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Performance Characteristics Analysis of Small Diesel Engines Fueled with Different Blends of Mustard Oil Bio-diesel

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Abstract

Energy is the prerequisite for modern civilization. Fossil fuel is still the main source of energy. But the endless consumption of fossil fuel has brought its reserve about to an end. As a result, fuel prices are gouging as a consequence of spiraling demand and diminishing supply. So we are always in search of alternative and cost effective fuels, to meet our need. Diesel engines are more efficient and cost-effective than other engines. So diesel engines have versatile uses (i.e. automobiles, irrigation, power plants etc.). That is why; consumption of diesel fuel is much higher than other gasoline fuels. This paper estimates the feasibility of **mustard oil** as an alternative fuel for diesel engine. Mustard is a renewable plant, widely growing in almost everywhere in Bangladesh. In this study, mustard oil is converted to bio-diesel by well known trans-esterification reaction. Bio-diesel has different fuel properties than diesel fuel. So other than modification of the engine or the fuel supply system, blends of bio-diesel (i.e. **B20, B30, B50** etc,) has been used. Finally, a comparison of engine performance for different blends of bio-diesel has been carried out to choose the correct blend for different operating conditions.

Keywords: *Mustard oil, Bio-diesel, Blends of bio-diesel, Trasn-esterification.*

1. Introduction

Still in the 21^{st} century, we are much dependent on petrochemical reserve (*i.e.* coal, gasoline, crude oil etc.) to satisfy our energy demand. The energy demand is on increase from year to year. According to IEA report [1], the TPES in Bangladesh in 1985 was 16000 ktoe which subsequently increased to 26000 ktoe (increase about 62.5% in 12 years) in 1997. In Bangladesh about 16.5% of total energy need is satisfied by crude oil import. In our country we have a very limited crude oil reserve. So to satisfy our demand we are fully dependent on crude oil import from foreign countries. In 2007, Bangladesh imported about 1219 ktoe of crude oil to satisfy our gasoline demand. According Bangladesh Statistical year book 2008, Bangladesh spent 4.5 billion U.S. dollar equivalent to 31 thousand crores as fuel bill for the last fiscal year. Among various gasoline fuels, diesel fuel is most widely used as it proves higher energy density (*i.e.* more energy can be extracted from diesel as compared with the same volume of gasoline fuel) than other gasoline. Therefore diesel engines have versatile uses in heavy-duty transportation, power generation and also in agricultural sectors. That's why the consumption of diesel is much higher than other gasoline. According to IEA report, Bangladesh imported about 2053 tones of crude diesel in 2007 which is 20% higher than 1997. As the underground crude oil reserve is non-renewable, so its reserve is decreasing rapidly due to gradual increase in its consumption. This phenomenon drives us to search for an alternative and renewable substitute of diesel fuel.

Moreover, the growing concern about environmental issues in the 90's (i.e. clean air act) has increased the interest in alternative fuels paving the way to greater funding and effort for research studies. The increasing amount of greenhouse gases (ghg) such as CO_2 which causes global worming and climate change as well as the declining reserve of fossil fuels, and more importantly, the high fuel prices have strongly increased the interest in the use of bio-oils and biodiesel for land, transport and power generation. The sources of bio-fuels are renewable, and their use ensures reduced amount of particulate matter, HC and NO_X emission to the environment. Thus bio-fuels can emerge as an excellent alternative to fossil fuels.

The use of vegetable oils as an alternative fuel for diesel engines dates back to around a century. Due to rapid decline of crude oil reserve and increase in price, the use of vegetable oils is again prompted in many countries. Depending upon soil condition and climate, different nations are looking for different vegetable oils- for example, soybean oil in U.S.A., rapeseed and sunflower oil in Europe, palm oil in Malaysia and

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Indonesia, coconut oil in Philippines are being considered as substitute to diesel [2]. Bio-diesel production from mustard oil has been found to be a promising alternative to diesel in a number of studies [3]. Mustard is a widely growing seed in Bangladesh. It is generally used in cooking. Every year the production of mustard seed surpluses our demand for it. This paper shows the prospect of mustard oil as a renewable and alternative source to diesel engine fuel.

