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Performance Comparison of Four Potential Seed Oil as a Feedstock for Bio-Diesel Production in Bangladesh

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Abstract

This paper investigates the production of bio-diesel (BD) from karanja (*Pongamia pinnata*), pithraj (*Aphanamixis polystachya*), neem (*Azadira chtaindica*) and mahua (*Madhuca longofolia*) seed oil by acid esterification followed by transesterification process and physicochemical properties of oils were studied. Study includes their effects on a DI diesel engine. All the oils were characterized by density, viscosity, specific gravity, pH value, flash point, fire points and cetane index using standard methods. The minimum BSFC 0.43kg/kW-hr was found for karanja bio-diesel at 4bar (BMEP) which was about 9.3% higher than neat diesel at the same condition. The brake power produced by the net diesel at 4 bar was 1.65 kW which was about 26.9% higher than the karanja seed bio-diesel. Maximum thermal efficiency 13.8% was observed for neat diesel, where as 11.45%, 10.90%, 10.63%, 10.38% was observed for karanja, neem, mahua and pithraj bio-diesel oil. Results indicate that these oils are potential biodiesel feedstock and can be used as an alternative to the diesel fuel in the near future.

Keywords: Biodiesel, Alternative fuel, methanol, transesterification process, catalyst.

1. Introduction

Rapid depletion of fossil fuels and stringent emission regulations strongly forced researchers to explore renewable sources of energy. Biodiesel is one of the promising renewable energy options already exploited by researchers in different countries. Different categories of feed stocks as sources of suitable oil for biodiesel production include seeds, nuts, leaves, wood, and even bark of trees. At present the world is highly dependent on petroleum fuels for generating power, vehicle movement, agriculture and domestic useable machinery operation and for running the different industries. With technological progress and improvement of living standard of the people the demand of the petroleum fuel increases simultaneously. But the reserve of the petroleum fuels are so evenly distributed that many regions have to depend on the others for their fuel requirements. The price of the petroleum is also increasing day by day and use of the petroleum fuel in engine produces harmful products which pollutes the environment. Due to the above reason, attention has gone to the search of renewable source of fuel which can meet the demand. Bangladesh has good potential of various edible and non-edible oils and locally available vegetable oils may be an alternative source of diesel fuel which can be produced in any local area [1].
Plant vegetable oils can be used as alternative fuels for diesel engine. Due to higher viscosity, lower volatility, carbon deposits and oil ring sticking, limit their direct uses to diesel engine [2]. There are several techniques to reduce the viscosity of vegetable oils. The techniques are dilution, pyrolysis micro emulsion and transesterification. Like vegetable oils, it is well known that biodiesel is also an alternative fuel and can be derived from straight vegetable oils (edible or inedible), animal fats, waste cooking oils or even from yellow grease through a process known as trans esterification [3]. The production of biodiesel involved in chemically reacting a vegetable oil or animal fat with an alcohol such as methanol. The reaction requires a catalyst, usually a strong base, such as sodium or potassium hydroxide, and produces new chemical compounds called methyl esters, which is known as biodiesel [4-5]. Most of the study suggests that engine power is reduced with the biodiesel as biodiesel has the low heating value compare to diesel. Factors which affect the engine power are content of biodiesel, properties of biodiesel and its feedstock, engine type and its operating conditions and additives. Proper optimization of injection timing, injection pressure and proper improvement of additives can solve this problem up to a great extent. And when biodiesel is used as blend with diesel are it is difficult perceive this problem. S. Romano et al. [5] reported that vegetable oils have acceptable cetane numbers, high viscosity (50 Cst), high flash points (220-285ºC) and high pour points (-6 to 12°C) and substantial heating values (about 90 % of diesel) and low sulfur content (< 0.02%) and also studied the properties of different

vegetable oils and modified fuels for automotive application. Srinivasa et al., 1991 [6], however, noted density increases when fueling with karanja based biodiesel.
In Bangladesh, non-edible renewable jatropha oil and pithraj (local name) oil can play a vital role in the production of substitute diesel fuel. Attention is given to the neem and pithraj oil because they are non-edible renewable source of oil and it is a new research over the world. The climatic and soil condition of Bangladesh is also suitable for the production of this plant. The oil as well as Bio-diesel can be prepared with most economical way. Nabi et al.,2009 [7] reported that by planting of jatropha, Bangladesh can reduce importing a huge amount (25%) of petroleum products from foreign countries as well as by planting of pithraj, can also be saved 21% of petroleum products.
The purposes of this study are to produce biodiesel from renewable sources of energy named pithraj oil, karanja oil, neem oil and mahua oil and to investigate the engine performance with these biodiesel blends (B10).
The subsequent section explains the materials and methods involved with the study, the comparison of neat diesel and the bio-diesel under consideration is given at third section. The performance of different bio-diesel is listed as results and discussions at section four. The environmental effect of bio-diesel emission is sorted at section five.

