Coconut oil as biofuel for diesel engines

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Self sufficiency in energy requirement is a critical factor for the success of any growing economy. With respect to the increasing rate of energy consumption, dependence on fossil fuels will necessarily have to be reduced. India as the 5th largest energy consumer, is importing almost 70% of its crude oil requirement (90 million tonnes) and the statistics indicate that this trade would rise to 95% by 2030. It is a paradox that, with a rich natural biomass resource that can be converted in to renewable energy, the import trade of the country for petroleum product remains exorbitant. Hence the search for new alternative source for fuel from nature, that is renewable, safe and non- polluting has become a part of innovative research today. Even though, different research agencies of the country have made several attempts in the production of biodiesel from oil crops under national mission on biodiesel by Ministry of Rural Development, none of them have come out at commercial level with accepted technical feasibility with that of diesel India has a good number of traditional oleaginous crops that can yield oil for both domestic and industrial purposes.

As a renewable energy resource, vegetable oils are the most promising alternative for making biofuel. The use of vegetable oil in combustion ignition engine (CIE) was first demonstrated by using peanut oil in diesel engine. The direct use of peanut, coconut, soybean, sunflower oil, palm, linseed and rape seed oils as fuel have been attempted by many researchers. However, the higher viscosity and other physico chemical features of the oils have limited its usage in engines for long term. Since trans-esterification process of the oil for making esters was found more compatible with the properties of fuel, the esterification process of vegetable oils have been tried in the production of biofuels.

The nutritional, therapeutic and industrial qualities of coconut oil, the commercial viability of non lipid components of coconut and the perennial nature of yielding of the coconut palms make the crop unique from other tropical oleaginous crops. The main focus of the previous reports on production of biofuel from coconut oil was the trans-esterification of the oil to ethyl and methyl esters for blending it with diesel in vehicles. An independent search on the standardization of the trans-esterification of coconut oil with respect to yield of CME, physico chemical properties of CME related to fuel quality and its technical feasibility as biofuel in CIE without any alteration has not been attempted to date scientifically. Therefore a detailed analysis of the coconut oil and the esters is inevitable for determining the functional efficacy of CME as biofuel.SCMS Institute of Bioscience & Biotechnology Research & Development, Kochi had made efforts to produce coconut methyl ester (CME) and glycerol from coconut oil and to analyze the physico-chemical features of CME for determining its technical feasibility as biofuel in diesel engine.

Extraction of the coconut oil

Matured coconuts (11- 12 months) were harvested from healthy coconut palms and dehusked. The dehusked nuts were broken into two halves and dried in a hot air oven for eight hours for deshelling. Initially the temperature of the hot air oven was kept at 90°C for three hours for fast recovery of moisture and then reduced the temperature to 70°C for avoiding the browning of the endosperm. After proper drying, the deshelled dry endosperm (copra) was fed into an expeller machine for the extraction of the oil. The quality of coconut oil was ensured by determining the parameters like moisture, lipid composition, fatty acid profile, iodine value,

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saponification value and peroxide value by AOCS and IUPAC methods.

Production of Coconut methyl ester

A known volume of coconut oil (FFA less than 0.1 %) was measured and heated separately at 90°C for 20 minutes for complete dehydration of the oil.

The catalyst used for the reaction is sodium methoxide. For standardizing the concentration of methanol and sodium hydroxide, several trials were done using a range of 5-25% methanol and 0.5-1.5 % NaOH. The methanol- alkali mixture was blended by continuous gentle agitation at 700 rpm for 20 minutes. The alcohol-alkaline solution was prepared freshly in order to maintain the catalytic activity and to prevent the moisture absorbance.

The freshly prepared methoxide solution was slowly charged to the preheated oil and the reaction vessel was connected with water condenser for avoiding evaporation of methanol. The temperature of the reaction was optimized by setting up the reaction at varied temperature ranging from 70-84°C. The reactions were continued for one hour at a constant speed (700 rpm), for the completion of the methyl ester formation.