2. Bio-diesel vs. Straight Vegetable Oil

Biodiesel is produced from vegetable oils. The main components of vegetable oil are triglycerides. Triglycerides are esters of glycerol with long chain acids, commonly called fatty acids. Bio-diesel is defined as mono alkyl esters of long chain fatty acids derived from renewable feed stock-such as vegetable oil or animal fats, for use in compression ignition (CI) engines [4]. This name is given to the esters when they are for used as fuel.

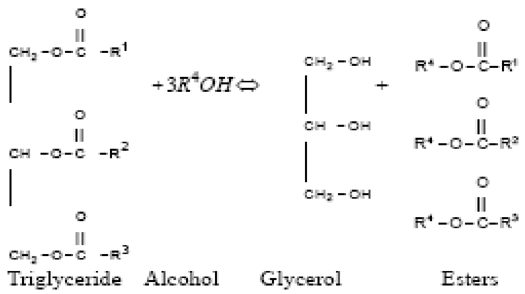
Problems associated with using straight vegetable oil (SVO) in diesel engine can be classified in two groups, namely: operational and durability problems. Operational problems are related to starting ability, ignition, combustion and performance. Durability problems are related to deposit formation, carbonization of injection tip, ring sticking and lubrication oil dilution. The problems associated with using SVO can be listed as below:

- It has been observed that SVO when used for long hours, tend to choke the fuel filter because of high viscosity and insoluble present in the SVO.
- High viscosity of SVO causes poor fuel atomization, large droplet size, and thus high spray jet penetration. The jet also tends to be a solid stream instead of a spray of small droplets. As a result, the fuel is not distributed or mixed with the air required for burning in the combustion chamber. This results in poor combustion accompanied by loss of power and economy.
- SVO has lower energy density than fossil diesel which causes higher BSFC for diesel engines.
- To use SVO efficiently in diesel engine, modification of fuel supply system and engine redesign is required; which is much costly.

Blending, cracking/ pyrolysis, emulsification or transesterification of vegetable oil may overcome these problems. Heating and blending of vegetable oil reduces the viscosity and improve volatility of vegetable oil but its molecular structure remains unchanged; hence polyunsaturated character remains. Blending of vegetable oils with diesel however reduces the viscosity drastically and the fuel handling system of engine can handle the vegetable oil diesel blends without any problems. On the basis of experimental investigations, it is found that converting vegetable oils into simple esters is an effective way to overcome all the problems associated with using SVO.

3. Trans-esterification Reaction

Transesterification, also called as alcoholysis is the displacement of alcohol from an ester by another alcohol in a process similar to hydrolysis except that an alcohol is used instead of water [5]. This has been widely used to reduce the viscosity of the triglycerides. The transesterification is expressed by the following reaction.



Experimental study shows that the major variables affecting the transesterification reaction are [6]:

- The free fatty acid (FFA) and the moisture content.
- Type of Catalysist.
- A literature (Freedmen et. Al. 1984) has revealed that, the rate of reaction is strongly influenced by the reaction temperature. (Fig. 1)

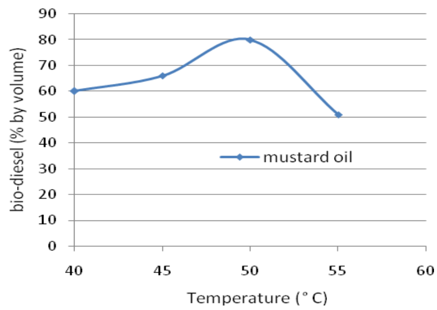


Fig. 1. Variation of biodiesel production with reaction temperature.

- Murugesan et. Al. reported that, after completion of the reaction, the product is kept for a certain time interval for separation (approx. 25 h +) of bio-diesel and glycerol separation.
- Murugesan et. Al. reported that, washing is a process to remove catalyst, soap and excess methanol.