2. Materials and Methods

The most important parameters relevant to biodiesel production are the FFA content and moisture content [1,3]. The FFA content of vegetable oil will vary and depends on the quality of the feed stock. During alkali catalyst based transesterification, higher the FFA content of the oil needs more alkali to neutralize the FFA and it leads to soap formation and the separation of products becomes difficult and as a consequence low yields of biodiesel are produced [8]. Acid esterification are advantageous for those oils having high FFA, as acid catalyze the FFA esterification to produce fatty acid methyl ester (FAME), increasing the bio-diesel yield, but reaction time and alcohol requirement are substantially higher than those of base catalyzed transesterification [6]. In this study biodiesel (BD) from karanja (*Pongamia pinnata*), pithraj (*Aphanamixis polystachya*), neem (*Azadira chtaindica*) and mahua (*Madhuca longofolia*) seed oil was produced by acid esterification followed by transesterification process due to high FFA concentration in these vegetable oils feedstock. For acid esterification H_2SO_4 was used as catalyst and methanol and NaOH were used as base catalysts for transesterification process.
Firstly, the vegetable oils were filtered and preprocessed to remove water and contaminants, and then fed to the acid esterification process. For acid pretreatment, the oils were taken to the rounded flask where CH_3OH and 1% H_2SO_4 were added to the flask and heated continuously for an hour. 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 vegetables oil. In this process, different parameters including catalyst to oil ratio (w/w), CH_3OH 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 maximum bio-diesel production, the volumetric percentage of CH_3OH was kept constant at 22% and temperature was varied from 40°C to 55°C and the weight percentage of catalyst was kept at 0.5%.

Table 1. Engine specification

Engine type	4-stroke DI diesel engine
Engine no.	4062 AVI
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 1000 rpm) 20 MPa (at high speed, 1100 to 1800 rpm)
Fuel injection timing	24 °BTDC

The experimental study was conducted by using a single cylinder water-cooled, naturally aspirated (NA) 4-stroke DI diesel engine. The specifications of the engine are shown in Table 1. The flow rate of the fuel was measured by timing with a stop watch the consumption for known quantity of fuel (10cc) from a burette. The speed was measured directly from the tachometer attached with the dynamometer. The engine torque was measured by using rope brake dynamometer which is coupled to the engine. The cooling water outlet and exhaust gas temperature were measured directly from the thermometer attached to the corresponding passages. An inclined water tube manometer, connected to the air box (drum) was used to measure the air pressure. A high pressure mechanical fuel pump and a printle type fuel injector with a nozzle hole (nozzle diameter 0.25 mm) were used in the injection system. The fuel injection time was set at 24° BTDC. Initially the engine was run by the diesel fuel for about 30 minutes to warm up and bring to the stable condition. At that situation emission and exit line temperature was uniform and it was ensured to be constant for every observation to evaluate performance. At first the experimental data was taken for diesel and then for 90% diesel and 10% pithraj, karanja, neem and mahua bio-diesel oil.

The engine was running at different speed ranging from 900 to 1400 rpm and then selected 1200 rpm on the basis of maximum thermal efficiency. All the experimental data was taken for three times and used the mean of them was used by running the engine at 1200 rpm and different load conditions.

3. Comparison of Bio-Diesel Properties with Neat Diesel

The major properties of biodiesel include calorific value, diesel index, flash point, fire point, cloud point, pour point, density, and kinematic viscosity. The various physicochemical properties of diesel and biodiesel produced from pithraj, karanja, neem, and mahua seed are measured and presented in Table 2 for comparison. It can be noted that the calorific value of mahua biodiesel is 17% less than that of diesel, pithraj and neem oil has almost same calorific value but 13% less than the diesel oil whereas karanja oil has the highest calorific value than that of other three biodiesel. This might be due to the presence of oxygen atoms in the fuel molecule of bio-diesel [3-5]. The kinematic viscosities of biodiesel are greater than the diesel oil but mahua oil has the viscosity close to diesel oil.

