



Original Research Paper

A study of production and characterization of Manketti (*Ricinodendron rautonemii*) methyl ester and its blends as a potential biodiesel feedstock

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HIGHLIGHTS

- Production and characterization of Manketti methyl ester and its blends with diesel.
- At all engine speeds and compared to B0, B5 produced lower brake power by 1.18% and higher BSFC by 2.26%.
- B5 increased the CO and HC emissions by 32.27% and 37.5%, respectively, but decreased NO emission by 5.26% compared to the neat diesel.

GRAPHICAL ABSTRACT



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ABSTRACT

Globally, more than 350 oil-bearing crops are known as potential biodiesel feedstocks. This study reports on production and characterization of Manketti (*Ricinodendron rautonemii*) methyl ester and its blends with diesel. The effect of Manketti biodiesel (B5) on engine and emissions performance was also investigated. The cloud, pour and cold filter plugging points of the produced biodiesel were measured at 1, 3 and 5 °C, respectively. However, the kinematic viscosity of the biodiesel generated was found to be 8.34 mm²/s which was higher than the limit described by ASTM D6751 and EN 14214. This can be attributed to the high kinematic viscosity of the parent oil (132.75 mm²/s). Nevertheless, blending with diesel improved this attribute. Moreover, it is observed that at all engine speeds, B5 produced lower brake power (1.18%) and higher brake specific fuel consumption (2.26%) compared to B0 (neat diesel). B5 increased the CO and HC emissions by 32.27% and 37.5%, respectively, compared to B0. However, B0 produced 5.26% higher NO emissions than B5.

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Nomenclature

ASTM	American society for testing and materials
B0	(100% diesel and 0% biodiesel)
B5	(95% diesel and 5% biodiesel)
BP	Brake Power
BSFC	Brake specific fuel consumption
CCIO	Crude <i>Calophyllum inophyllum</i> oil
CCO	Crude coconut oil
CIME	<i>Calophyllum inophyllum</i> methyl ester
CMO	Crude Manketti oil
COME	Coconut oil methyl ester
CO	Carbon monoxide
CO ₂	Carbon dioxide
CPEO	Crude <i>Pangium edule</i> oil
GC	Gas chromatography
HC	Hydrocarbons
MME	Manketti methyl ester
NO	Nitrogen oxides
PEME	<i>Pangium edule</i> methyl ester
rpm	Revolution per minute

1. Introduction

The research on alternative fuels is currently gaining worldwide attention due to the increasing energy demands and depleting fossil reserves. Moreover, the increasing global warming and other environmental hazards have forced almost all countries to reduce their dependence on fossil fuels (Ramaraju and Kumar, 2011). Biodiesel (Greek, bio, life + diesel from Rudolf Diesel) is currently the most common alternative fuel being developed and used as a replacement for petroleum-based diesel. It can be defined as a mixture of mono-alkyl esters of long chain fatty acids (FA) derived from renewable lipids such as vegetable oils and animal fats when reacted with an alcohol (methanol or ethanol) in presence or absence of a catalyst (Demirbas, 2009; Atabani et al., 2012; Kafuku and Mbarawa, 2013). Biodiesel is biodegradable, non-toxic, renewable, and has low emissions of CO, SO₂, particulates and hydrocarbons (HC) as compared to conventional diesel (Kafuku and Mbarawa, 2013). The use of vegetable oils (edible and non-edible) plays an important role in biodiesel production. However, availability of these raw materials varies. This necessitates the search for new low-cost agricultural crops (Ibeto et al., 2012; Atabani et al., 2013c). Globally, there are more than 350 oil-bearing crops identified for biodiesel production (Atabani et al., 2012).

Currently one of the main concerns of biodiesel research area is to identify, characterize and perform engine performance analyses on biodiesels derived from many new feedstocks as well as their blends with diesel. For instance, the potential of *Stantonia chinensis*, Alperujo, Baobab (*Adansonia digitata* L.), Milkweed (*Calotropis gigantea*), *Raphanus sativus* (oilseed radish), *Syagrus romanzoffiana* and *fodder radish* as new sources for biodiesel production has been studied by researchers (de Andrade Ávilaa and Sodr , 2012; Chammoun et al., 2013; Moreira et al., 2013; Hern ndez et al., 2014; Modiba et al., 2014; Phoo et al., 2014; Wang et al., 2014). This indicates the importance of exploring and testing non-conventional biodiesel feedstocks. Manketti (*Ricinodendron rautonemii*) oil is one of the possible alternative oil crops for biodiesel production. Most previous reports on this plant have been focused on its use in the herbal cosmetic industry (Kafuku and Mbarawa, 2013), and only recently Manketti was explored for biodiesel production (Ruttoo and Enweremadu, 2011; Kafuku and Mbarawa, 2013).