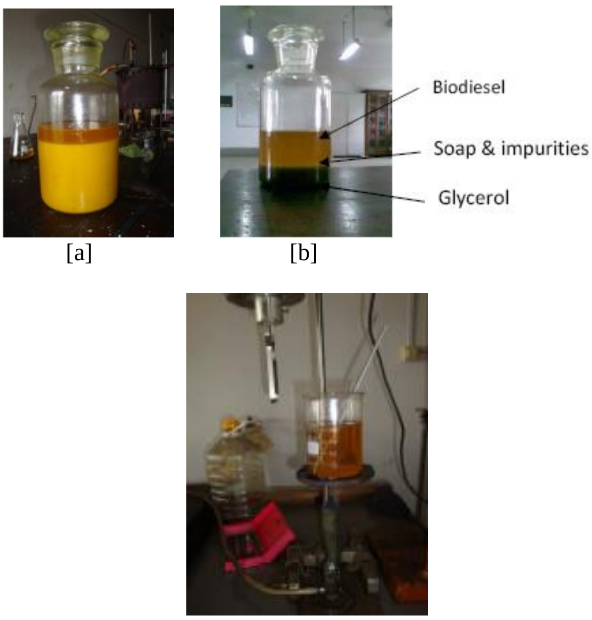
4. Procedure to Convert Mustard Oil into Bio-diesel

For the transesterification of mustard oil, Dr. Peeper's style has been followed in our work. First 250 ml (90% pure) methanol was mixed with 150 ml (1 N) NaOH. This mixture was swirled in a glass container until NaOH is fully dissolved in methanol. As this is an exothermic reaction, so the mixture would get hot. This solution is known as methoxide, which is a powerful corrosive base and is harmful for human skin. So, safety precautions should be taken to avoid skin contamination during methoxide producing.

Next, methoxide was added with 1 liter of mustard oil, which was preheated about 55° C. Then the mixture was jerked for 5 minutes in a glass container. After that, the mixture was left for 24 hours (the longer is better) (Fig. 2 (a), (b)) for the separation of glycerol and ester. This mixture then gradually settles down in two distinctive layers. The upper more transparent layer is 100% bio-diesel and the lower concentrated layer is glycerol. The heavier layer is then removed either by gravity separation or with a centrifuge. In some cases if the mustard oil contains impurities, then a thin white layer is formed in between the two layers. This thin layer composes soap and other impurities.

Bio-diesel produced in the above process contains moisture (vaporization temperature 100° C) and methanol (vaporization temperature 60° C.) and usually some soap. If the soap level is low enough (300-500 ppm), the methanol can be removed by vaporization and the methanol will usually be dry enough to directly recycle back to the reaction. Methanol trend to act as a co-solvent for soap in biodiesel; so at higher soap levels the soap will precipitate as a viscous sludge when the methanol is removed. Anyway, heating the biodiesel at temperature above 100° C would cause the removal of both the moisture and methanol as well.

In our study, food grade quality mustard oil was used, other than raw mustard oil to ensure that the vegetable oil contains lesser impurities.



[a] [b]

[c]

Fig. 2. (a) Biodiesel production after 3 hours of separation. (b) Biodiesel production after 24 hours of separation. (c) Produced biodiesel is separated and then heated to remove methanol and water.

5. Fuel Properties of Bio-diesel and Their Blends

Biodiesel produced from mustard oil has comparable fuel properties with the conventional fossil diesel. A comparative study of fuel properties for fossil diesel, neat biodiesel and their blends have been carried out in this work to find out the suitable blending of biodiesel. In our study, we have prepared **B20, B30, B40, B50** and **B100** blend to compare the fuel properties.

5.1. Heating Value of Bio-diesel and their Blends

Heating value indicates the energy density of the fuel. In our study, **ASTM 2382** method has been applied to measure the heating value of biodiesel and their blends. Table 1 shows the heating value of diesel, neat biodiesel and their blends in MJ/Kg.