After completion of the reaction, the reaction mixture was allowed a settling time of 8-10 hrs in a separate funnel. Two layers were obtained with a top layer of Coconut Methyl Ester (CME) and the bottom layer of sodium salt of glycerol with other organics. The crude glycerol layer obtained was decanted out and used for further separation of glycerin while the top CME layer was used for further purification

The recovered coconut methyl ester layer contains traces of the catalyst NaOH and methanol. For removing the alkali, the CME layer was washed gently with hot water. The process was repeated for 6 - 7 times, till it became neutral. The neutral CME was distilled under vacuum for removing the traces of methanol and water present in the ester.

The pH of the collected glycerol layer from the reaction was reduced to 5-6 by the addition of phosphoric acid. After acidification, the mixture was kept for settling for 12 hours. After settling, two layers appeared a bottom layer of inorganic salts and glycerol and a top layer of impurities. For the partial purification of glycerol, the bottom layer was neutralized with 5M NaOH and the inorganic salt present in the layer was precipitated by the addition of methanol. The precipitate was filtered out and the filtrate that contains glycerol was distilled for removal of methanol for obtaining partially purified glycerol. The amount of glycerol was determined by colorimetric method.

The physico chemical properties of CME as against BIS specifications of biodiesel were analyzed at Kochi Refineries and Bharat Petroleum Cooperation Limited, Cochin. The data was compared with the biodiesel standards, India.

The functional property of the CME was checked in a new diesel vehicle (TATA Ace -Magic) and the torque and power of the diesel vehicle using CME was checked on a Dynamometer. The torque@nm and power@bph of the vehicle using CME were determined and compared with the specification stipulated by the manufacturer.

Physico chemical characteristics of coconut oil

Coconut oil was extracted from dried copra processed from fresh mature nuts by effective expeller extraction procedure and an average yield of 68-70% was obtained at each trial.

Table 1 demonstrates the physico chemical properties of the expeller extracted coconut oil. The trace amount of free fatty acid (FFA- 0.1%) and the moisture (0.05%) content showed the stability of the oil for storage. The saponification and iodine values (250 and 8) of the oil indicate the presence of higher level of saturated lipids. The lipid composition of extracted oil exhibit a profile of 95.6% -tri-acyl glycerides (TAG), 0.57 % -di acyl glycerides (DAG), 3.4%- polar acyl glycerides, 0.04% phospholipids, 0.02% glycolipids and traces of mono acyl glycerides (MAG). The fatty acid profile of coconut oil reveals the content of short and long chain fatty acids with 93% saturated lipids and the remaining unsaturated (Table 2).

Table 1 Technical specifications of the new diesel vehicle - TATA Ace-Magic

Engine Type	4 Stroke, Naturally aspirated, Indirect injection, Water cooled diesel engine.
Engine Capacity (CC)	702
Emission Norms	BSIII and BSIV
Power (HP at rpm)	16 at 3200 rpm
Torque (Nm at rpm)	38 at 2500 rpm

The distribution of short chain fatty acids of Lauric (47.2 %), Myristic (19.42 %), Caprylic (8.21 %) and Capric (5.59 %) acids exhibits the uniqueness of coconut oil in comparison with other vegetable oils.

The transesterifcation (TE) reaction of the oil was standardized by doing more than 50 trials with a capacity

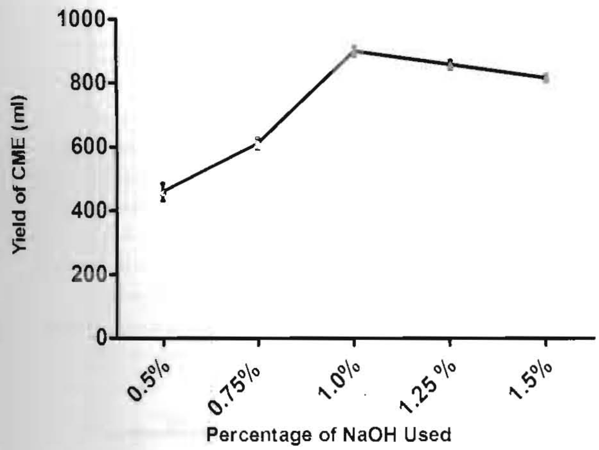
Table 2 Physico chemical properties of coconut oil