Manketti (*Ricinodendron rautonemii*) belongs to the family *Euphorbiaceae*, locally known as mongongo and feather weight tree. It is a large (7 to 20 m high and 60 cm in diameter), and deciduous tree which grows in the wild on sandy soils between the latitudes of 15 and 21 °S in many parts of Botswana, South Africa, Zambia, Angola, Namibia and up to Mozambique. It is commonly used as a street tree in Victoria Falls, where the Zambesi river falls off the arid southern Zambian plains at North western Zimbabwe (Naturalhub, 2013; Nerd et al., 2013). Some countries such as Mauritania, Guinea, Liberia, Ethiopia, Sudan, Chad, Mali, Niger and Uganda are also suitable for the cultivation of Manketti tree (Beau, 2003)(Figure1). Moreover, the tree was introduced to Australia in the late 1980's (Naturalhub, 2013).

This tree prefers hot and dry climates with low amounts of rain (Beau, 2003). Manketti is considered as an important source of food to many rural communities in southern Africa as well (European Commission, 1998).

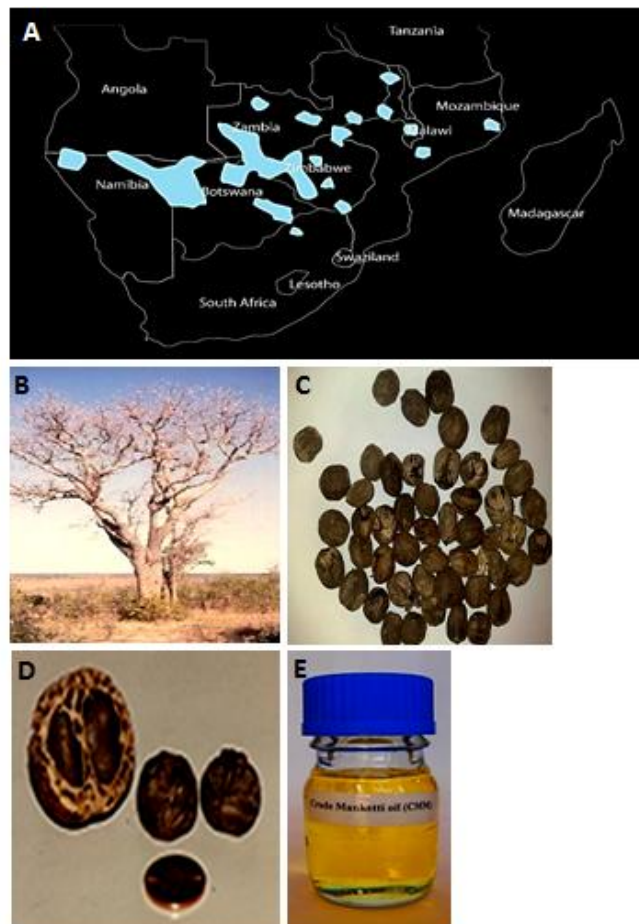


Fig.1. Distribution map, tree, fruit, seeds and crude oil of Manketti (*Ricinodendron rautonemii*) (Beau, 2003; Savaneskin, 2013)

It is worth mentioning that Manketti is considered a rapid growing tree and has been designated a protected tree in Namibia since 1952. The tree has a large, straight trunk with stubby and contorted branches and a large spreading crown (Beau, 2003). The branches are stubby and contorted. The trees take around 25 years to commence fruiting. The tree flowers depending on local climatic variations such as temperature and rainfalls, which is around October to December. The small whitish-yellow flowers become a somewhat oval, vaguely plum-like fruit of about 3.5 cm long and 2.5 cm wide. The young fruit is at first covered in fine small hairs on its thin but tough outer skin; under the skin is a narrow spongy layer, at first green, then turning whitish brown with maturity (Naturalhub, 2013). Fruits are egg-shaped, velvety and contain a thin layer of edible flesh around a thick, hard pitted nutshell that encloses the edible oil-bearing kernel (Kafuku and Mbarawa, 2013). The nuts yield a high quality yellow transparent edible oil of which about 60% is used for food and cosmetics. The protein content of the nut is nearly 30%. The shell of the nuts are used as fuel while the leaves are used as fodder (European Commission, 1998). Recently, the tree has been explored for biodiesel production (Ruttoo and Enweremadu, 2011). Figure 1 shows the distribution map, tree, fruit, seeds and crude oil of Manketti (*R. rautonemii*) (Beau, 2003; Savaneskin, 2013).

The purpose of this work was to produce biodiesel from Manketti (*R. rautonemii*) oil using alkaline KOH catalyst followed by a detailed study of physical and chemical properties of the produced biodiesel (MME) and its blends with diesel. The important fuel properties such as density, kinematic viscosity, oxidation stability, viscosity index, calorific value, as well as cold flow properties i.e. cloud point, pour point and cold filter plugging point were measured and compared with ASTM D6751 and EN 14214 standards. Moreover, the current study aimed to investigate the effect of Manketti biodiesel blends (B5) on engine and emissions performance. The success of this study could yield promising and massive new raw material for biodiesel production on a large scale.

2. Material and method

2.1. Materials and chemicals

Crude Manketti oil (CMO) was supplied by Universiti Sains Malaysia (USM), Malaysia, through a personal communication. Reagent grade methanol, potassium hydroxide, sodium sulphate anhydrous and qualitative filter paper (Filtres Fioroni, France) of 150 mm size were used as received.