Table 1 comparison of heating value of different fuels

	Heating value (MJ/Kg)
Fossil Diesel	44.00
B20	42.65
B30	42.21
B40	42.18
B50	41.97
Neat biodiesel B100	39.51

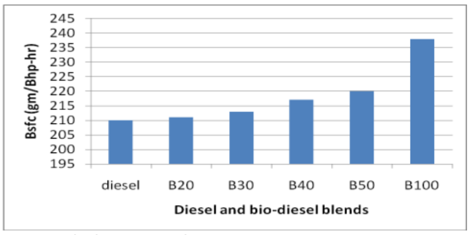


Fig. 3. Bsfc for diesel fuel and biodiesel blends at Bhp 3 Hp

From table 1 it is observed that, diesel fuel has heating value about 44 MJ/Kg. Heating values of the fuel decreases as we choose higher blending of biodiesel. Fig. 3 indicates that diesel fuel has Bsfc about 210 gm/Bhp hr, and B50 blend has Bsfc about 220 gm/Bhp hr which is 5% higher than the diesel fuel. As heating value of the fuel decreases for higher blending of biodiesel, so Bsfc of the fuel also increases for higher and higher blending of biodiesel. This is because as biodiesel has lower energy density than diesel fuel, so higher amount of biodiesel is required for producing same amount of energy as compared to diesel fuel. Neat biodiesel B100 has 10% lower heating value as compared to diesel fuel. So it requires about 13% extra fuel to produce the same amount of energy.

5.2. Density

Density is an important property of CI engine fuel. Fig. 4 shows density for diesel, biodiesel and their blends.

From fig. 4 it is observed that B20 and B30 have almost same density as that of fossil diesel at room temperature (30 ° C). So preheating is not required for using B20 and B30. B40 has about 1.50% higher density than fossil diesel, and it attains same density as that of diesel fuel at 55 ° C. So preheating B40 fuel at this temperature is necessary for using it in CI engine. Similarly B50 has 2.5% higher density than that of diesel fuel. And at temperature 60 ° C, it attains the same density as that of diesel fuel. For B100, it has about 5% higher density than diesel fuel, and it requires preheating at 120 ° C to attain similar density as that of diesel fuel. From fig. 4 we find that, density of the fuel increases with the increase in blending number. On the other hand, the exhaust from CI engine has temperature around 250 ° C. So, for using higher blending number, the intake manifold of the engine should be redesigned so that preheating can be done utilizing the exhaust of CI engine.

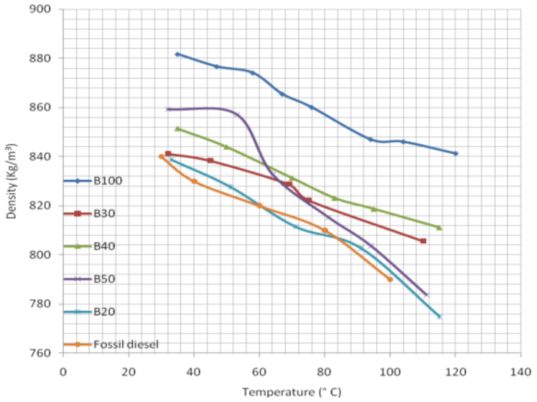


Fig. 4. Temperature vs. density curve for diesel, biodiesel and their blends.

5.3. Viscosity

Viscosity of the fuel exerts a strong influence on the shape of the fuel spray; high viscosity for example, causes low atomization (large-droplet size) and high penetration of the spray jet. Note that a cold engine, with higher viscous oil, discharge wills almost a solid stream of fuel into the combustion chamber and starting may be difficult while a smoky exhaust will almost invariably appear. On the other hand, very low viscous fuel would cause to pass thorough the leakage of piston and piston wall especially after wear has occurred, which subsequently prevents accurate metering of the fuel.

Fig. 5 indicates that, B20 has 1.5 times higher viscosity than fossil diesel at the room temperature. On the other hand, B30, B40 and B50 have almost the same viscosity at room temperature, and it is about 2.5 times higher than the fossil diesel. But a slight preheating would cause to achieve comparable viscosity as that of diesel fuel. So using B20, B30, B40 and B50 blend would not cause much change in the fuel spray pattern, and thus these fuels can be used in the existing diesel engines without modification of the fuel supply system.

