**Proceedings of the**
**International Conference on Mechanical Engineering and Renewable Energy 2013**
**(ICMERE2013) 1 - 3 May 2014, Chittagong, Bangladesh**

**ICMERE2013-PI-059**

# BIODIESEL PRODUCTION FROM *APHANAMIXIS POLYSTACHYA* (PITRAJ OIL) AND ITS COMPARATIVE ANALYSIS OF FUEL PROPERTIES WITH DIESEL AS AN ALTERNATIVE FUEL IN DIESEL ENGINE

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***Abstract-****This paper aims to study the opportunity of biodiesel production from Aphanamixis polystachya oil. The study shows the physical and chemical properties of Aphanamixis polystachya methyl ester and its blends (APME$_5$, APME$_{10}$, APME$_{20}$, APME$_{30}$, APME$_{40}$, APME$_{60}$ and APME$_{80}$). This is followed by evaluating the performance of APME$_5$ and APME$_{10}$ in a multi-cylinder diesel engine. It has been found that the properties of biodiesel and their blends are comparable with ASTM D6751 and ASTM D7467standards respectively. Over the entire range of speed, it hasbeen found that APME$_5$ and APME$_{10}$ give average reduction in torque, brake power (BP) and increased brake specific fuel consumption (BSFC) compared to diesel. In case of engine emission, fuel blends of APME give an average reduction in carbon monoxide (CO) and hydrocarbon (HC) emissions. However, APME blends emit higher nitrous oxides (NO) emission compared to diesel. In conclusion, it is concluded that B$_5$ and B$_{10}$ can be used as a diesel fuel substitute with no engine modifications*.

**Keywords:** Aphanamixis polystachya, biodiesel production, blending, Engine performance, Emissions.

## 1. INTRODUCTION

Nowadays, researchers around the world are very interested to develop alternative, sustainable and clean renewable energy fuels because of the increasing petroleum fuel price, expected depletion of fossil fuels and their increasing threat to the environment from engine exhaust emissions. As a renewable energy source, biodiesel has achieved great attraction due to its potentiality of emitting less greenhouse gas emission; reducing the dependency on imported fossil fuels and fulfilling the global energy demand [1-3]. Biodiesel has some important benefits such as non-explosive, biodegradable, has a relatively high flash point, non-flammable, renewable, inherent lubricity, non-toxic and environment friendly. Moreover, it can be blended with diesel fuel at any proportions, can be used in a CI (compression ignition) engine with no modification, does not contain any harmful substances and produce less harmful emissions to the environment than diesel fuel [4-7]. However, the use of edible vegetable oils for biodiesel production have given raise to debate of ‘food versus fuel’ and have also resulted in increase of food price in the recent years. Therefore, non-edible oils such as Jatropha (*Jatropha curcas*), Polanga (*Calophylluminophyllum)* and *Moringa oleifera* have generated a great attention globally [7-12].

This paper reports for the potential of *Aphanamixis polystachya* as a promising non-edible biodiesel feedstockwith vast information. Biodiesel was produced using esterification followed by transesterification process. The study firstly presents the results of physical and chemical properties of *Aphanamixis polystachya* methyl ester together with their blends such as kinematic viscosity, viscosity index, density, flash point, cloud point, pour point, cold filter plugging point and oxidation stability. Secondly, the blends of 5% and 10% by volume havebeen tested in a multi-cylinder Mitsubishi Pajero diesel engine and compared with base diesel fuel. The outcome of this study is expected to identify this feedstock as a potential non-edible biodiesel feedstock.

## 2. BOTANICAL DESCRIPTION OF APHANAMIXIS POLYSTACHYA

*Aphanamixis polystachya*is commonly known as Pithraj. *Aphanamixis polystachya* is a tall tree about 20-30 m and it belongs to *Meliaceae* family. The climatic and soil condition of Bangladesh is suitable for the production of this plant [13]. Its leaves are odd-or even-pinnate, 30-60 cm long, with 9-21 leaflets. Flowers are 6-7 mm in diameter, with 3 bracteoles. The flowers of this tree are generally seen during May to September [14]. This oil is non-edible and can be used as biodiesel and lighting [15]. Fig. 1 shows pictures of *Aphanamixis polystachya* tree, fruit and dried seeds.