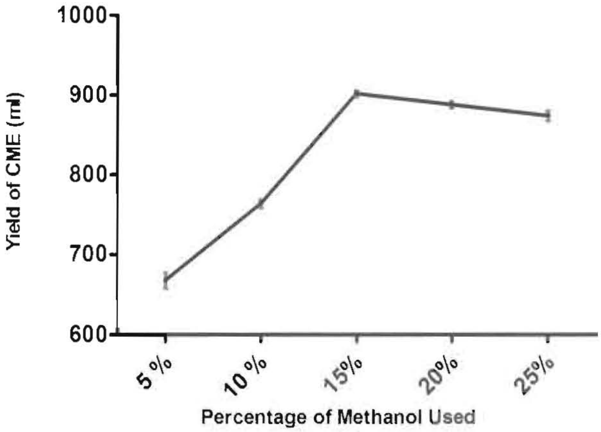
Properties	Test values
Moisture Content	0.05%
Free fatty Acid (mg KOH/gm)	0.1%
Density (gm/cc)	0.920
Saponification Value	249.4
Iodine Value	7.7
Peroxide Value	Nil
Refractive index	1.45
Non saponificable matter	0.05-0.1 %

of three litres for optimizing the methoxide composition, temperature of the reaction and the yield of CME and glycerol. For the reaction 15% methanol with 1 % sodium hydroxide was found adequate for getting maximum catalytic effect (Fig. 1a & b).

Temperature range of the reaction was optimized by performing the reactions at varied temperature ranging from 70-84°C and the temperature at 76°C was found critical for getting maximum yield of CME (Fig. 2).

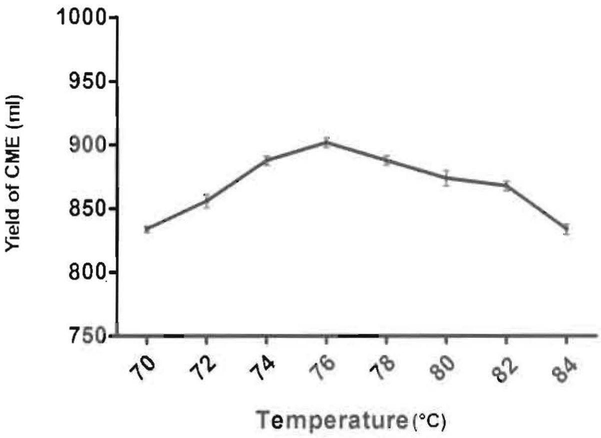
Table 3 demonstrates the mean value of the material balance and each value is the mean of five repeats. An average yield of 900 ml CME and 115 ml glycerol were recovered from one litre of coconut oil by transesterifcation. No difference was observed in the





amount of purified CME after the recovery of methanol and moisture by separation and distillation processing.

Biofuel Quality of CME



In order to ascertain the characteristic features of CME as a biofuel, the physicochemical properties of CME was analyzed against BIS specifications for biodiesel (Table 4).

The main criterion of biofuel quality is the inclusion of its physical and chemical properties into the requirements of the adequate standard. Though the current standards for regulating the quality of biofuels vary from region to region, their similarity with the existing diesel fuel standards common in the regions will be crucial in determining the fuel quality. The test values strongly support the functional similarity of CME with that of diesel as per the requirement of fuel quality.

