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Production of Biodiesel in Bangladesh from Inedible Renewable Pithraj Oil *(Aphanamixis polystachya)* and Experimental Investigation of Methyl Esters as Biodiesel on C.I. Engine

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Abstract – *This paper investigates the production of biodiesel from inedible renewable pithraj (Aphanamixis polystachya) oil and its effect on engine performance and emissions. In the first part of this work, the pithraj oil was used to produce biodiesel by transesterification process followed by the determination of fuel properties like density, viscosity, higher heating value, P^H value, flash point, pour point and cetane index. A maximum of 96% by volume methyl ester (biodiesel) was obtained at a methanol concentration of 22 vol%, catalyst concentration of 0.45wt% and a temperature of 60℃. In the second part of this work, a four-stroke, single cylinder, direct injection (DI), naturally aspirated (NA) diesel engine was used to investigate the engine performance and emissions fuelled with neat diesel fuel biodiesel blends. The engine experimental results showed that exhaust emissions including carbon monoxide (CO), smoke and engine noise were reduced with all biodiesel blends, while the NOx emission was found to be higher compared to baseline diesel fuel. Engine thermal efficiency was lower and the brake specific fuel consumption was higher with biodiesel blends.*

Keywords – Alternative fuel, biodiesel, engine emissions, pithraj oil, transesterification process.

1. INTRODUCTION

Due to price hikes in 80's and depletion of petroleum fuels at an alarming rate, fuel researchers have been forced to explore alternative fuels for internal combustion engines. 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 [1]. There are several techniques to reduce the viscosity of vegetable oils. The techniques are dilution, pyrolysis micro emulsion and transesterification [2]. 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 transesterification. 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 [3]. Not only biodiesel is an alternative fuel, but also an oxygenated fuel as biodiesel contains around 11% oxygen in its molecule.

It is widely accepted that biodiesel offers several advantages including biodegradable, non-toxic and no sulfur content [4]. In addition to these properties, biodiesel has excellent lubricating properties and even no engine modification is needed when the engine is fuelled with biodiesel. Biodiesel can be blended at any ratio to petroleum diesel fuel. Several reports [5]-[8] elucidated lower soot/PM, CO and THC emissions with biodiesel. Most studies have reported increased NOx emission from BD without using any after treatment system [9], [10]. However, some studies have reported decreased NOx emission [11]-[12]. The purposes of this study are to produce biodiesel from a new renewable source of energy (inedible pithraj oil) and to investigate the engine performance and exhaust emissions with different biodiesel blends. To compare the results with those of a baseline diesel fuel and to suggest an alternative fuel from the different biodiesel blends are the additional targets of the current investigation.

2. MATERIALS AND METHODS

2.1 Materials

Pithraj seeds are the source of inedible renewable energy. It can be cultivated even in the barren lands and without much care and irrigation. In Bangladesh, it is cultivated to provide live hedge for farms to arrest the menace of stray cattle. In the current investigation, pithraj fruits were collected locally from Rajshahi, Bangladesh. About 20 kg seeds can be collected from a plant.

Figure 1 shows the pithraj plants and seeds. The amount of seeds per plant depends on the quality of the plant. The diameter of the seeds varies from 1.5 to 5 cm, the length from 1.0 to 1.5 cm and the colour of the seeds are reddish black. Each fruit contain 2 to 4 seeds. About 25 to 35% oil can be extracted from a pithraj plant

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Fig. 1. (a) Pithraj tree (b) Pithraj fruits and seeds.

2.2 *Test Procedure*

The engine used in this experiment was a single cylinder, water cooled naturally aspirated, 4-stroke, DI diesel engine. The specifications of the engine are shown in Table 1. A flue gas analyzer (IMR 1400) was used to measure the exhaust emissions. A sound level meter (CEL-228 Impulse sound level meter and analyzer) was used to record the engine noise. The dynamic fuel injection timing was set at 24°BTDC.

Table 1. Test engine specifications.