2.2. Biodiesel production (Alkaline-catalysed Transesterification process)

In this study, a small scale laboratory reactor consisting of 1L batch reactor (Brand: Favorit), condenser to recover methanol, overhead stirrer (IKA EUROSTAR digital), water bath (WiseCircu® Fuzzy Control System), thermometer and sampling outlet was used to produce biodiesel from CMO. Figure 2 shows the adopted methodology to transesterify CMO to obtain MME. It can be seen that a single step of Alkaline-catalysed transesterification process was adopted as the FFA% of CMO was 1.04% (Table 3) (Atabani et al., 2012). The yield of biodiesel was measured at >90%.

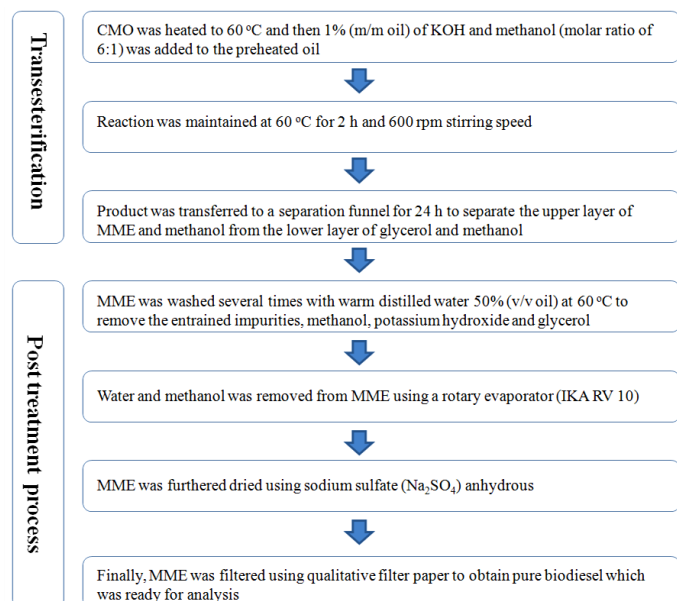


Fig.2. Flow chart of transesterification process of CMO to obtain MME.

2.3. Determination of fatty acid compositions of MME using GC

To determine the FA compositions of MME, a biodiesel sample (1 μ L) was injected into a gas chromatography (Shidmadzu, GC-2010A series) equipped with a flame ionization detector and a BPX70 capillary column of 30 m \times 0.25 μ m \times 0.32 mm (Column head pressure: 56.9 kPa). An initial temperature of 140 $^{\circ}$ C was maintained for 2 min, which was then increased at 8 $^{\circ}$ C per min to 165 $^{\circ}$ C, 3 $^{\circ}$ C per min to reach 192 $^{\circ}$ C and finally 8 $^{\circ}$ C per min to reach 220 $^{\circ}$ C. The column was maintained at the final temperature for

another 5 min. The oven, injector and the detector ports were set at 140, 240 and 260 $^{\circ}$ C, respectively. The carrier gas was helium with the column flow rate at 1.10 mL/min at a 50:1 split ratio (Linear velocity 24.2 cm/sec).

2.4. Analysis of fuel properties

In this study, the physical and chemical properties of CMO, MME and Manketti-diesel blends (0-20% by volume) were determined. Moreover, Table 1 shows a summary of the equipment and test methods used in this study to analyse properties according to the ASTM D 6751 standard.

Table 1.
Equipment list.

Property	Equipment	ASTM D6751
Kinematic viscosity	SVM 3000 ^a	ASTM D7042/D445
Flash Point	Pensky-martens flash point-automatic NPM440 ^b	D 93
Oxidation stability	873 Rancimat ^c	D 675
Cloud & Pour point	Cloud and Pour point tester-automatic NTE450 ^b	D 2500 & D 97
CFPP	Cold filter plugging point-automatic NTL450 ^b	D 6371
Density	SVM 3000 ^a	D 1298
Dynamic viscosity	SVM 3000 ^a	N/S*
Viscosity Index (VI)	SVM 3000 ^a	N/S
Caloric value	C2000 basic calorimeter ^d	N/S
Refractive Index	RM 40 Refractometer ^e	N/S
Transmission	Spekol 1500 ^f	N/S
Absorbance	Spekol 1500 ^f	N/S

Manufacturer: a: Anton Paar (UK), b: Normalab (France), c: Metrohm (Switzerland), d: IKA (UK), e: Mettler Toledo (Switzerland) and, f: Analytical Jena (Germany).
N/S = not specified in ASTM D6751 test methods.