Cetane number (CN) of CME is observed as 42.1. As the primary indicator of ignition quality of fuels, the optimal range of the CN was identified in between 41-56 based on the global biodiesel standards. The cetane

Table 3 Fatty acid composition of coconut oil

Fatty acid Name	Composition (%)
Caproic acid (C6:0)	0.37
Caprylic acid (C8:0)	8.21
Capric acid (C10:0)	5.59
Lauric Acid (C12:0)	47.08
Myristic acid (C14:0)	19.42
Palmitic acid (C16:0)	7.80
Stearic acid (C18:0)	4.29
Oleic acid (C18:1)	4.30
Linoleic acid (C18:2)	1.81
Arachidic acid (C20:0)	1.03

number of biofuel depends on the molecular structure of the vegetable oil, the degree of unsaturation, number of carbon atoms and the nature of alcohol used for esterification of the oil. The cetane number 42 of CME supports the recommended value.

Density of CME was found very close to that of biodiesel. Since density is strongly influenced by temperature, the quality standards state the determination of density at 15°C. As an effective parameter of fuel quality, the density directly affects the fuel performance, quality of atomization and combustion.

Viscosity is a crucial factor of liquid fuels that can highly influence the ease of starting the engine, the spray quality, size of the particles, the penetration of the injected jet and the quality of the fuel-air mixture, combustion. The similarity observed in the viscosity of CME with diesel strongly indicates the smooth operational power of the fuel.

One of the main attractions of fuel quality, the pour point (PP) and cold filter plugging point (CFPP) property of the CME was found supportive to biodiesel as per the

Table 4 Yield of CME at different batches of transesterifcation with constant temperature (76°C) and concentration of methoxide (15%) and NaOH (1%)

Particulars	Temperature	CME (ml /1000 ml Coconut oil)	Glycerine
Batch-I	76	886±0.05	122±0.012
Batch-II	76	910±0.0316	115±0.022
Batch-III	76	880±0.04	118±0.012
Batch- IV	76	910±0.0332	118.4±0.009
Batch-V	76	904±0.068	109.8±0.026
Batch- VI	76	898±0.08	117.4±0.022
Batch- VII	76	904±0.068	110±0.030
Batch-VIII	76	894±0.051	115±0.025
Batch- IX	76	908±0.038	110±0.035
Batch-X	76	906±0.51	114.4±0.032
	AVG	900 ml	115 ml

standards. Since the PP and CFPP values represent the cloud flow performance of the fuel for CIE (compression ignition engine), the values of CME supports its efficiency as biofuel in cold environment.

The similarity observed in the flash point of CME (96°C) and biodiesel indicate the ability of ignition. Moreover, it makes the fuel comfortable during storage, transportation and handling. The range of flash point recommended for the fuel is 93°C to 120°C. The values of lubricity, oxidation stability, water content and acid value of CME showed a competent nature with biodiesel standards and the values support its excellence as a good biofuel. The low carbon residue, minimal acidity and the absence of sulphur elements add more positiveness in the quality of CME than other methyl esters and it may elevate CME as an ecofriendly fuel.

As a plant methyl ester (PME), a comparative analysis of physico chemical properties of CME was done with other methyl esters of oil seeds like Jatropha, Karanja, Oil palm, Cotton seed, sunflower and Soyabean based on their earlier reports. Table 5 demonstrate the preparation of CME with that of other plant methyl esters. The values were further compared with that of diesel. The properties of CME Viz. Kinematic viscosity, acid

Table 5 Physicochemical properties of Coconut methyl ester against biodiesel standard.