Engine type	4-stroke DI diesel engine
Number of cylinders	One
Bore x Stroke	80 x 110 mm
Swept volume	553 cm^3
Compression ratio	16.5:1
Rated power	4.476 kW@1500 rpm
Fuel injection timing	24°BTDC

The engine was started with diesel fuel and warmed up for 45 minutes. The measurements were performed when the engine was in stable condition. The experiments were conducted at an optimized engine speed of 950 rpm (result not shown). The optimization was based on the engine thermal efficiency. All experimental data were taken three times and the mean value of the three was used. The volumetric blending ratios of biodiesel to diesel fuel were set at 10%, 20%, and 30%. The diesel fuel used in this study was No. 2 diesel as a baseline fuel.

3. RESULTS AND DISCUSSIONS

3.1 *Parameters Optimization for Maximum Biodiesel Yield*

Effect of Methanol Concentration on Biodiesel Yield

In order to investigate the effect of methanol (CH_3OH) content on biodiesel yield by transesterification process, experiments were performed with catalyst (NaOH) concentration of 0.50 wt% and the temperature was kept at 60°C [10]. Figure 2 shows the effect of methanol concentrations on biodiesel yield. The experiments were conducted with various methanol concentrations ranging from 15 to 26%. It can be seen that the biodiesel yield increases with the increase of methanol concentrations and reaches maximum at 22% and then decreases. This is due to fact of incomplete conversion of oil to biodiesel with lower methanol concentration. Higher than 22 vol% methanol concentration results to difficulty in separating the methyl ester (biodiesel) from water layer. This is attributed to the fact that methanol has one OH group, which assists emulsification. Thus, addition of excess methanol causes complication in the separation process results in lower biodiesel yield.

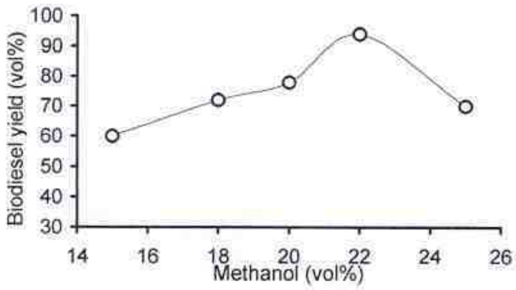

Fig. 2. Variation of biodiesel yield with methanol percentages (NaOH=0.50 wt%, temperature=60°C).

Effect of Catalyst Concentration on Biodiesel Yield

The experiments are extended by varying the catalyst (NaOH) concentration. The variation of biodiesel yield with catalyst concentrations is shown in Figure 3. The catalyst concentrations are varied from 0.35 to 0.5 wt% with 18 to 25 methanol percentage. It can be seen from the figure that the biodiesel yield increases with the increase in catalyst concentrations and reaches maximum at 0.45 wt%. The biodiesel yield decreases after 0.45 wt%. A maximum of 96% biodiesel is obtained with a catalyst concentration of 0.45 wt%. Inadequate amount of catalyst concentration results in incomplete conversion of triglycerides (pithraj oil contains triglycerides) into biodiesel as evidenced from its lower biodiesel yield. However, when the catalyst concentration is increased from 0.45 to 0.50 wt%, the biodiesel yield drops from 96% to 94%. This is due to soap formation with excess catalyst concentration. The excess catalyst takes part in saponification reaction results in biodiesel yield reduction. It has been reported earlier that excess NaOH caused soap formation resulted in ester yield reduction [13]. It can be observed from the figure that biodiesel yield is maximum with 22 vol% methanol. Lower or higher than 22 vol% results in biodiesel yield reduction as explained in Figure 2.

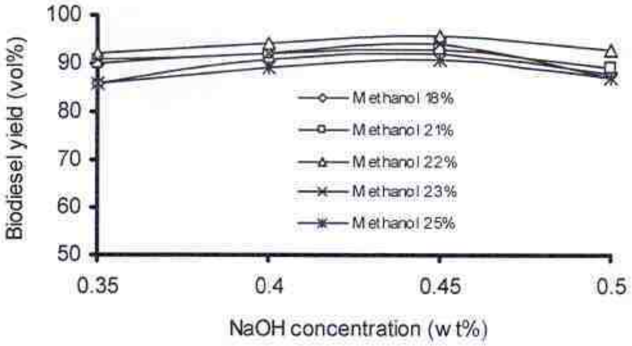

Fig. 3. Variation of biodiesel yield with catalyst (NaOH) concentration (temperature=60°C).

