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Preparation and evaluation of biodiesel from Egyptian castor oil from semi-treated industrial wastewater

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ABSTRACT

Biodiesel derived from Egyptian castor oil was prepared via the conventional base-catalyzed transesterification with methanol. Fatty acid profiles of castor oil and the obtained fuel properties of the biodiesel were analyzed and tested in accordance with the ASTM standards. Castor oil contains: > 6%, > 6%, > 8%, 82% of saturated, monounsaturated, polyunsaturated and hydroxy mono-saturated fatty acids, respectively. The present study reports the preparation of biodiesel from castor oil using sodium methoxide as a catalyst. The resultant biodiesel was evaluated for physic-chemical properties namely: Iodine value (82.7 g I_2/100 g oil), cetane number (55.82), density (0.878 g/cm^3), kinematic viscosity (40°C: 4.65 cSt; 100°C: 1.28 cSt), cloud point (0 °C), flash point (151 °C), fire point (156 °C), carbon residue (0.052 %), and ash residual (0.025%). The obtained biodiesel properties were compared with those of several biodiesels from different vegetable oils such as: sunflower, soybean and rapeseed oils and found to be comparable. The performance of the diesel engine was improved by blending regular diesel with 10 % biodiesel (B10). The brake specific fuel consumption was decreased using B10 blend. The brake thermal efficiency was also increased for B10 from 25% to 27.36%. The brake specific fuel consumption was increased for B10 blend compared to regular diesel. In general, Egyptian castor oil has been identified as the ideal feedstock for biodiesel production, and was found to be the promising feed stock for biodiesel production.

1. Introduction

Conventional fossil-based fuels are not renewable and are destined to become exhausted, which inspires the use of alternative fuels [1]. Recently, global warming due to the heavy consumption of fossil fuels and the depletion of natural resources has become an increasing cause of concern. For the considerations of sustainable development, biomass –to-biodiesel has progressively gained international attention as a potential source of renewable energy. Biodiesel is a mixture of fatty acid methyl esters (FAME) obtained from plant seed oil by the transesterification reaction. This reaction occurs after heating the triglycerides in plant seed oil with methanol in the presence of a catalyst, with the resulting product mixture comprising FAME and glycerol. The homogeneous catalyst system transesterification reaction is relatively fast with high conversion [2]. Biodiesel has received increasing attention due to its less polluting nature and because it is a renewable energy resource as opposed to conventional diesel [3]. Fatty acid methyl esters (FAMEs) used as biodiesels are biodegradable and non-toxic to plants, animals and humans. These biodiesels can be mixed with petroleum diesel in any proportion or directly used in diesel engine without modification [4]. The high cost of biodiesel is the major barrier to its commercialization [5], and 80 % of the total cost of biodiesel production is the cost of the raw materials [6]. The choice of feedstock for today's commercial biodiesel plants depend largely on geography; rapeseed oil dominating the EU production, soybean oil dominating the US and Latin American production, and palm oil mainly being used in Asia. There is an increasing interest to search for suitable alternative oils for the production of biodiesel [7, 8] as the use of edible oils are being discouraged globally. Even though several non-edible oils like Jatropha and karanja are being exploited for biodiesel preparation, very few unusual fatty acids-containing oils such as castor oil and lesquerella have been exploited for this purpose. Studies on castor oil and lesquerella suggested that their uniquely high level of the hydroxy fatty acids which impart increased lubricity to the oil and its derivatives as compared to other vegetable oils [9]. Biofuels are obtained by cracking of different vegetable oils including: Alcea pallid oil [10], woody oils [11], soybean oil [12], palm oil [13], cotton seeds oil [14], Jatropha oil [15], and waste cooking

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oils [16]. Cracking oil vegetable oils performed either thermally without using any type of catalyst [17], or by using alkaline catalysts [18], metal oxides [19], zeolite [20–22]. Fish oils [23], animal fats [24] and microalgae oils [25] are also used as considerable sources for biofuels. Owing to economic reasons, the use of low cost raw material, such as Egyptian castor oil (ECO) planted in Upper Egypt in Al-Alaki valley and irrigated using industrial and pretreated wastewater, is being considered for biodiesel production. FAMEs of ECO were investigated as being possibly suitable for use as a promising biodiesel feedstock [26]. Castor oil is planted in Upper Egypt and is widely distributed in the southern and southwestern regions with a total area of about 2,000,000 ha, and the annual seeds production is above 250,700 tons [27]. The yield of the seed castor oil is about 40–60%. In addition, the castor trees are gaining importance due to its low maintenance and fewer crop husbandry management practices required [27]. This paper aimed to evaluate the biodiesel that is produced from alkali transesterification of Egyptian castor oil using ASTM standards, and to compare its fuel properties with fossil-based fuel (petroleum diesel), and compare different diesel-biodiesel blends with different ratios.