Sl No.	Test	Test values	Standard Biodiesel
1	Acidity (inorganic)	Nil	0-0.5
2	Acidity (Total)	0.24 mg/KOH/g	0.2-0.5 mg/KOH/g
3	Ash	Nil	0
4	Carbon residue (Ramsbottom) on 10% residue	<0.1	0.3
5	Cetane Number	42.1	41-56
6	Cetane index	40.20	-
7	Cold filter plugging point	<-9	-4-+3 °C
8	Copper strip corrosion, 3Hrs@100°C	1b	1b
9	Density @ 15°C	884.3 kg/m^3	860 -900 Kg/m^3
10	Flash point (Abel/PMC)	96°C	93-120°C
11	Kinematic Viscosity @ 40°C	3.65 cST	3.5-5.0 cST
12	Lubricity, corrected wear scar diameter (WSD) @ 60°C	151 Microns	150-155 Microns
13	Oxidation Stability	14 g/m^3	12-16 g/m^3
14	Pour Point	-3 °C	-3 – 0 °C
15	Total contamination	13 mg/Kg	24 mg/Kg
16	Total sulphur	Nil	0.001 – 0.05%
17	Water Content	500mg/Kg	500 mg/ Kg

value, flashpoint, pour point and the cetane number were found different and unique compared to other PME. At the same time, the similarity observed between the properties of diesel and CME reflects the biofuel quality of CME. It is possible to interpret that the uniqueness noticed in the CME may be due to the higher percentage of short chain of fatty acids and lipid saturation, and other physicochemical properties of coconut oil.

From the quality analysis of Coconut Methyl Ester, a positive functional correlation was observed between coconut methyl ester and the performance of CME as fuel. As the first phase, CME was used as fuel in a diesel engine test tig of matador vehicle without any modification to the engine system or fuel lines. The engine started and achieved maximum rpm and was stable across various acceleratory inputs without any unusual sound or missing. The engine stopped when the ignition was switched off. The functional test of coconut methyl ester provided a positive sign for using CME as a fuel for road trials in a new diesel vehicle. Table 6 shows the technical specification of the new vehicle. The torque and the power of the vehicle using diesel as fuel is recorded as 16@ 3200 rpm and 38@ 2000 rpm. The successful part of any prospective biofuel is, whether an engine using the biofuel will perform similarly or better than an engine using normal gasoline based diesel. With respect to the similarity noticed in the functional feature of CME as a biofuel, as per the standards, the CME was used in a diesel engine of a new vehicle (TATA Ace Magic-diesel) for determining its technical feasibility. The torque and the power of the engine were determined using CME as a fuel in the new vehicle. It was reported that, performance of any fuel can be judged by power and torque output that it can generate. The test run was done on TATA Ace Magic-diesel vehicle on dynamometer for determining the power and torque as against the specifications of the manufacturer of the vehicle. The power and the torque of the CME as a fuel were found similar to the values as per the specifications. Figures 3a & b indicates the power and torque of CME as a biofuel. Under the Dynamometer, the CME provides a power of 16 bph at 3000 rpm and a torque of 38.5 nm at 2000 rpm as against manufacturer specification of 16 bhp at 3200 rpm and 38 nm torque at 2000 rpm. Thus the study clearly indicates that there is no overall marked difference in the performance of coconut methyl ester as biofuel in a diesel engine. Besides the similarity noticed in the power and torque of the engine between CME and diesel showing the fuel energy, the mileage of the vehicle using CME fuel showed a significant increase of 22.5 km/l from the 16 km/l recommended for diesel by the manufacturer, which indicates the thermal efficiency of the CME. Even though the overall fuel efficiency may vary from vehicle to vehicle, the higher mileage of CME than diesel supports

Table 6 Physicochemical properties of CME with other methyl esters of plant origin

Sl No:	Characteristic Properties	**CME as Biofuel**	*Jatropha* Methyl ester	*Karanja* methyl ester	Palm methyl ester	Cotton seed methyl ester	Sun flower Methyl ester	Soyabean methyl ester	Diesel
1	Density (gm/CC)	**0.8843**	0.868	0.860	0.9168	0.871	0.88	0.88	0.84
2	Kinematic Viscosity at 40°C (cST)	**3.65**	5.33	4.78	4.6	5.17	4.90	4.7	2.6
3	Acid Value (mg KOH/gm)	**0.24**	0.011	0.42	2.72	0.018	0.24	0.28	0.2
4	Pour Point	**-3°C**	-	6°C	-	-	-4°C	-2°C	-10°C
5	Flash Point	**96°C**	162°C	144°C	164°C	174°C	170°C	178°C	75°C
6	Cetane Number	**42.1**	50	41.7	62	55	58	45	45-55

the thermal efficiency of CME during the performance of the vehicle. Precisely the important technical advantages of using CME as fuel in diesel engines can be listed out as follows.

