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Karanja (*Pongamia Pinnata*) biodiesel production in Bangladesh, characterization of karanja biodiesel and its effect on diesel emissions

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ABSTRACT

This paper presents production of biodiesel (BD) from non-edible renewable karanja (*Pongamia Pinnata*) oil, determination of BD properties and influence of BD on engine performance and emissions. Bangladesh imports 2.4 million metric ton (MT) DF each year [M.N. Nabi, M.S. Akhter, K.M.F. Islam, Prospect of biodiesel production from jatropha curcas, a promising non edible oil seed in Bangladesh, International Conference on Mechanical Engineering (ICME, Dhaka, Bangladesh) Proceedings 2007, paper no. ICME07-TH-06. [1]]. It has 0.32 million hectare of unused land [M.N. Nabi, S.M.N. Hoque, M.S. Uddin, Prospect of Jatropha curcas and pithraj cultivation in Bangladesh, Journal of Engineering and Technology, IUT, Dhaka, Bangladesh, 7 (1) (2009) 41–54. [2]]. It has been found that cultivating of karanja plant in such unused land; Bangladesh can reduce DF import by 28%. Karanja methyl ester (KME), which is termed as BD, has been produced by well-known transesterification process. The properties of B100 (B100) and its blends were determined mainly according to ASTM standard and some of them were as per EN14214 standard. The Fourier transform infrared (FTIR) analysis showed that the DF fuel contained mainly alkanes and alkens, while the B100 contained mainly esters. The gas chromatography (GC) of B100 revealed that a maximum of 97% methyl ester was produced from karanja oil. Engine experiment result showed that all BD blends reduced engine emissions including carbon monoxide (CO), smoke and engine noise, but increased oxides of nitrogen (NOx). Compared to DF, B100 reduced CO, and smoke emissions by 50 and 43%, while a 15% increase in NOx emission was observed with the B100. Compared to DF, engine noise with B100 was reduced by 2.5 dB.

1. Introduction

Due to non renewable nature of fossil fuels, different nations are looking into different vegetable oils as potential DF replacement. USA and some European countries use soybean and rapeseed oils for production of BD and the effect of these BDs on engine performance and emissions have been conducted previously [3,4]. But soybean and rapeseed oils are edible in nature. Densely populated countries like Bangladesh, India and some Asian countries cannot afford edible oils as a fuel substitute. Use of such edible oil to produce BD in these countries is not feasible in view of a big gap in the demand and supply of such oils for dietary consumption. Specially in Bangladesh and India, a variety of non-edible oils like karanja jatropha, neem, linseed, mahua, karanja, rice bran, and castor are available in surplus quantities. Rudolf Diesel, the inventor of the diesel engine, made engine experiments on groundnut oil at the Paris exposition of 1900. Since then, vegetable oils have been used as fuels when petroleum supplies are expensive or difficult to obtain. The use of raw vegetable oils in engines without any modification results in poor performance and leads to wear of engine components [5]. The problems faced with raw vegetable oils as fuels are poor atomization due to their high viscosity and incomplete combustion leading to higher smoke density. Kumar et al. [6] and Huzayyin et al. [7] reported that the emissions of CO, HC and SOx are found to be higher, whereas NOx and particulate emission are lower compared to petro DF. Since straight vegetable oils are not suitable as fuels for diesel engines, they have to be modified to bring their combustion related properties closer to diesel. This fuel modification is mainly aimed at reducing the viscosity to eliminate flow or atomization related problems. Several techniques can be used to reduce the viscosity of vegetable oils, such as, pyrolysis, micro-emulsion and transesterification [8]. Due to price hike and non-renewable nature of fossil fuel BD is one of the best options for nowadays automotive fuel. All vegetable oils or fats are triglycerides. These triglycerides are converted to mono alkyl esters, through a transesterification process. Transesterification is a well-known and well established chemical reaction in which alcohol reacts with the triglycerides of fatty acids (vegetable oils or animal fats) in presence of a catalyst. The alcohol may be methyl alcohol or ethyl alcohol and the catalyst may be NaOH or KOH. It is a reversible reaction of fats or oils (triglycerides) with a primary alcohol to form esters and glycerol. The alcohol combines with the triglycerides to form glycerol and esters. The stoichiometry for the reaction is 3:1 molar ratio of alcohol to oil, however, since the reaction is reversible, in practice, excess alcohol is required to shift the equilibrium to the products side to raise the product yield [9,10]. Methanol and

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ethanol are used most frequently, specially methanol because of its low cost and its physical and chemical advantages (polar and shortest chain alcohol). It can quickly react with triglycerides, and NaOH gets easily dissolved in it. [10]. For a base catalyst transesterification, triglycerides should have low free fatty acid (FFA) and the catalyst must be anhydrous because water makes the reaction partially change to saponification, which produces soap. Soap formation lowers the yield of esters and renders the separation of esters and glycerol as well as water washing of esters is difficult [10]. For oils or fats having high FFA acid esterification are advantageous, as acid catalyze the FFA esterification to produce fatty acid methyl ester (FAME), increasing the BD yield, but reaction time and alcohol requirement are substantially higher than those of base catalyzed transesterification [11]. Besides acid and base catalyzed transesterification, several researchers [12–14] did transesterification without using any catalyst in supercritical methanol, which eliminates the need for the water washing. Saka et al. [13] and Kusadina et al. [14] found that in supercritical methanol, the reaction requires only 4 min, and also, the presence of water did not affect the yield of ester, but substantially high pressure, temperature and very high molar ratio of alcohol to oil is required. Boocock et al. [15] reported that the addition of a co-solvent (tetrahydrofuran and methyl tertiary butyl ether) creates a single phase, and this accelerates the reaction so that it reaches substantial completion in a few minutes. It has been reported that the tailpipe emissions with BD are significantly lower as BD is a partially oxygenated fuel [16]. The objectives of the proposed project are to reduce import of DF, security of BD supply and creating employment opportunities in Bangladesh. The purposes of the proposed project were to focus mainly on gradual development of plots and cultivation of karanja plant on the areas, where crop cultivation was not done. It was specially emphasized to cultivate karanja plant in the huge unused area (wasteland) in the southern part of Bangladesh. Also this work was a motivation to cultivate the karanja plant along the huge unused sideways of railway tracks.