2.5. Engine tests

A Mitsubishi Pajero (model 4D56T) multi-cylinder diesel engine was used. The experimental investigation was carried out using diesel fuel (B0) and B5 (95% diesel and 5% Manketti methyl esters). Firstly, the engine was run with diesel for 15 min to warm up before running with B5. The engine was run by diesel before the engine was shut down. This was a very important procedure to ensure that the engine was free from biodiesel blends before proceeding to the next test. The engine was run at various speeds ranging from 1000 to 4000 rpm at full load condition. Engine test conditions were monitored by REO-DCA controller connected through a desktop computer to the engine test bed. A BOSCH exhaust gas analyser (model BEA-350) was used to measure the exhaust emission i.e. NO, HC, CO₂ and CO. In order to get the average values, all tests were repeated three times. Figure 3 shows the test rig of the engine. The details of the engine specification are tabulated as Table 2.



Fig.3. Engine test bed set-up.

Table 2.
Detailed specification of the engine.

Model	Mitsubishi Pajero (4D56T)	
Engine type	4 cylinder inline (Natural aspiration)	
Displacement	L	2.5
Cylinder bore x stroke	mm	91.1 x 95
Valve mechanism	Single overhead camshaft	
Rocker arm	Roller flow type	
Compression ratio	21:1	
Maximum engine speed	rpm	4200
Maximum power	kW	55
Fuel system	Distributor type injection pump	
Lubrication System	Pressure feed , full flow filtration	
Oil pump	Trochoid type	
Combustion chamber	Swirl type	
Cooling system	Radiator cooling	
Water pump type	Centrifugal impeller type	
A/F ratio	26	

2.6. Error analysis

Errors and uncertainties in the experiments could be associated with instrument selection, condition, calibration, environment, observation, reading and test planning. Uncertainty analysis was needed to prove the accuracy of the experiments. The accuracy of the various parameters were as follows: BP ± 0.07 kW, BSFC ± 5 g/kWh, CO ± 0.001 vol.%, HC ± 1 ppm, NO ± 1 ppm and CO₂ ± 0.01 vol.%. An uncertainty analysis was performed using the following formula described by Shahabuddin et al. (2012a) (Eq. 1):

$$\text{Total uncertainty\%} = \text{Square root of } \{(\text{uncertainty of BP})^2 + (\text{uncertainty of BSFC})^2 + (\text{uncertainty of CO})^2 + (\text{HC})^2 + (\text{uncertainty of NO})^2 + (\text{uncertainty of CO}_2)^2\}$$

Eq. 1

For example, the total uncertainty% of this experiment while using B0 was calculated at 2.27% as presented below:

$$\text{Total uncertainty\%} = \text{square root of } \{(0.18)^2 + (1.44)^2 + (0.00012)^2 + (0.08)^2 + (0.38)^2 + (0.123)^2\} = 2.27\%$$

3. Results and discussion

3.1. Properties of CMO

Table 3 shows the main properties of CMO in comparison with those of the crude *Pangium edule* oil (CPEO), crude *Calophyllum inophyllum* oil (CCIO) and crude coconut oil (CCO). As seen, CMO was shown to have a very high kinematic viscosity of 132.65 mm²/s compared to 55.677 mm²/s for CCIO, 27.64 mm²/s for CCO and 27.175 mm²/s for CPEO. The acid value of CMO was found favourable for biodiesel production, at only 2.08 mg KOH/g oil compared to 41.74 mg KOH/g oil for CCIO and 19.62 mg KOH/g oil for CPEO. The oxidation stability of CME was only 0.16 h compared to 0.23 h for CCIO, and 6.93 h for CCO.

Table 3.
Properties of CMO in comparison with those of CPEO, CCIO and CCO.

Property	CMO	CCIO ^a	CCO ^a	CPEO ^b
Kinematic viscosity at 40 °C (mm ² /s)	132.75	55.68	27.64	27.18
Kinematic viscosity at 100 °C (mm ² /s)	20.62	9.56	5.94	6.64
Dynamic viscosity at 40 °C (mpa.s)	122.81	51.31	25.12	24.39
Viscosity Index (VI)	179.9	165.4	168.5	216.2
Flash Point (°C)	192.5	236.5	264.5	N/D
Cloud point (°C)	N/D	N/D	N/D	-6
Pour point (°C)	-9	N/D	N/D	-10
Density at 40 °C (kg/m ³)	925.1	N/D	908.9	897.6
Density at 15 °C (kg/m ³)	943.0	951.0	N/D	N/D
Specific gravity at 15 °C	0.9443	0.952	N/D	N/D
Acid Value (mg KOH/g oil)	2.08	41.74	N/D	19.62
Free fatty acid (FFA)	1.04	N/D	N/D	N/D
Caloric value (kJ/kg)	38,682	38,511	37,806	39,523
Oxidation stability (h at 110 °C)	0.16	0.23	6.93	0.08

Refractive Index	1.487	1.4784	1.4545	1.4683
Transmission (%T)	89.3	34.7	91.2	86.1
Absorbance (Abs)	0.049	0.46	0.04	0.064

^a Atabani et al., 2013b^b Atabani et al., 2014

3.2. Fatty acid compositions of MME

Table 4 shows the results of FA compositions analysis of MME in comparison with the other biodiesel samples i.e. *Pangium edule* methyl ester (PEME), *Calophyllum inophyllum* methyl ester (CIME) and coconut oil methyl ester (COME). Based on the GC analysis, it was found that MME contained 18.3% saturated FAs and 81.7% unsaturated FAs compared to the values reported previously i.e. 17.2% saturated FAs and 82.9% unsaturated FAs by Kafuku and Mbarawa (2013) and 27.4% saturated FAs and 72.8% unsaturated FAs by Ruttoa and Enweremadu (2011). It can be concluded that MME, PEME and CIME are mainly dominated by unsaturated FAs while COME is dominated by saturated FAs.