**Fig. 1***Aphanamixis polystachya* tree, fruit and dried seeds

## 3. MATERIALS AND METHODS

### 3.1. Materials and Chemicals

The crude oil of *Aphanamixis polystachya* (CAPO) was purchased from Bangladesh. All other chemicals, reagents and accessories required for biodiesel production and engine performance were purchased from local market in Malaysia.

### 3.2. Production of *Aphanamixis Polystachya* Methyl Ester

The high acid value of crude *Aphanamixis polystachya* oil (CAPO) of 26.1 mgKOH/goil prevents the use of single step alkaline-transesterification process. Therefore, a two-step process of acid-base catalyst was used to produce biodiesel. In the first stage, esterification process was used to reduce the high acidity of the crude oil. While in the second stage, transesterification process was used to convert the esterified oil to methyl ester. The obtained biodiesel from CAPO is shown in **Fig. 2**.


**Fig. 2**The obtain biodiesel from CAPO

### 3.3. Biodiesel-Diesel Blending

*Aphanamixis polystachya* methyl ester (APME) was blended with diesel at 5%, 10%, 20%, 30%, 40%, 60% and 80% by volume using a magnetic stirrer (model: IKA® C-MAG HS 7) at 2000 rpm for 30 minutes and shaker (model: IKA® KS 130 basic) at 400 rpm for 30 minutes.

### 3.4. Engine Performance and Emissions Tests

The engine test has been conducted using Mitsubishi Pajero (model 4D56T) multi-cylinder diesel engine was used. The specifications of the engine are shown inTable 1.The emissions value of NO, HC and CO, $CO_2$ were measured using BOSCH exhaust gas analyzer (model BEA-350).

**Table 1**Detailed technical specification of the tested engine

| Parameter | Specification |
|---|---|
| **Model** | Four cylinder inline diesel engine |
| **Type** | Four stroke |
| **Displacement (L)** | 2.5 |
| **Cylinder bore x stroke (mm)** | 92x96 |
| **Compression ratio** | 21:1 |
| **Maximum engine speed (rpm)** | 4500 |
| **Maximum power (kW)** | 55 at 4200 rpm speed |
| **Fuel system** | Distribution type jet pump |
| **Lubrication system** | Pressure feed |
| **Combustion chamber** | Swirl type |
| **Cooling system** | Radiator cooling |

## 4. RESULTS AND DISCUSSION

### 4.1. Characterization and Fatty Acid Composition of Crude Aphanamixis Polystachya Oil

Table 2 shows the physico-chemical properties of *Aphanamixis polystachya* oil. In this table, a comparison with other crude oils properties such as *Jatropha curcas* (CJCO) and *Calophyllum inophyllum* (CCIO) was conducted.

Table 2 The physico-chemical properties of *Aphanamixis polystachya* oil

| Property | CAPO | CJCO | CCIO |
|---|---|---|---|
| **Kinematic viscosity ($mm^2/s$) at 40 °C** | 35.093 | 48.091 | 55.677 |
| **Kinematic viscosity ($mm^2/s$) at 100 °C** | 7.2547 | 9.1039 | 9.5608 |
| **Dynamic viscosity (mpa.s) at 40 °C** | 32.159 | 43.543 | 51.311 |
| **Viscosity Index** | 177.9 | 174.10 | 165.4 |
| **Cloud Point (°C)** | 5 | - | - |
| **Pour Point (°C)** | 4 | - | - |

| | | | |
|---|---|---|---|
| **Density (kg/m³) at 40 °C** | 916.4 | - | - |
| **Density (kg/m³) at 15 °C** | 934 | 915 | 951 |
| **Calorific value (kJ/kg)** | 38,729 | 38,961 | 38,511 |
| **Oxidation stability (h) at 110 °C** | 0.09 | 0.32 | 0.23 |
| **Acid value (mgKOH/goil)** | 26.7 | 17.63 | 41.74 |
| **Refractive Index** | 1.4789 | 1.4652 | 1.4784 |
| **Transmission (%)** | 61.6 | 61.8 | 34.7 |
| **Absorbance (Abs)** | 0.209 | 0.209 | 0.46 |