Table 2.Comparison of various bio-diesel (B10) properties and diesel oil

Properties	Neat Diesel	Pithraj oil	Karanja oil	Neem oil	Mahua oil
Density (gm/cc)	0.86	0.948	0.9434	0.9466	0.872
Viscosity (cSt)	4.98	6.22	5.86	6.05	5.2
Higher heating value(kJ/kg)	44579	38588	40750	38150	37000
Fire point(°C)	90	210	220	228	150
Flash point(°C)	80	197	210	220	118
Cetane index	47	51	58	43	52
pH value	7	7.00-7.46	7.58-8.87	4.38-4.92	7.14-7.31

The higher viscosity of biodiesel could potentially have an impact on the combustion characteristics because the high viscosity affects its atomization quality. The flash and fire points of the four seeds biodiesel are much higher than that of diesel, which make biodiesel safer than diesel from ignition due to accidental fuel spills during handling. Pithraj oil, karanja oil and mahua oil has the higher cetane number while neem oil has lower cetane index compared to diesel oil [9]. The density of karanja oil, pithraj oil and neem oil has almost same but greater than mahua oil which shows almost same value that of diesel oil.

4. Results and Discussions

Effect of Methanol Percentage on Biodiesel Yield

The transesterification process was performed to yield bio-diesel from the neem, karanja, pithraj and mahua by keeping the catalyst NaOH concentration constant at 0.5%. From the Fig. 1 it can be noted that the bio-diesel yield was varied with the varying CH_3OH concentration (ranging from 16% to 24%). The bio-diesel yield was increased for all the non-edible seeds with the increase in CH_3OH concentration up to a maximum near about 22% and then decreased steadily. This fact can be characterized by, with the increase of CH_3OH concentration the rates of complete transformation of oil to bio-diesel is increased and after exceeding the optimum CH_3OH concentration level it is found difficult to separate bio diesel from the water.

Although the emulsification process gets complicated with the increasing CH_3OH concentration as it has one OH group that contributes to the more H_2O production. The esterification reaction is presented in equation (1) as-

$$RCOOH + CH_3OH = RCOOCH_3 + H_2O \qquad (1)$$

Also the higher CH_3OH concentration causes more reaction time with higher density. The maximum bio-diesel yield could be attained for the seeds under consideration were about 22% of CH_3OH concentration (%wt) while the temperature range was varied from 40°C to 55°C. From the experimental data it was obvious that, the maximum bio-diesel yield was obtained for the neem seeds due to its physiological properties which correspondent with the previous research [10].

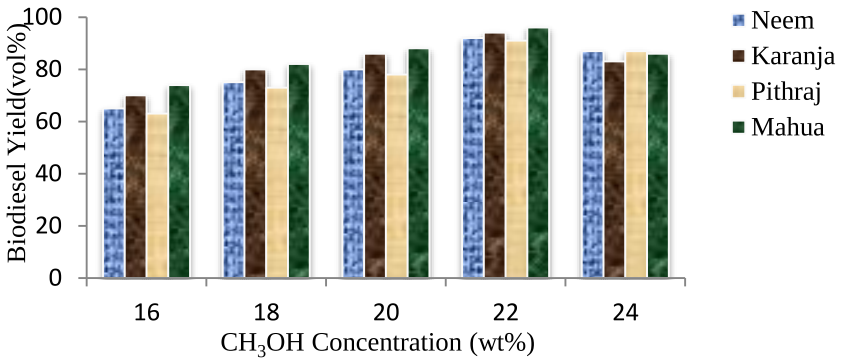

Fig.1. Variation of bio-diesel production with CH_3OH (%wt)

The concentration of the NaOH catalyst was varied from 0.4% to 0.55% by % of wt. For the optimum bio-diesel production the volumetric percentage of CH_3OH was kept constant at 22% and temperature was varied from 40°C to 55°C. It was observed that, the bio-diesel production increases with the increase in the catalyst concentration until it reach to a value about 0.48 wt% to 0.5 wt% and then decreases with the decreases in catalyst concentration. But with increasing amount of catalyst causes higher free fatty acids (FFA) and forms more wax and glycerol. Also higher NaOH content results in soapanification reaction which hampers bio-diesel production.

Effect on Brake Specific Fuel Consumption for Various Bio-Diesel Fuels

The average effective cylinder pressure that does useful work obtained calculated from the engine 'brake horse power (BHP)' is referred as the "Brake Mean Effective Pressure or BMEP". It's a function of temperature of gases in cylinder. To obtain more heat energy, more fuel needs to be burnt. Whereas torque is a function of BMEP and engine displacement. On the other hand, the, BHP is a function of engine speed and torque. The ratio of the work done during one complete engine revolution to the engine swept volume, gives the engine BMEP. Thus, BMEP measures the effective work output of the engine.

$$BMEP = \frac{2\pi TN}{V_S} \qquad (2)$$

In equation (2), T refers to torque developed (N-m), N is the number of revolution per cycle (N=1 for two stroke engine and N=2 for four stroke engine), V_s is the swept volume (m).