Table 4.
Fatty acid composition of MME and comparison with CIME, COME and PEME

Fatty acid composition (as % methyl esters)	MME	MME ^a	MME ^b	CIME ^c	COME ^c	PEME ^d
C8:0	N/D	N/D	N/D	N/D	8.2	N/D
C10:0	N/D	N/D	N/D	N/D	6.6	N/D
C12:0	N/D	N/D	N/D	N/D	48.3	N/D
C14:0	N/D	N/D	N/D	N/D	16.4	0.1
C16:0	10.5	9.8	15.4	14.4	9.3	8.3
C16:1	N/D	N/D	1.6	0.3	N/D	0.1
C18:0	7.8	7.2	11.5	15.2	2.4	4.0
C18:1	18.2	16.4	23.4	41.9	7	45.2
C18:2	43.9	43.4	45.1	26.6	1.7	39.3
C18:3	19.3	N/D	1.7	0.2	N/D	2.5
C20:0	N/D	0.2	0.5	0.8	N/D	0.2
C20:1	0.3	0.3	1.0	0.2	N/D	0.3
C20:2	N/D	0.2	N/D	N/D	N/D	N/D
C20:5	N/D	22.6	N/D	N/D	N/D	N/D
C22:1	N/D	N/D	N/D	0.5	N/D	N/D
Total Saturated FA (%)	18.3	17.2	27.4	30.4	91.3	12.6
Total Monounsaturated FA (%)	18.5	16.7	26.0	42.8	7	45.6
Total Polyunsaturated FA(%)	63.2	66.2	46.8	26.8	1.7	41.8

N/D = Not detected ^a Kafuku and Mbarawa, 2013 ^b Ruttoa and Enweremadu, 2011
^c Atabani et al., 2013a ^d Atabani et al., 2014

3.3. Physico-chemical properties of MME

Table 5 shows the physico-chemical properties of the produced MME in comparison with those of the CIME, COME and PEME (Ruttoa and Enweremadu, 2011; Atabani et al., 2013a; Kafuku and Mbarawa, 2013; Atabani et al., 2014). Having considered the data presented in Tables 3 and 4 for CMO and MME, it can be seen that the kinematic viscosity was successfully reduced from 132.75 to 8.03425 mm²/s, refractive index from 1.487 to 1.4698, and density at 40 °C from 925.1 to 887.8 kg/m³. However, the kinematic viscosity of MME was still higher than the limit specified by both the ASTM D 6751 and EN 14214 standards. This might be attributed to the high kinematic viscosity of the parent oil (132.75 mm²/s). The same was observed by Sanford et al. (2009) for castor methyl ester as the kinematic viscosity of castor methyl ester was 15.25 mm²/s compared to 251.2 mm²/s for the crude oil.

The cloud, pour and cold filter plugging points of MME were measured at 1, 3 and 5 °C which were considerably lower than the values previously reported for CIME i.e. 10, 11 and 9 °C, respectively (Atabani et al., 2013a), but were higher than those of COME i.e. 0, -4 and -4 °C (Atabani et al., 2013a) and PEME i.e. -6, -4 and -8 °C (Atabani et al., 2014). Moreover, the oxidation stability of MME (0.52 h) also failed to meet both the ASTM D6751 and EN 14214 standards of 3 and 6 h, respectively. Therefore, it is necessary to supplement the MME with conventional antioxidants such as propyl gallate (PrG) to make up for its low oxidation stability (Hajari et al., 2014).

Table 5.
Physico-chemical properties of MME in comparison with those of CIME, COME, and PEME.

Property	MME	CIME ^a	COME ^a	PEME ^b	ASTM D6751	EN 14214
Kinematic viscosity at 40 °C (mm ² /s)	8.34	5.75	4.06	5.23	1.9-6.0	3.5-5.0
Kinematic viscosity at 100 °C (mm ² /s)	2.67	2.03	1.57	1.97	N/A	N/A
Dynamic viscosity at 40 °C (mpa.s)	7.41	5.04	3.52	4.56	N/A	N/A
Viscosity Index (VI)	176	174.9	180.7	211.8	N/A	N/A
CP (°C)	1	10	0	-6	Report	Report
PP (°C)	3	11	-4	-4	Report	Report
CFPP (°C)	5	9	-4	-8	Report	Report
Density at 40 °C (kg/m ³)	887.8	877.4	866.4	871.0	N/A	N/A
Density at 15 °C (kg/m ³)	906.0	N/D	N/D	890.0	N/A	860-900
Specific gravity at 15 °C	0.9068	N/D	N/D	0.8910	N/A	N/A
Caloric value (kJ/kg)	39,070	39,273	38,006	39,625	N/A	N/A
Refractive Index	1.4698	N/D	N/D	1.4551	N/A	N/A
Transmission (%T)	71.5	N/D	N/D	69.2	N/A	N/A
Absorbance (Abs)	0.146	N/D	N/D	0.160	N/A	N/A
Oxidation stability (h at 110 °C)	0.52	0.09	5.12	0.57	3h (min)	6h (min)