Effect of Temperature on Biodiesel Yield

The effect of temperature on biodiesel yield is shown in Figure 4. For this experiment, the temperature was varied from 40 to 65°C. The optimum methanol and catalyst concentrations were kept constant at 22% and 0.45% respectively. It can be seen from the figure that biodiesel yield increases up to temperature of 60°C and then decreases. At lower or higher temperature than 60°C, biodiesel yield is lower. This is attributed to the incomplete transesterification reaction at lower temperature, while the lower biodiesel yield at higher than 60°C temperature is due to evaporation of methanol (boiling temperature of methanol is 64.7°C) leading to incomplete transesterification reaction. Leung *et al.* [13] made biodiesel with canola and used frying oil and reported maximum ester yield at 45 and 60°C, respectively. Based on the discussions in sections 3.1.1, 3.1.2 and 3.1.3, the optimum conditions for maximum biodiesel yield are: methanol concentration of 22 vol%, catalyst concentration of 0.45 wt% and a reaction temperature of 60°C.

Test Fuel Properties

Table 2 illustrates the comparison of different fuel properties with neat diesel, biodiesel and pithraj oil. The cetane index of biodiesel was higher than that of diesel fuel. The higher cetane index with biodiesel indicates earlier ignition. The heating value of biodiesel is lower than that of diesel fuel due to oxygen content in biodiesel molecule. The density and viscosity were found closer to diesel fuel. The flash point and fire point are higher than those of diesel fuel. The higher flash and fire points with biodiesel indicate safer transportation of fuel.

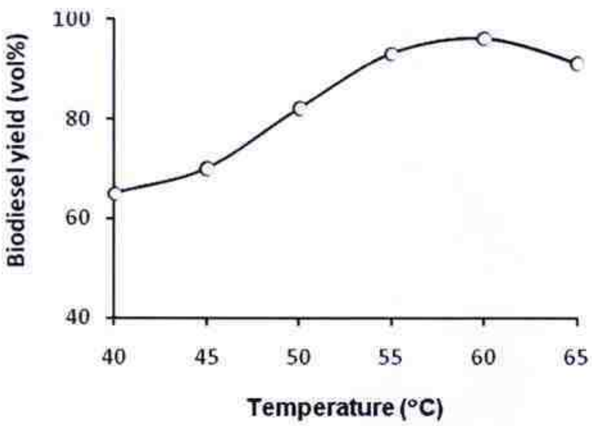

Fig. 4. Variation of biodiesel with temperature (Methanol concentration=22 vol%, NaOH=0.45 wt%).

Table 2. Test fuel specifications.

Properties	Neat diesel	Pithraj oil	Neat biodiesel
Density (gm/cc) @ 15°C	0.86	0.948	0.87
Viscosity (cSt) @ 23°C	4.98	8.04	6.22
Higher heating value (kJ/kg)	44579	36200	38588
Cetane index	47	42	51
Flash point (°C)	74	243	153
Fire point (°C)	84	249	164
PH value	7.00	8.30	7.00-7.46

3.2 Engine Performance

Brake Specific Fuel Consumption (bsfc)

The BSFC was calculated using Equation 1.

$$BSFC = \frac{\dot{m}_f}{BP} \quad (1)$$

where, BP represents the brake power available at the crank shaft in kW and $\dot{m}_f$ represents the fuel mass flow rate in kg/hr.

Figure 5 illustrates the BSFC with neat diesel fuel and different biodiesel blends. The BSFC decreases with the increase in engine loads and becomes minimum at around 4 bar and then again increases. It can be seen from the figure that the BSFC for biodiesel blends are higher for all engine loads compared to neat diesel fuel. This is due to the fact of lower energy content (heating value) in biodiesel blends.