2. Materials and methods

2.1. Extraction of castor oil

Dry castor seeds (500 g) were crushed using a domestic grinder and the oil was extracted by petroleum ether using a Soxhlet apparatus at 45–50 °C for 6–8 h until the extraction was completed. The oil content was determined as the difference in weight of the dried castor seeds before and after the extraction (38%). The determination was performed in triplicate, and the amount of obtained oil was considered as the average [28].

2.2. Treatment of extracted castor oil

The conversion of castor oil into biodiesel was performed by two steps. The first is esterification of free acids in the oil by methanol using H_2SO_4 as a catalyst to decrease the amount of free acids in the oil. The second is transesterification of the treated oil by sodium methoxide [29].

2.3. Free fatty acid esterification

In a round flask (1000 mL) equipped with Dean-Stark apparatus connected to a condenser, castor oil (513 g; 1.1 mol) was mixed with methanol (192 g; 6 mol) and stirred. Sulfuric acid (7.6 ml; 0.76 wt% of oil) was added slowly and reaction mixture was refluxed. After 1–1.5 h refluxing, the reaction was monitored by IR spectroscopy and TLC, showing esterification of free fatty acids present in the castor oil [30].

2.4. Alkaline transesterification

In the transesterification reaction with refined castor oil, the treated oil (1 mol) was charged into the reactor, followed by slow addition of methanol (6 moles). The mixture was stirred with heating at 55 °C and Na–methoxide (1% of oil) was added as a catalyst. After 2 h of refluxing, two phases were obtained, the upper is the biodiesel phase and the lower is glycerine phase. The upper biodiesel layer was separated and the excess methanol was filtered off under reduced pressure and then washed by deionized water to remove the traces of glycerin and catalyst [31].

2.5. FAME analysis

The FAME of castor oil was identified by gas chromatography-mass spectrometry (GC–MS). The hexane (1 μL) extract was injected into a highly polar HP Innowax capillary column with a length of 30 m (inner diameter 0.32 m, film thickness 0.5 mm, split 1:20). An Agilent 6890 (CA, USA) equipped with a flame ionization detector was used. The injector and detector temperatures were 250 and 280 °C, respectively. The oven temperature was programmed from 190 °C holding at 3 min to 240 °C at the rate of 15 °C /min for 17 min. The carrier gas was high-purity hydrogen. The peaks of FAME were identified by comparing their retention time with that of the known standards, carried out under similar separation conditions. Peak integration was performed by applying HP3398A software. Each FAME determination was run in triplicate and averages were reported.

2.6. Castor oil and biodiesel specifications

The following data were determined for castor oil: refraction index, saponification value, iodine value, acid value, photometric color, water content, and oil percent in castor seeds. The characteristic specifications of the produced biodiesel including: kinematic viscosity (at 40 °C and at 100 °C), iodine value, density, cetane number, pour point, cloud point, ash %, carbon residue %, flash point, and fire point were also determined. The mentioned properties were determined according to AOCS methods and ASTM specifications [32–40].

2.7. Engine test

The engine tests of the biodiesel and diesel-biodiesel blends were performed using a direct injection four stroke single cylinder diesel engine of capacity 624 cm^3. The running speed of the engine was 1500 rpm, and the tests were carried out at five different loads of: 6.37, 12.74, 19.11, 22.3 and 25.48 N. Four fuels were used in the tests: regular diesel fuel, and three blends of regular diesel with: 10% biodiesel (B10), 20% biodiesel (B20) and 40% biodiesel (B40). The fuel volume used in each run was 50 cm^3 and the time of its consumption (sec) and the brake power (kW) were recorded for each fuel type. The break specific fuel consumption, BSFC (gm/kWh) and the break thermal efficiency, BTE (%) were calculated according to the following formulations:

$$\text{BSFC} = (\text{Fuel consumption rate})/(\text{Brake power})$$

$$\text{BTE} = (\text{Brake Power} \times 360000)/(\text{Fuel consumption rate} \times \text{Calorific value})$$

where: fuel consumption rate in gm/h, brake power in kW, and Calorific value in kJ/g.

3. Results and discussion

3.1. Fatty acid composition and properties

The fatty acid content (FAC) of the used castor oil is shown in Table 1. The fatty acids in castor oil were determined as: palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1), linoleic acid (C18:2), linolenic acid (C18:3), and recinoleic acid (C18:1:OH). The predominant fatty acids found were linoleic acid and recinoleic acid. A total of six different fatty acids were identified in percentages of the total fatty acid of the castor oil. In this study, recinoleic acid had the highest percentage of total fatty acids (81.93%); linoleic acid had the second highest percentage (6.33%). Ramos et al. [41] suggested that the ideal vegetable oil composition for biodiesel includes a high percentage of monounsaturated fatty acids, in addition to low proportions of polyunsaturated acids and a minimum content of saturated fatty acids. Based on these principles, the castor oil under study is an ideal feedstock for biodiesel production. The other properties identified for the used castor oil