^a Atabani et al., 2013a ^b Atabani et al., 2014

3.4. Physico-chemical properties of MME and its blends with diesel

Table 6 shows the physico-chemical properties of MME-diesel blends of 5%, 10%, 15% and 20%, as well as the ASTM D975 specifications for diesel fuel and blends up to 5% by volume (B5) and ASTM 7467 for blends (B6-B20). Considerable improvements in kinematic viscosity, calorific value and density of MME when blended with diesel were observed (Table 6). However, viscosity index and flash point values dropped as the percentage of diesel increased in the blends.

Table 6.
Physico-chemical properties of diesel and MME-diesel blends (5-20%).

Property	Diesel	MME (5%)	ASTM D975	MME (10%)	MME (15%)	MME (20%)	ASTM D7467
Calorific value (kJ/kg)	45,272	44,888	N/A	44,614	44,352	43,962	N/A
CP (°C)	8	6	Report	7	6	7	Report
PP (°C)	0	2	Report	4	1	1	Report
CFPP (°C)	8	8	Report	8	8	7	Report
K Viscosity at 40 °C (mm ² /s)	3.23	3.31	1.9-4.1	3.47	3.62	3.79	1.9-4.1
D Viscosity at 40 °C (mm ² /s)	2.70	2.78	N/A	2.92	3.05	3.21	N/A
Density at 40 °C (kg/m ³)	827.2	838.7	N/A	841.2	843.5	845.8	N/A
K Viscosity at 100 °C (mm ² /s)	1.24	1.31	N/A	1.36	1.40	1.46	N/A
Viscosity Index	90	138.7	N/A	140	140.8	143.5	N/A
Flash point (°C)	68.5	73.5	52 (min)	74.5	74.5	75.5	52 (min)

Figure 4 presents the effects of blending MME and diesel on kinematic viscosity, density, viscosity index, and calorific value.

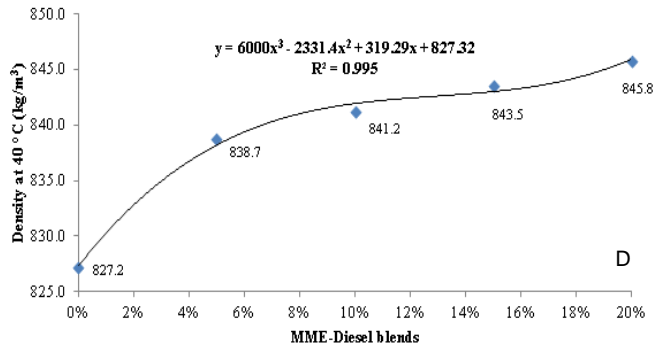
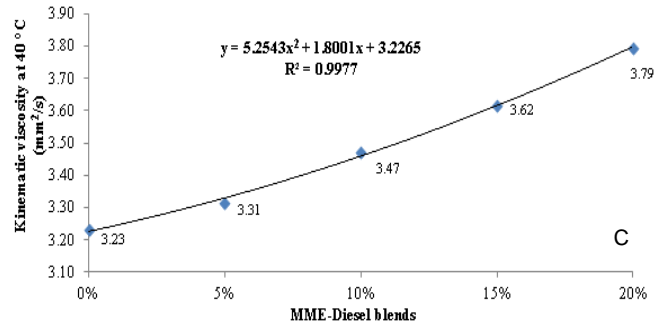
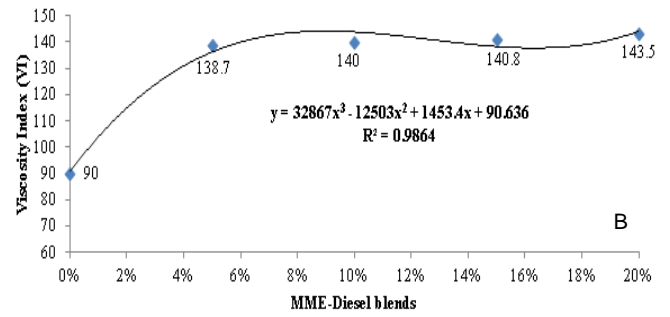
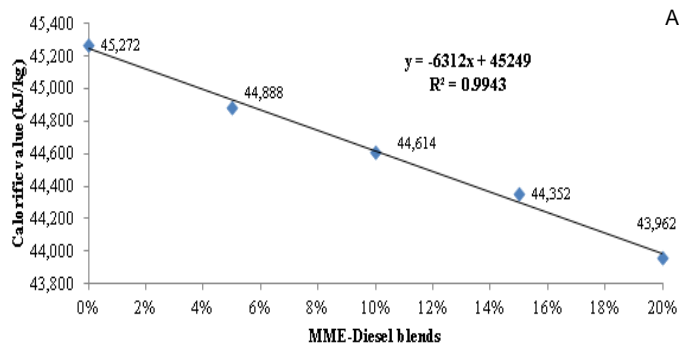


Fig.4. Effects of blending MME and diesel on, A) calorific value (kJ/kg), B) viscosity index (VI), C) kinematic viscosity at 40 °C (mm²/s) and, D) density at 40 °C (kg/m³).