Engine Thermal Efficiency

The variation of engine thermal efficiency for the same fuels mentioned in Figure 5 is shown in Figure 6. The thermal efficiency was calculated with Equation 2.

$$\eta_b = \frac{BP \times 3600 \times 100}{\dot{m}_f \times HV} \quad (2)$$

where, η_b indicates the thermal efficiency in percent, HV shows the heating value of the fuel in kJ/kg.

It can be observed from the figure that with the increase in engine load the thermal efficiency increases and reaches maximum at around 4 bar and then decreases. This trend is observed for all fuels. Biodiesel blends show lower thermal efficiency than that of diesel fuel. The thermal efficiency is inversely proportional to the BSFC and vise versa as can be seen from equations 1 and 2. The higher BSFC with biodiesel blends resulted in lower thermal efficiency relative to neat diesel fuel. This is associated with the lower energy content (heating value) and higher viscosity with the biodiesel blends as explained in Section 3.2.1. Previous research reports revealed that engine thermal efficiency was lower with biodiesel [14]-[16].

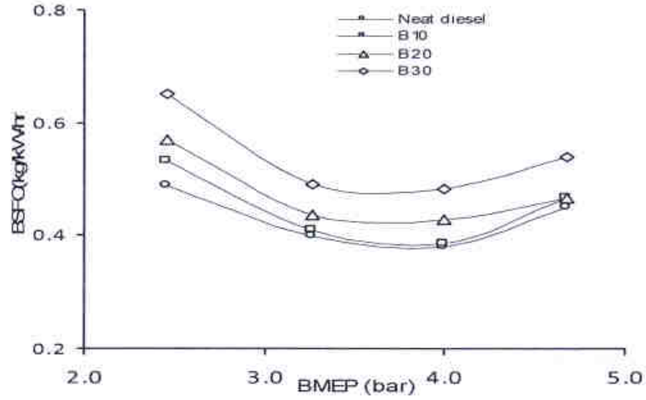

Fig. 5. BSFC with different fuels (engine speed = 950 rpm).

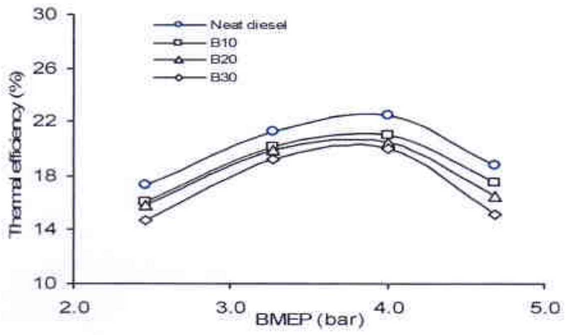

Fig. 6. Thermal efficiency with neat diesel and biodiesel blends (engine speed = 950 rpm).

Brake Power

Figure 7 represents the variation of brake power with neat diesel fuel, B10, B20 and B30 fuels. It is observed from the figure that as the load increases, brake power increases upto certain level and then decreases for all the fuel samples. The power output for the biodiesel blends are lower than that of neat diesel fuel. As can be seen from Table 2 that biodiesel has about 11% lower energy content (heating value) than that of neat diesel fuel. Lower energy content in the biodiesel blends are the reason of lower power output.

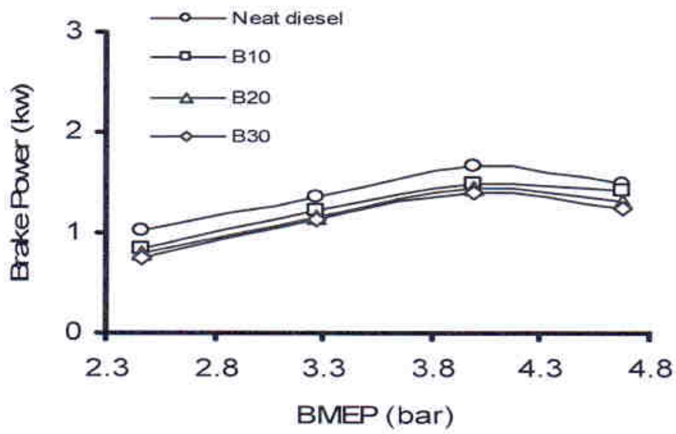

Fig. 7. Brake power with neat diesel and biodiesel blends (engine speed = 950 rpm).