On the other hand B100 is a much viscous fuel, and its viscosity is about 6 times higher than that of diesel fuel. The high viscous fuel would exhibit almost a solid stream of spray pattern in the combustion chamber and so cold starting of the engine would be difficult. So, using B100 fuel in the existing diesel engine would require modification of the fuel supply system so that the fuel supply system exerts high spray pressure to achieve the desired spray pattern inside the engine cylinder.

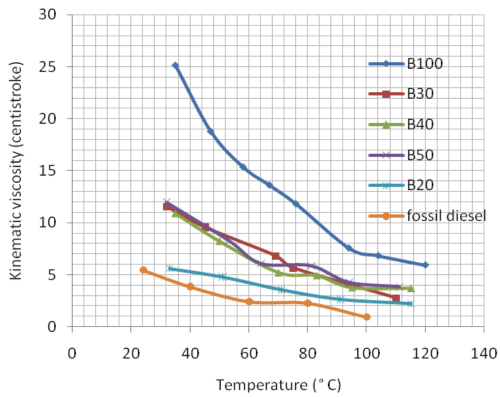


Fig. 5. Temperature vs. kinematic viscosity curve for diesel, biodiesel and their blends.

5.4. Cloud Point & Solidifying Point of Bio-diesel

Cloud point and solidifying point is another important property of fuel which should be taken into account, especially for colder countries. Pure biodiesel B100 has cloud point at -6° C and solidifying point at -11.5 ° C. So, for our country it is not required to use antigel or pour point depressant while using B100 even in winter times.

However for colder countries where the atmospheric temperature is below the solidifying point of B100, starting a colder engine would be much difficult as waxing of B100 may clog the fuel filter & fuel supply line as well. An easy solution of this would be to use additive (i.e. antigel or pour point additive). The additives that are formulated for petroleum diesel would not work well with biodiesel. Some of the additives that are formulated for biodiesel are listed as below:

- Wintcorn XC30
- Lubrizol biodiesel cold flow antigel
- Arctic express biodiesel antigel.

6. Engine Performance Analysis with Bio-diesel and their Blends

The final product of biodiesel from mustard oil was used as an alternative fuel to operate a diesel engine and the performance data were recorded. All data was derated as per **BS5514** standard. The specification of the engine is given in table 2.

Table 2 Engine specifications

Model	Z170F
Method of starting	Hand starting
type	Horizontal, 4-stroke, 1 cylinder
Cylinder dia	70 mm
Piston stroke	70 mm
Nominal speed	2600 rpm
Rated power	2.94 Kw
Cooling system	Air cooled
rotation	Anti-clockwise
Fuel filter	Present
Lube oil filter	present

6.1. Viscosity

The experimental setup (Fig. 6) consisted of engine test bed with fuel supply system and different metering and measuring devices with the engine. A water brake dynamometer was coupled with the engine. Load was varied by means of flow control of the dynamometer. Fuel was supplied from an external source. Preheating of fuel was done manually by gas burner. B40 blend was preheated at 55 ° C and B50 blend was preheated at 60 ° C. B100 was preheated at temp. 90 ° C. Engine speed was measured by digital tachometer. Lube oil temperature and exhaust gas temperature was measured by K-type thermocouple. Operating condition of the engine is given in table 3.

Table 3 Engine operating conditions

Engine speed	2200 rpm
Engine load	1kg to 3.5 kg
Fuels tested	100% diesel, B20, B30, B40, B50 and B100.
Lube oil used	SAE-40

Fig. 6. Experimental setup

6.2. Comparison of Engine Performance

Fig. 7 shows the variation of Bsfc with Bhp for different fuels. The curve shows that, Bsfc for biodiesel blends is higher at low % load. And it decreases with the increase in % load. It is also observed from the curve that, specific fuel consumption increases with the increase in biodiesel blend. This is mainly due to the relationship among volumetric fuel injection system, fuel specific gravity, viscosity and heating value. As a result, more biodiesel blend is needed to produce the same amount of energy due to its higher density and lower heating value in comparison to conventional diesel fuel. Again as biodiesel blends have different viscosity than diesel fuel, so biodiesel causes poor atomization and mixture formation and thus increases the fuel consumption rate to maintain the power.

