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Biodiesel production, characterization, diesel engine performance, and emission characteristics of methyl esters from *Aphanamixis polystachya* oil of Bangladesh

S.M. Palash [a], H.H. Masjuki [a], M.A. Kalam [a], A.E. Atabani [b,*], I.M. Rizwanul Fattah [a,*], A. Sanjid [a]

[a] Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] Department of Mechanical Engineering, Faculty of Engineering, Erciyes University, 38039 Kayseri, Turkey

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ABSTRACT

This paper presents the prospect of biodiesel derived from *Aphanamixis polystachya* oil in diesel engine. The study deals with the physicochemical properties of *A. polystachya* methyl ester (APME) and its blends followed by evaluation of performance and emission characteristics of APME5 and APME10 in a multi-cylinder diesel engine. It has been observed that the properties of biodiesel and its blends are compatible with the ASTM D6751 and ASTM D7467 standards, respectively. It was found that, APME5 and APME10 showed an average 0.9% and 1.81% reduction in torque and 0.9% and 2.1% reduction in brake power (BP), and 0.87% and 1.78% increase in brake specific fuel consumption (BSFC) compared to diesel. In the case of engine emissions, diesel blends of APME gave an average reduction in carbon monoxide (CO) and hydrocarbon (HC) emissions compared to pure diesel. However, APME blends emitted higher levels of nitrous oxide compared to diesel. It was found that APME5 and APME10 could be used as a diesel fuel substitute without any engine modifications.

1. Introduction

With the increasing stringent environmental legislations and growing energy demand, researchers are looking for environment friendly alternative energy sources among which biodiesel is one potential candidate. Biodiesel refers to the fatty acid alkyl esters (FAAEs), mainly methyl esters which are derived from lipid substances originated from oils, fats, waste greases, recycled oils etc. [1,2]. To produce biodiesel, vegetable oils of edible origin were treated as one of the potential feedstocks once. Due to food vs. fuel controversy of edible oil use for fuel production, other sources e.g. non-edible oils of plant origin with high free fatty acid (FFA) content etc. are now being used for biodiesel production [3–6].

Aphanamixis polystachya (AP) is a widespread species found in Indo-China and western Malaysia. It is native to Indonesia, Malaysia, Singapore and Taiwan. It is commonly known as 'Pithraj' in Bangladesh and 'Amoora' in India. Fig. 1 shows the images of the tree, fruit, and dried seeds. This non-edible oil has been reported to be a potential biodiesel feedstock by some researchers and its use will be acceptable as it will not compete with food supply [7,8]. In the published literature there are handful amount of articles which mainly deals with biodiesel production and its characterization. Kumar *et al.* [9] reported on Indian amoora oil which had 4.62% Free Fatty Acids (FFA) content. Two stage biodiesel production processes was employed for biodiesel production. In acid pretreatment step, the oil was treated with 5% H_2SO_4 and 40:1 methanol to FFA by molar ratio in order to reduce FFA content. After that transesterification process was carried out with 1:6 oil to methanol in presence of more than 3.5 g/L of NaOH at 60 °C temperature which yielded 96% (v/v) biodiesel with 1 h reaction time. Ferdous et al. [10] studied the Bangladeshi pithraj oil which had FFA content of 7.5%. They also carried out two step esterification-transesterification process. For esterification 5% H_2SO_4 and a molar ratio of 1:6 (oil to methanol) were selected for 1 h reaction time at 70 °C. After that, with NaOH at 1 wt% of oil and 1:6 molar ratio of methanol, methyl ester conversion was complete within 1 h at a temperature of 60 °C. Both studies concurred that quality of the biodiesel was found to be comparable with the ASTM D6751, hence its suitability for internal combustion engine application. Till date there is no literature which deals with biodiesel production from *A. polystachya* oil, its characterization along with its effect on engine performance and emission. Thus, the motivation of this work is to establish the suitability of blends of *A. polystachya* biodiesel in diesel engines in terms of its performance and emission characteristics.

* Corresponding authors.
E-mail addresses: a_atabani2@msn.com (A.E. Atabani), rizwanul.buet@gmail.com (I.M. Rizwanul Fattah).