The results of FAC of APME showed that APME is mainly dominated by Oleic acid (18.3%), Linoleic acid (26.7%) andLinolenic acid (23.3%). The saturated fatty acid for APME is 30.7%. In general, the results of APME show a comparable trend of CIME and JCME. Therefore, it can be understood that non-edible biodiesel feedstock's exhibit the similar fatty acid composition.

### 4.2. Characterization of *Aphanamixis Polystachya* Methyl Ester

The important physico-chemical properties of APME were studied and compared with ASTM D6751 standard specification. The detailed physico-chemical properties of APME are shown in Table 3.

Table 3The detailed physico-chemical properties of APME

| Property | APME | ASTM D6751 | DIN 14214 |
|---|---|---|---|
| **Kinematic viscosity (mm²/s) at 40 °C** | 4.7177 | 1.9-6.0 | 3.5-5.0 |
| **Kinematic viscosity (mm²/s) at 100 °C** | 1.8239 | N/A | N/A |
| **Dynamic viscosity(mpa.s) at 40 °C** | 4.1210 | N/A | N/A |
| **Viscosity Index (VI)** | 220.7 | N/A | N/A |
| **Cloud Point (°C)** | 8 | Report | Report |
| **Pour Point (°C)** | 8 | Report | Report |
| **Cold filter plugging point(CFPP)** | 5 | Report | Report |
| **Density(kg/m³) at 40 °C** | 873.5 | - | - |
| **Density(kg/m³) at 15 °C** | 893 | 880 | 860-900 |
| **Specific gravity (f/t) at 15 °C** | 0.8938 | 0.86 | - |
| **Flash point(°C)** | 188.5 | 130 (min) | > 101 |
| **Acid value(mgKOH/goil)** | 0.448 | 0.80 (max) | 0.5 (max) |
| **Calorific value(kJ/kg)** | 39,960 | N/A | 35,000[a] |
| **Oxidation stability (h)** | 0.16 | 3 (min) | 6 (min) |
| **Cetane number** | 44 | 47 (min) | 51 (min) |
| **Iodine value (g I/100 g)** | 129.4 | 120 (max) | 130 (max)[a] |
| **Saponification number** | 202.9 | - | - |
| **Refractive Index (RI) at 25°C** | 1.4583 | - | - |
| **Transmission (%) at WL 656.1** | 82.0 | - | - |
| **Absorbance (Abs) at WL 656.1** | 0.086 | - | - |

### 4.3. Physical and Chemical Properties of APME-Diesel Blends and Prediction of Properties

In this paper, the properties of $B_5$, $B_{10}$, $B_{20}$, $B_{30}$, $B_{40}$, $B_{60}$ and $B_{80}$ blends were also determined and compared with ASTM D7467 standard. Table 4 shows the developed equations from different blends properties datato predict the propertiesof APME-diesel blends (in the range of 0-100% blends).