3.3 Exhaust Emissions

NO_x Emission

Diesel NOx formation depends on flame temperature, residence time and available oxygen. The variation in NOx emission with neat diesel fuel and three different biodiesel blends are shown in Figure 8. Higher NOx emission is resulted in for all biodiesel blends compared to the neat diesel fuel. The higher NOx emission with biodiesel blends could be associated with oxygen in biodiesel molecule. The higher NOx emission with biodiesel blends not only depends on fuel oxygen, but also the injection advance and the unsaturated compounds in biodiesel. Though the unsaturated compounds of biodiesel are not determined and injection timing with respect to crank angle is not measured in the current investigation, it is believed that there will be higher unsaturated compounds in the biodiesel and the injection will be earlier than diesel injection. However, further investigation on NOx emission with biodiesel blends is necessary. Compared to neat diesel fuel, average NOx emission with B10, B20 and B30 fuels are found to be higher by 14.4, 25.5 and 33.3%, respectively. It has been reported earlier that biodiesel increases NOx emission, thus, authors current result is a good agreement with the earlier reports [17]-[18].

Carbon Monoxide (CO) Emission

It is widely accepted that the CO emission results from incomplete combustion of fuel rich region. The effect of biodiesel addition to diesel fuel on CO emission is shown in Figure 9. It is interesting to note that all biodiesel blends reduce CO emission compared to neat diesel fuel. This is attributed to the fact of additional oxygen in biodiesel molecule. The fuel oxygen makes the fuel rich region to fuel leaner region resulted in a lower CO emission. Compared to neat diesel fuel, B10, B20 and B30 reduce CO emission by 12.2, 22.1 and 29.7%, respectively.

Smoke Emission

Smoke emission results from the incomplete combustion of fuel. Figure 10 shows the smoke emission for neat diesel fuel, B10, B20 and B30 fuels for wide operating load ranges. It is clearly seen from the figure that all biodiesel blends reduce smoke emissions at all engine loads compared to neat diesel fuel. The reductions are higher with higher biodiesel blends. The explanation of lower smoke emission using biodiesel blends is the fuel oxygen. The additional fuel oxygen enhances more complete combustion, as a result of lower smoke emission. Most of the previous studies reported lower smoke emission with biodiesel [19]-[21].

Engine Noise

The engine noise comes from the mechanical linkage in the engine cylinder and thrust of combustion product. Figure 11 illustrates the variation of engine noise with neat diesel fuel, B10, B20 and B30 fuels. From the figure it is seen that the engine noise for the biodiesel blends are lower than that of neat diesel fuel at all engine loads. The significant engine noise reduction with biodiesel blends are found to be at high engine loads.

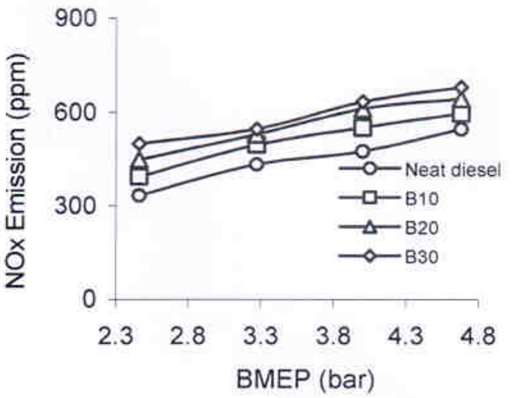

Fig. 8. NOx emission with neat diesel and biodiesel blends (engine speed = 950 rpm).

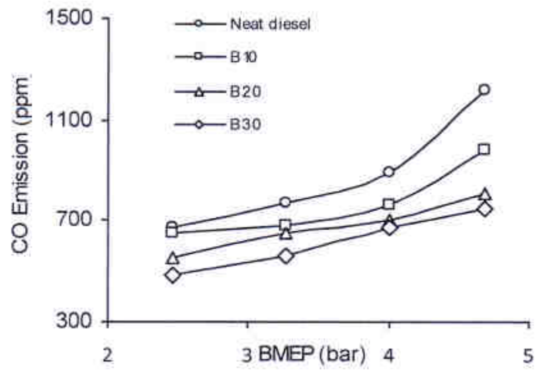

Fig. 9. CO emission with neat diesel and biodiesel blends (engine speed = 950 rpm).