3.5. Engine performance

In this study, engine performance was evaluated in terms of the brake power (BP) and brake specific fuel consumption (BSFC). The details of this evaluation are discussed as follows:

3.5.1. Brake Power (BP)

Figure 5 shows the BP output of diesel (B0) and Manketti biodiesel blend (B5) at different engine speeds. For all tested fuels, the BP increased steadily with the engine speed. At all the test speeds, the average BP values of the B0 and B5 fuels were 39.85 and 39.38 kW, respectively. Compared to diesel fuel, the B5 fuel produced lower BP by 1.18% due to its lower calorific value and higher viscosity (Table 6), which influenced the combustion characteristics. Fuels with high kinematic viscosity tend to form larger droplets during injection which can consequently lead to poor combustion. Therefore, the uneven combustion characteristics of the produced biodiesel fuel reduced the engine BP herein (Muralidharan et al., 2011).

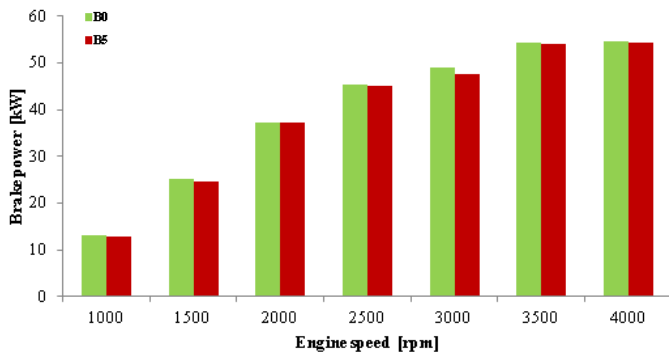


Fig.5. Variation of brake power at different engine speeds and full load condition.

3.5.2. Brake Specific Fuel Consumption (BSFC)

Figure 6 illustrates the variation of the BSFC values for the tested fuels at different engine speeds. It can be observed that the biodiesel-blended fuel (B5) resulted in higher BSFC values than the neat diesel fuel (B0). This observation was consistent with the literature (Chauhan et al., 2012; Shahabuddin et al., 2012b; Wang et al., 2013). Factors such as the volumetric fuel injection system, density, kinematic viscosity and the lower heating value could affect the BSFC of diesel engines (Qi et al., 2010). At all speeds, the average BSFCs for the B0 and B5 were 345.18 and 352.98 g/kWh, respectively. Compared to the neat diesel fuel, the BSFC of B5 was 2.26% higher. This could be ascribed to the higher density and kinematic viscosity and lower energy content of the B5 compared to diesel (Mofijur et al., 2013). Fuel is injected into the engine on volume basis.

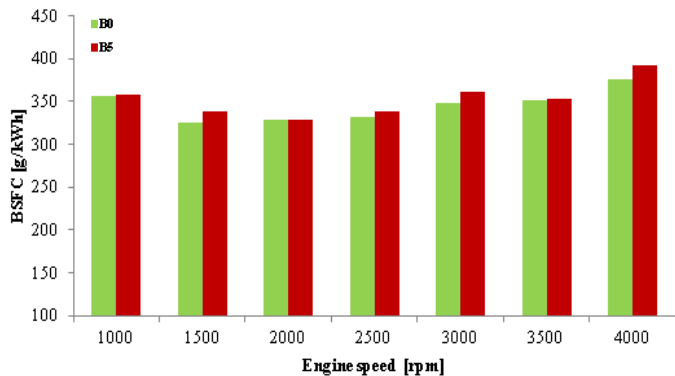


Fig.6. Variation of brake specific fuel consumption at different engine speeds and full load condition.

3.5.3. Emissions analysis

In general, factors such as the atomization, volatility, air-fuel ratio, engine speed, injection timing and pressure and fuel type influence CO emissions (Gumus et al., 2012). The variation of CO and HC emissions with diesel and the MME-diesel blend are shown in Figure 7 and 8, respectively. At all speeds, the average CO emissions for the B0 and B5 were 0.12 and 0.15 vol%, and HC emissions for the B0 and B5 were 4 and 5 ppm, respectively. Over the entire range of engine speeds, the B5 increased the CO emissions by 32.27% and HC emission by 37.5% relative to B0. This result was in line with those previously reported elsewhere (Banapurmath et al., 2008; Sahoo et al., 2009). This increase in CO and HC emissions could be attributed to the poor atomization, lower volatility of the investigated biodiesel fuel. In fact, the high kinematic viscosity of the biodiesel led to a less homogenous mixture.