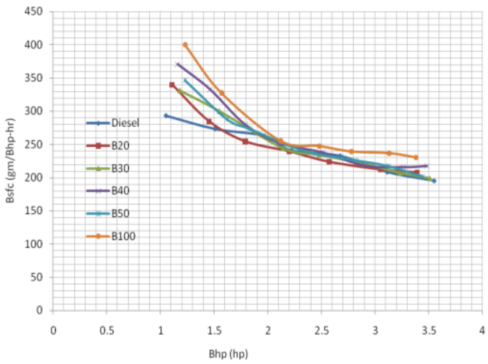


Fig. 7. Variation of Bsfc with Bhp for different fuels

Fig. 8 shows the relation in between Bhp and brake thermal efficiency η_b for different fuels. Bsfc is a measure of overall efficiency of the engine. Bsfc is inversely related with efficiency. So, lower the value of Bsfc, higher is the overall efficiency of the engine. However for different fuels with different heating values, the Bsfc values are misleading and hence brake thermal efficiency is employed when the engines are fueled with different types of fuels. From the figure, it is evident that Bsfc for biodiesel blends is always higher and η_b is always lower than that of diesel fuel. It is evident from the figure that, η_b for B100 is 20% less than the fossil diesel. B20 and B 30 has about 10~12% less η_b than diesel. So using B20 and B30 is economically viable than neat biodiesel B100. This is because biodiesel has lower heating value than conventional diesel fuel. One other cause for lower η_b for biodiesel blends is the poor atomization which is attributed to higher density and kinematic viscosity of biodiesel blends.

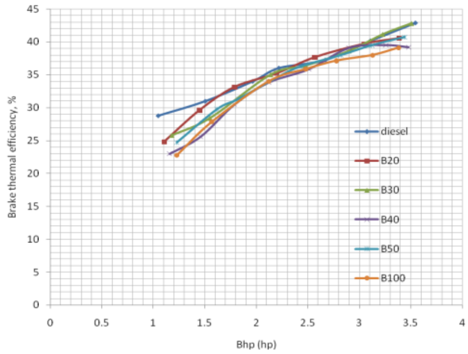


Fig. 8. Variation of Bhp with brake thermal efficiency, η_b

Fig. 9 depicts about variation in exhaust gas temperature with Bhp for different fuels. From the curve it is observed that except B30, all other biodiesel blends have higher exhaust gas temperature than diesel fuel. At starting condition, higher exhaust gas temperature but low power output for biodiesel blends indicate late burning to the high proportion of biodiesel. This would increase the heat loss, making the combustion a less efficient. At higher load condition, B30 and B40 have lower exhaust temperature as compared to diesel fuel. B100 has almost similar exhaust gas temperature as fossil diesel.

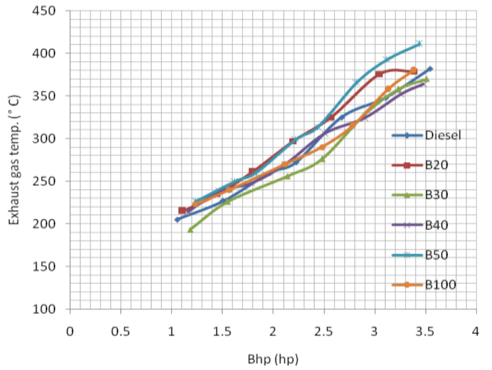


Fig. 9. Variation of exhaust gas temperature with Bhp for different fuels

Fig. 10 shows the relation in between lube oil temperature and Bhp for different fuels. At lower Bhp, diesel fuel and biodiesel blends have similar lube oil temperature. At higher % load condition, B50 shows higher lube oil temperature than other fuels. This phenomenon can be attributed to the preheating of the B50 fuel at 60 ° C. However, there is not wide variance in the lube oil temperature for diesel fuel and biodiesel blends; which indicates that SAE-40 lube oil is suitable for biodiesel run engines.