The variation of the BSFC with neat diesel fuel and different biodiesel is depicts in Fig. 2. BSFC for various bio-diesel decreases with the increases in BMEP and reaches it minimum value near at BMEP 4 bar. At the initial stage the BSFC decreases which may be accredited to the complete combustion of fuel. After a while the engine reaches the full load level and the time for complete combustion gets reduced and a slender raise in BSFC is observed. This fact can be illustrated as, the brake power of the engine increases with the load but the time needed for the complete combustion of a certain amount of fuel is increased. Thus the BSFC is decreased after attaining full load.

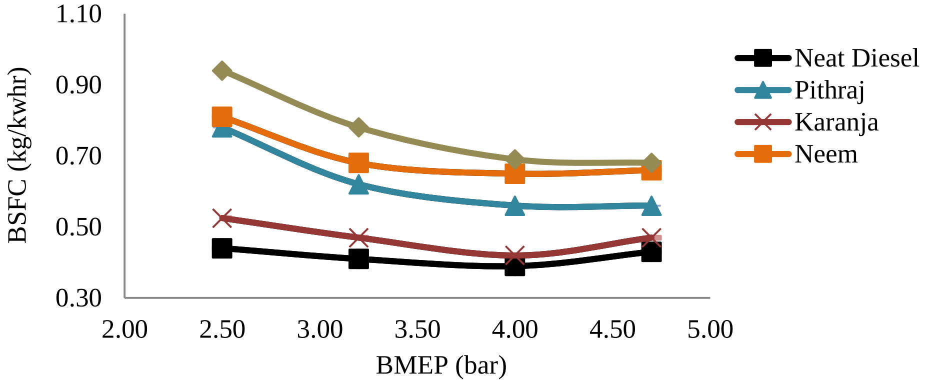

Fig. 2.BSFC with neat diesel and different bio-diesel fuels

The BMEP obtained for Karanja oil has the lower BSFC than the other three type biodiesel and close to diesel oil at BMEP 4 bar. From Fig. 2 it is clear for different engine loads that the BSFC is higher for all the bio-diesel than neat diesel due to the higher heating value of the diesel fuel and a higher content of oxygen in bio-diesel [11]. Also the viscosity and specific gravity of the bio-diesel fuels affects the atomization process as well as the BSFC of the fuel.

Effect on Engine Brake Power for various Bio-Diesel Fuels

The general trend of the curves in Fig. 3 represents that the BP of crank shaft increases with the increase in BMEP up to a certain value (around 4 bars) of BMEP and then decreases. At around 4 bar the BP for neat diesel is higher than karanja, pithraj, neem and mahua oil by 16.97%, 34.55%, 38.1% and 45.45% respectively. The calorific value of different fuels is an indication to the energy output by the fuel. Thus, neat diesel has the highest energy output among the others. From Fig. 3, it is also evident that, after reaching the full load condition incomplete combustion takes place and the energy output for all fuels are decreased that also reveals the earlier reports on bio-diesel fuels [11-12].

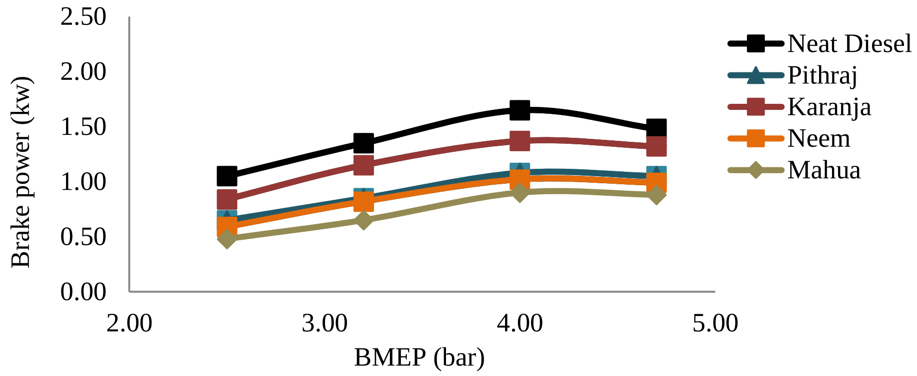

Fig. 3.Brake power with neat diesel and different bio-diesel fuels

Effect on Engine Thermal Efficiency for Various Bio-Diesel Fuels

The brake thermal energy indicates the proportion of thermal energy extracted by combustion system and transfers the suitable mechanical work to the crank shaft.