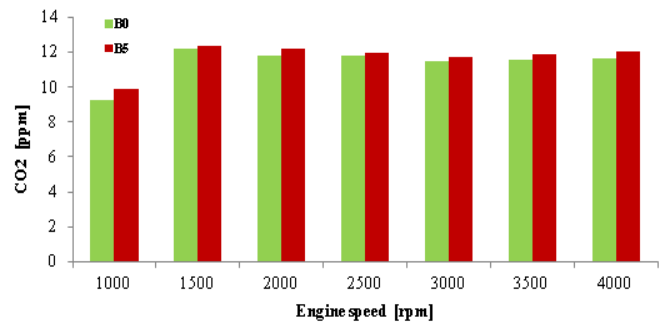


Fig.7. Variation of CO emissions at different engine speeds and full load condition.

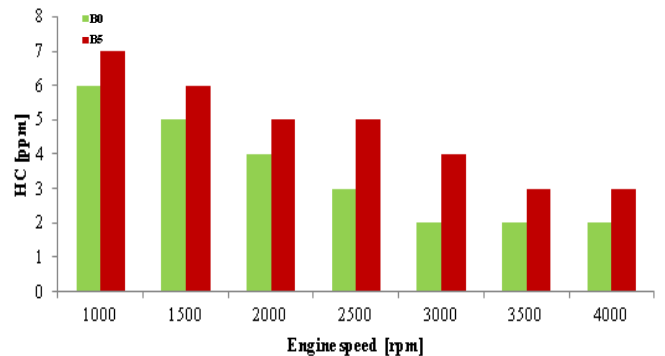


Fig.8. Variation of HC emissions with respect to engine speed at full load condition.

The variation of the NO emissions for diesel and biodiesel-blended fuel is presented in Figure 9.

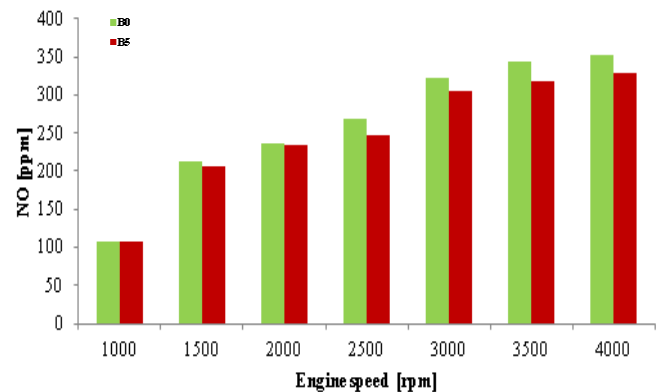


Fig.9. Variation of NO emissions at different engine speeds and full load condition.

The NO values were measured higher for diesel than biodiesel-blend fuel. Similar observations were reported by other researchers (Utlu et al., 2008; Qi et al., 2009). In general, the fuel spray properties depend on droplet size, droplet momentum, degree of mixing with air and penetration rate, evaporation rate, and radiant heat transfer rate. A change in any of those properties may change the NOx production. On an average, the B0 generated 5.26% higher NO emissions than B5 fuel over the entire range of speeds. The reason may be less reaction time and temperature in case of biodiesel blend.

The variation of CO₂ emissions for the fuel samples at various speeds are shown in Figure 10. B0 and B5 resulted in almost similar amount of CO₂ emissions at 11.397 and 11.71ppm, respectively. However, the CO₂ emitted through the combustion of biofuel e.g. biodiesel is of biological origin (plant or animal) and therefore, does not increase the atmospheric CO₂ carbon level as is the case for fossil fuels (Ramadhas et al., 2005).

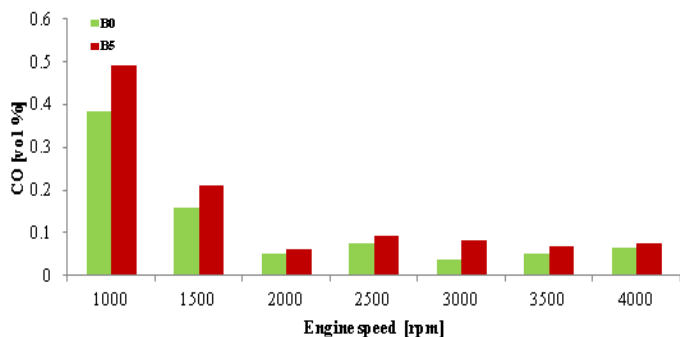


Fig.10. Variation of CO₂ emissions at different engine speeds and full load condition.

4. Conclusion

In this study, MME was produced and tested for various properties. MME was found to have a good potential to be used as a future energy source due to its significant calorific value and comparatively better cold flow properties than some other methyl esters. Blending of MME with diesel resulted in significant improvements in the kinematic viscosity, calorific value and density of MME. Though the B5 blend produced lower BP, higher BSFC, higher CO and HC emission but it significantly reduced NO emission compared to diesel fuel.

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