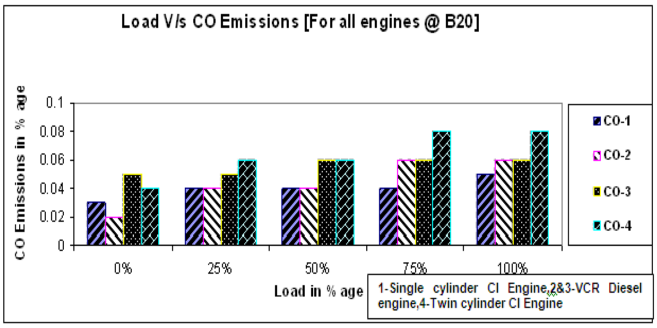

Fig. 6. CO Emissions v/s load at 20% blends

4. Conclusion

The properties like density, viscosity, flash and fire points of cardanol biofuel 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 biofuel 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 NOx emissions occur in all engines at 0% load and 100% load conditions; the reason for these variations could be malfunctioning of biofuel 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 reason for this could be incomplete combustion and physical properties of the CBF.

The carbon monoxide emissions at different load conditions in different engines are not uniform. The reason for this could be malfunctioning of CBF volumetric blends in different injection systems and may be due to change of operating parameters in CI engines.

From this work it is proved that, up to 20% CBF volumetric blends can be used in the diesel engines without any major hardware modifications.

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