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Nomenclature

APME	*Aphanamixis polystachya* methyl ester
ASTM	American society for testing and materials
BP	brake power
BSFC	brake specific fuel consumption
CAPO	crude *Aphanamixis polystachya* oil
CCaO	crude canola oil
CCIO	crude *Calophyllum inophyllum* oil
CI	compression ignition
CIME	*Calophyllum inophyllum* methyl ester
CJCO	crude *Jatropha curcas* oil
CaME	canola methyl ester
CN	cetane number
CO	carbon monoxide
CPaO	crude palm oil
CSO	crude soybean oil
EGT	exhaust gas temperature
FAC	fatty acid composition
GC	gas chromatography
HC	hydrocarbon
IV	iodine value
JCME	*Jatropha curcas* methyl ester
MJ/kg	mega joule/kg
NO	nitrous oxide
NOx	oxides of nitrogen
PaME	palm oil methyl ester
PM	particulate matter
rpm	revolution per minute
SME	soybean oil methyl ester
SN	saponification number

1.1. Objectives of this study

This paper presents the potential of *A. polystachya* as a promising non-edible feedstock for biodiesel production. To achieve this, quantification of fatty acid methyl esters, characterization of physicochemical properties e.g. density, kinematic viscosity, viscosity index, flash point, cold filter plugging point, cloud point, pour point, and oxidation stability etc. of produced biodiesel and its blends with diesel was carried out and compared with corresponding ASTM standards. In addition, to test its suitability in diesel engines, performance and emission study of 5% and 10% by volume diesel/biodiesel blends was carried out and compared with petroleum based diesel fuel in a multi-cylinder diesel engine. The outcome of this study shows the potential of *A. polystachya* as a non-edible biodiesel feedstock for diesel engines.

2. Materials and methods

2.1. Materials and chemicals

The crude AP oil (CAPO) was purchased from Bangladesh. Other chemicals such as methanol, potassium hydroxide (KOH) and anhydrous sodium sulfate (Na_2SO_4) were of Friendemann Schmidt Chemicals, USA. All purchased chemicals i.e. methanol, hydrochloric acid (HCl) etc. were of analytical grade and catalysts were of 99.5% purity.

2.2. List of apparatus

The summary of the equipment used to measure the properties of CAPO, neat biodiesel, and its blends with diesel are shown in Table 1.

2.3. Calculation of the cetane number, iodine value, and saponification number of biodiesel

The cetane number, iodine value, and saponification number of APME were determined empirically using the equations presented in the literature [7,11].

$$SN = \sum \left(\frac{560 * A_i}{MW_i} \right) \quad (1)$$

$$IV = \sum \left(\frac{254 * D * A_i}{MW_i} \right) \quad (2)$$

$$CN = \left(46.3 + \left(\frac{5458}{SN} \right) - (0.225 * IV) \right) \quad (3)$$

where

$A_i \equiv$ the percentage of each component,
$D \equiv$ the number of double bond and
$MWi \equiv$ the molecular mass of each component.

2.4. Biodiesel production from CAPO

The high acid value of CAPO, 26.1 mg KOH/g of oil, prevents the use of a single-step alkaline-transesterification process. Therefore, a two-step process of acid-base catalysis was used to produce biodiesel. In the first stage, the esterification process was used to reduce the high acid value of the crude oil, while in the second stage; the transesterification process was used to convert the esterified oil to methyl ester or biodiesel (APME). Fig. 2 shows a detailed flow chart of the production of biodiesel from CAPO.

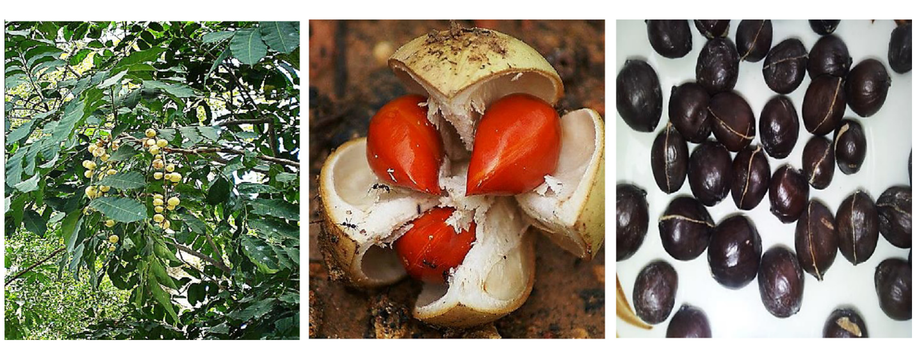

Fig. 1. *Aphanamixis polystachya* tree, fruit and dried seeds.