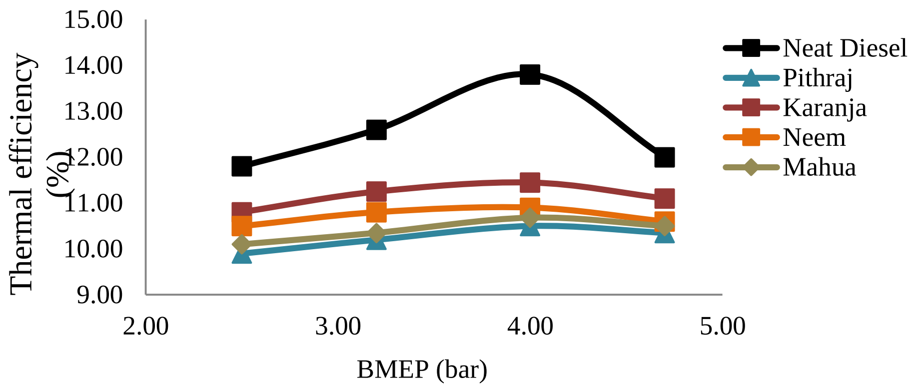

Fig.4.Thermal efficiency with neat diesel and different bio-diesel fuels

Fig. 4 illustrates the variation of thermal efficiency with BMEP for neat diesel and various bio-diesel fuels. The trends of the curves follow an increase in the efficiency with the increase in BMEP up to almost 4 bar and then slightly decreased. The initial increase is due to the proper combustion of the fuel and for bio-diesel excess amount of oxygen contributes to a greater extent. But after reaching full load the efficiency is decreased due to incomplete combustion of fuel with a higher BSFC [13-14]. From the above equation it is clear that the engine torque increases with the engine load and results in a higher thermal efficiency. At higher load more fuel is injected in the combustion chamber and causes incomplete combustion of fuel. Thus the thermal efficiency is decreased.

5. EMISSION

Engine emission is mainly characterized by the NO_X and CO_x emission. NO_x formation varies with the engine maximum temperature (attains before the end of compression stroke), fuel injection angle, engine operating condition, type of fuel used [8-9]. With an increase in temperature, the higher O_2 content of bio-diesel causing oxidation of the nitrogen. This concentrated NO_x remains unchanged after the expansion stroke. On the contrary, this excess O_2 content of bio-diesel produces leaner A/F ratio compared to diesel [11]. This excess O_2 content causing the emitted CO to be oxidized and formed into CO_2. Thus, bio-diesel attributes to the reduction of CO_x and increment of NO_x formation compared to the diesel fuel at the same engine operating condition.

6. CONCLUSION

This experimental work was conducted to produce the bio-diesel from the potential inedible feedstock in Bangladesh which will be a novel alternate to the traditional diesel fuel. In this work bio-diesel was extracted from the karanja (*Pongamiapinnata*), pithraj (*Aphanamixispolystachya*), neem(*Azadirachtaindica*) and mahua(*Madhucalongofolia*) seed oil, their properties were compared and a detail of their performances were investigated. The following conclusion can be drawn for this work-

i. Bio-diesel was produced by using the transesterification process. The optimum condition for bio-diesel production was set close to 22 vol% of methanol, 0.5wt% of NaOH and 55 º C reaction temperatures. At this condition maximum bio-diesel was obtained 96% for mahua oil, 94% for neem oil, 92%for pithraj oil and 91% for karanja oil. The maximum bio-diesel production was determined after 15hrs.of reaction time.
ii. The different physiochemical properties of bio-diesel was evaluated and compared with the diesel fuel. The experimental data shows that the characteristics of all four inedible oil as bio-diesel are quite close toneat diesel. The density, viscosity, flash point and fire point is higher for bio-diesel fuel that is not desirable but the cetane number of bio-diesel is very promising except Neem oil.
iii. Brake thermal efficiency of bio-diesel was lower than the diesel at the same rated load due to the lower heating value and higher BSFC of the bio-diesel.

Thus, from a consideration of 3E's (energy, economy and environment), the bio-diesel fuel can be a prospective feedstock for Bangladesh which is also renewable in nature.

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