**Table 4** Prediction of properties of APME-diesel blends (0-100%)

| Property | Blend ratio[a] | Predicted equation | $R^2$ |
|---|---|---|---|
| **Viscosity (mm²/s)at 40°C** | 0≤x≥100 | Viscosity = 1.2976x + 3.4019 | 0.9981 |
| **Calorific value(kJ/kg)** | 0≤x≥100 | Calorific value = -5580.2x + 45270 | 0.9943 |
| **Density (kg/m³)at 40°C** | 0≤x≥100 | Density = 0.0438x + 0.83 | 0.9998 |
| **Viscosity Index** | 0≤x≥100 | Viscosity index= 106.72x + 117.34 | 0.9849 |

[a] x ≡% of APME in the blends

### 4.4. Engine Performance

Biodiesel play an important role on engine performance due to its higher oxygen contents, higher density, higher viscosity, lower heating values and higher cetane number [16]. In this study, the effect of *Aphanamixis polystachya* methyl ester (APME) blends with diesel on engine performance in terms of brake power (BP) and brake specific fuel consumption (BSFC) was evaluated.

#### 4.4.1 Brake Power

Fig. 3 shows the variation of (BP) of diesel, $APME_5$ and $APME_{10}$ at full load condition and different engine speeds. In general, biodiesel-diesel blends produce lower brake power compared to diesel fuel. Over the entire range of speed, the average BP for diesel, $APME_5$ and $APME_{10}$wasfound 40.48, 40.11 and 39.64 kW respectively. The average reductions of BP for APME5 and APME10 havebeen found 0.9% and 2.1% respectively compared to diesel. This reduction occurred mainly due to their lower heating values and higher viscosities compared to diesel [17].

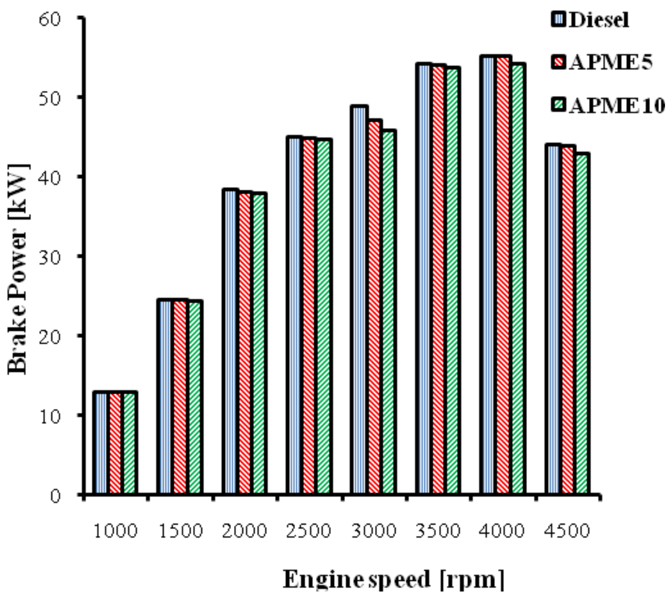


**Fig. 3** the variation of (BP) of diesel, $APME_5$ and $APME_{10}$

**4.4.2 Brake Specific Fuel Consumption (BSFC)**

The BSFC of diesel engine depends mainly on the relationship among volumetric fuel injection system, fuel density, viscosity and energy contents [18]. Fig. 4showsthe variations of BSFC for diesel, $APME_5$ and $APME_{10}$ at full load condition and different engine speeds. It has been observed that the BSFC values are higher forbiodiesel blends at all engine speeds. These findings are supported by Ref. [19-21]. Over the entire range of speeds, the average BSFC for diesel, $APME_5$ and $APME_{10}$ are found 352.96, 365.57 and 370.23 g/kWh respectively. The average increase in BSFC for $APME_5$ and $APME_{10}$ were found about 3.57% and 4.89% compared to diesel fuel. This observed phenomenon is due to higher viscosity and density of the fuel [12].

## 5. EXHAUST EMISSIO

**5.1.1. CO Emission**

Carbon monoxide (CO) is a toxic gas formed due to the incomplete combustion of any fuel. Over the entire range of speeds, $APME_5$ and $APME_{10}$ give an average reduction of CO emission by 3.15% and 8.10% compared to diesel fuel. These results are supported by literature such as [22-26]. This is due to the higher oxygen content (10-12% higher oxygen that diesel fuel) of biodiesel which results in a complete combustion [27]. Therefore, as the percentage of biodiesel increase in the blend, the higher oxygen content of biodiesel allows more carbon molecules to burn and therefore combustion becomes completed.