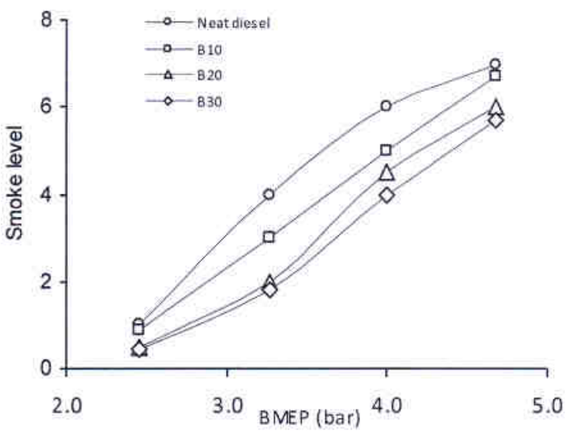

Fig. 10. Smoke emission with neat diesel and biodiesel blends (engine speed = 950 rpm).

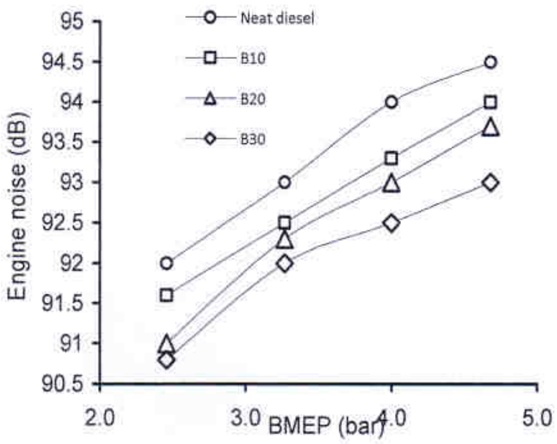

Fig. 11. Engine noise with neat diesel and biodiesel blends (engine speed = 950 rpm).

4. CONCLUSIONS

In this work, biodiesel was produced from a new renewable energy source (pithraj oil) and the engine performance and exhaust emissions with biodiesel were investigated. The results of this work can be summarized as follows.

1. Biodiesel from pithraj oil was produced by the well-known transesterification process. A maximum of 96% methyl ester (biodiesel) was found at 22 vol% methanol, 0.45wt% NaOH and 60°C reaction temperature.
2. The different properties of neat diesel fuel, pithraj oil and biodiesel were determined and compared with those of conventional diesel fuel. The properties of biodiesel were close to diesel fuel and some cases better than those of diesel fuel, cetane index for instance.
3. Compared to neat diesel fuel, the biodiesel blends showed lower CO, engine noise and smoke emissions. On the other hand, higher NOx emission was resulted in with biodiesel blends. The reductions in CO, and smoke emissions and the increase in NOx emission were mainly due to fuel oxygen in biodiesel blends. Although, the increase in NOx emission with biodiesel not only depended on fuel oxygen, but also might be injection advance and the unsaturated compounds and thus, needs further investigation.
4. Compared to neat diesel fuel, all biodiesel blends showed lower engine thermal efficiency. This was due to the higher viscosity and lower energy content in biodiesel blends.
5. Based on the emissions, B10 can be suggested as alternative fuel for diesel engine.

NOMENCLATURE

BMEP	brake mean effective pressure
BSFC	brake specific fuel consumption
B30	30% biodiesel and 70% diesel
B20	20% biodiesel and 80% diesel
B10	10% biodiesel and 90% diesel
CH_3OH	methanol
CO	carbon monoxide
CO_2	carbon dioxide
cSt	centistokes

DI	direct injection
dB(A)	decibel(A)
kg	kilogram
kW	kilowatt
NaOH	sodium hydroxide
°C	degree celsius

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