2. Materials and methods for BD production

Biodiesel was produced by acid esterification followed by transesterification process due to high FFA concentration in the karanja oil. For acid esterification H_2SO_4 was used as catalyst. For base catalyzed transesterification process methanol was used as alcohol and NaOH was used as lye catalyst. Instead of methanol and NaOH, ethanol or KOH can also be used for making biodiesel. Methanol and NaOH were used for lower cost and higher conversion efficiency. Karanja seed were collected from local farmers in Bangladesh. The crude karanja oil was extracted mechanically with a crushing machine from which a maximum of 31% oil was extracted. Eijck et al. [17] reported that a maximum of 33% oil was extracted from jatropha seed using a screw press. For maximum production of BD, extensive investigations were conducted to optimize the best condition. Karanja oil contains approximately 20% FFA [18]; therefore acid esterification was carried out to reduce the FFA concentration to less than 1%. Base catalyzed transesterification was then carried out.

2.1. Purification (acid pretreatment)

Karanja oil were filtered and preprocessed to remove water and contaminants, and then fed to the acid esterification process. High FFA to karanja oil leads to soap formation during Alkaline (base catalyzed) transesterification. Different ratios of methanol to oil were investigated for low acid value of less than 2 mg KOH/g-oil and low FFA concentration of less than 1%. For acid pretreatment a round flask was used. A hot plate with a magnetic stirrer was used for heating the mixture in the flask. The karanja oil was taken into the flask and heated. Then methanol and 1% H_2SO_4 were added to the flask and heated continuously for an hour. Berchmans et al. [19] reported that for complete FFA esterification in some vegetable oils, the reaction temperature has been set to 50 °C, the reaction time 1 h and the acid to oil ratio 1% w/w. During heating and stirring the mixture, acid value and FFA concentration were tested. When the FFA concentration was less than 1% the alkalized transesterification was then conducted with pretreatment karanja oil.

2.2. Alkaline (base catalyzed) transesterification

Based on the discussion in Section 2.1 it was expected to get maximum biodiesel when the acid value was less than 2 mg KOH/g-oil and the FFA concentration in karanja oil was less than 1% using base catalyzed transesterification. For base catalyzed transesterification, different parameters including catalyst to oil ratio (w/w), methanol to oil ratio (w/w), and the reaction temperature were investigated. The acid value was found to be less than 2% and the FFA concentration was less than 1% at a methanol to oil ratio of 55 wt.%. It was also observed that the BD yield was maximum (97%) for methanol to oil ratio of 20% (w/w) and NaOH to oil ratio of 1%. The current results are almost identical to those of Berchmans et al. [19].

3. Experimental setup and procedure of experimentation

The engine used in this experiment was a single cylinder, water-cooled, NA, 4-stroke, DI diesel engine. The engine was a commercial diesel engine and it was coupled with a dynamometer. The specifications of the engine are shown in Table 1. The engine speed was measured directly from the tachometer attached with the dynamometer. A water brake dynamomer was used for engine torque measurement. The outlet temperatures of cooling water and exhaust gas were measured directly from the thermocouples (Ni–Cr) attached to the corresponding passages. The dynamic fuel injection timing was set at 24° BTDC (before top dead center). The emissions of NOx and CO were measured with a portable digital gas analyzer (IMR 1400) (specification shown in Table 2). The engine noise was measured with a sound level meter of model CEL-228 (Impulse Sound Level Meter). The exhaust emissions were measured at 30 cm from the exhaust valve. The engine speed was kept fixed at 1200 rpm and an inclined water tube manometer connected to the air box (drum) was used to measure the air pressure. Fuel consumption was measured by a burette attached to the engine and a stop watch was used to measure fuel consumption time for every 10 cm^3 fuel. A mechanical fuel pump and a one hole injector nozzle with a hole diameter of 0.25 mm was used in the injection system. Each experimental data reading was taken three times and the mean of the three was taken.

4. Results and discussion

4.1. Quantity of BD production in Bangladesh

In Bangladesh BD from Karanja oil can be produced and the quantity of BD can be calculated as follows:

Unused land in Bangladesh: 0.32 million hectare
Expected seed per hectare per annum: 9 MT [20]

Table 1
Specification of the tested engine.

Engine type	4-stroke DI diesel engine
Number of cylinders	One
Bore × stroke	80 × 110 mm
Swept volume	553 cc
Compression ratio	16.5:1
Rated power	4.476 kW at 1800 rpm
Types of fuel pump	High pressure mechanical type
Fuel injection pressure	14 MPa (at low speed, 900 to 1099 rpm) 20 MPa (at high speed, 1100 to 1800 rpm)
Fuel injection timing	24 °BTDC
Type of injection nozzle	Pintle
Number of nozzle hole	One
Nozzle hole diameter	0.25 mm