**5.1.2. HC Emission**

Unburned hydrocarbons are mainly resulted from the incomplete combustion of fuel and the flame quenching in crevice regions and at cylinder walls [12]. It is evident that unburned hydrocarbons for biodiesel-diesel blends are lower than that of diesel. Over the entire range of speed, the average BSFC for diesel, $APME_5$ and $APME_{10}$ are found 9.25, 8.25 and 6.75 ppm respectively. The average reductions in HC emission for $APME_5$ and $APME_{10}$ compared to diesel fuel are 10.81% and 27.03% respectively. It can be seen that HC emissions are reduced as the percentage of biodiesel in the blends increases. This can be attributed to the higher oxygen content and lower carbon and hydrogen of biodiesel than diesel which resulted in a complete combustion [28, 29].

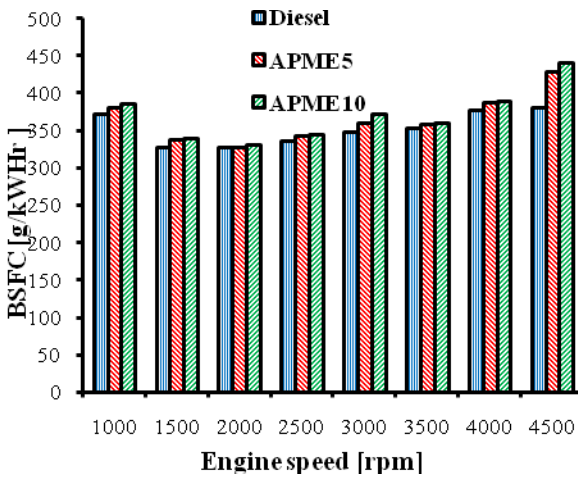


Fig. 4 the variations of BSFC for diesel, $APME_5$ and $APME_{10}$

**5.1.3. NO emission**

It has been observed that the NO values are little bit higher when $APME_5$ and $APME_{10}$ are used. Over the entire range of speed, the average NO emission for diesel, $APME_5$ and $APME_{10}$ are 288.88, 292.38 and 299.38 ppm respectively. The average increase in NO emission for $APME_5$ and $APME_{10}$ compared to diesel are 1.21% and 3.63% respectively. This can be attributed to the lean air/fuel ratio, as biodiesel is an oxygenated fuel and contains 11-12% more oxygen in its molecular structure which causes higher combustion temperature by improving combustion at warmed-up condition [30].

## 6. CONCLUSION

Based on the experimental study, the following conclusions can be drawn:

- The properties of *Aphanamixis polystachya*biodiesel and its blends agree with ASTM D6751 and ASTM D7467 standards respectively.

- Over the entire range of speed, the average reduction of brake power for $APME_5$ and $APME_{10}$ are 0.9% and 2.1%, respectively compared to diesel.

- $APME_5$ and $APME_{10}$ increase the BSFC 3.57% and 4.89% respectively than diesel fuel.

- $APME_5$ and $APME_{10}$ give an average reduction of CO emission by 3.15% and 8.10% respectively than that of diesel.

- The average reductions in HC emission for $APME_5$ and $APME_{10}$ compared to diesel are 10.81% and 27.03% respectively.

- The average increase in NO emission for $APME_5$ and $APME_{10}$ compared to diesel are 1.21% and 3.63% respectively.

- Finally, it can be concluded that APME and their blends ($APME_5$ and $APME_{10}$) can be used as a diesel fuel substitute without modifications.

**Acknowledgment**

The authors would like to express their t hanks to the University of Malaya, Kuala Lumpur, Malaysia f or financial support through Fundamental Research Grant Scheme (FRGS) and the University of Malaya Research Grant (UMRG) with Grant numbers FP020-2011A and RP016_2012E respectively.

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