CME can be used straight away as fuel in any diesel engine. All that is required is a thorough cleaning of the fuel system including fuel lines and fresh fuel filters.

No modification is required in the engine components and in the fuel lines. CME need not be blended with any other fuel for use in diesel engines. Emission is negligible. All vital engine parameters like temperature, oil pressure, fuel consumption, power and torque are within the limits or slightly better than the specification of the vehicle manufacturer.

The results of the present study demonstrate a new trend in the field of renewable energy source and in the area of biofuel production. The distinct and unique features of the coconut oil and the CME compared to other vegetable oil esters were supported by the functional test of CME in diesel vehicle. Based on the standardized parameters of CME production and the functional properties of CME, the data has been filed for getting Indian patent. The functional effectiveness of CME as biofuel in diesel vehicle without any technical modification of the engine further demands more trial runs in diesel vehicles using CME under varied conditions and parameters for confirming the efficiency of CME. Plot plant trials for scale up the production of CME and more extensive functional runs using CME are warranted to establish the efficacy of CME in Combustion Ignition Engines (CIE) as a primary substitute of fuel energy source in near future. As a potential oleaginous crop with nutritional, therapeutic and industrial advantages, the commercial feasibility of CME as biofuel can be evaluated only through an integrated approach of CME production initiated from mature coconuts.

Table 7 Computerized pollution under control certificate using CME as fuel

Free Acceleration	K Value (1/m)	Actual RPM
T1	0.53	3500
T2	0.51	3500
T3	0.51	3640
T4	0.51	3750

(contd from page 7)

between male and female grafts is to be kept at 10:1. Pits of 60 X 60 X 60cm size may be taken and filled wit a mixture of FYM/compost and topsoil. Manuring at the rate of 20gN, 18g P2O5 and 50gK2o/year has to be done in the first year. Gradually the dose is to be increased so as to reach 500g N, 250g P2O5 and 1000g K2O/ tree/year by the 5th year. The fertilizers may be applied in the drip area of the tree and forked into the soil. The nutmeg tree grows to a height of 5-13m and sometimes as tall as 20m. It flowers at 5-8 years of age, full bearing reaches at 15-20 years and continues for 30 to 40 years or more. Flowering season is from June to August and the fruit takes six months to ripen. Fruits are to be harvested when they have split and the aril turns bright red in colour. The mace is dried in the sun for 10 – 15 days, till they become brittle and turn yellowish brown from the initial red colour. The nuts are dried till the kernel rattles within the shell. A tree produces 1500-2000 fruits per year which comes to 8 – 12 kg nuts. (100-250 nuts/kg) and 1.5 to 2kg mace. An average yield of 3 kg is obtained from a tree per year. An additional income of Rs1.20 lakh can be obtained from one acre coconut–clove system with the present market price of Rs.700/- per kg.

The above crops under coconut based farming system render enhanced employment opportunities, make available multiple farm produce and ensure ecological sustainability. The beneficial effects include improvement in soil fertility status, increased microbial activities, higher interception of sunlight, better micro-climate and reduced weed growth. Deleterious effects of surface run off and soil erosion will also be reduced in this system. The litters from the falling leaves and other plant parts have a salutary effect on the properties of soil through the degradation process and related activities undergoing in the soil. Experimental results from various coconut based cropping systems show that the high level of productivity could be sustained with lower level of fertilizer input which is one of the most costly input for farming. Coconut based integrated farming system with the above four money spinning cash crops as mixed crops not only provide additional income but also would help achieve higher productivity of coconut on a sustainable basis in future.