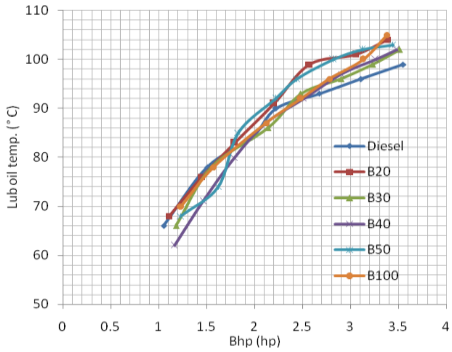


Fig. 10. Variation in lub oil temperature with Bhp for different fuels.

Fig. 11 indicates that for the engine load conditions tested, it is found that the trend of BMEP does not seem to be changed that much weather the fuel is diesel or bio-diesel blend.

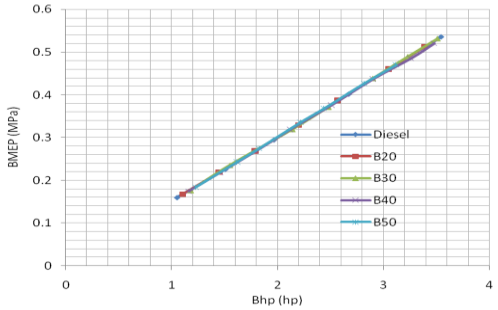


Fig. 11. Variation in BhP vs. BMEP for different fuels.

7. Cost Analysis

The present costing of running a diesel engine with biodiesel blends derived from mustard oil are given in table 4.

Table 4 Cost of running engines with different fuels

Fuel	Cost (tk/lr)
Diesel	46
B20	62.8
B30	71.2
B40	79.8
B50	88
B100	130

From table 4 it is clear that, running diesel engine with biodiesel blends is costly as compared to diesel fuel. However, cost can be drastically reduced, if methanol can be recycled after the transesterification reaction. Moreover, commercially production of biodiesel in biorefinaries may further reduce its production cost.

In Bangladesh, government grants a huge subsidy on diesel fuel, which causes the lower price for diesel fuel. So a thorough study is required for the feasibility analysis of biodiesel by comparing it production cost with international market price of diesel.

8. Conclusion

Experiment was conducted on a small four stroke diesel engine to determine the feasibility of mustard oil as an alternative to diesel engine. The following conclusions may be drawn from the experiment.

- Biodiesel can be produced from mustard oil using transesterification reaction.
- It is possible to run diesel engine with biodiesel blends.
- Bsfc for biodiesel increases for higher blending of biodiesel, because of the lower heating value of biodiesel as compared to diesel fuel.
- For using higher blending of biodiesel, the fuel must be preheated in order to reduce the density and viscosity of the fuel.
- Compared to diesel fuel, a little amount of power loss occurs for biodiesel blends. So using biodiesel does not hamper the efficiency of the engine that much. However, slight redesign of diesel engine for biodiesel fuel may overcome this obstacle.

The use of biodiesel has certain advantages over the fossil diesel. It emits cleaner emission (except for NO_x), reduces global warming and enhances rural development. Operating cost of diesel engine with biodiesel is still costly. But however, commercial production of biodiesel in biorefinaries may drastically reduce its production cost. Finally it can be concluded that, in the far future when there would be shortage in fossil fuel reserve, mustard oil can be a suitable renewable substitute to fossil diesel.

Nomenclature

TPES	:	total primary energy supply
Ktoe	:	kilo ton oil equavalent
ghg	:	green house gas
HC	:	hydro carbons
NO_x	:	oxides of nitrozen
SVO	:	straight vegetable oils
Bsfc	:	brake specic fuel consumption, gm/Bhp-hr
Bhp	:	brake horse power
LV	:	lower heating value of fuels, MJ/Kg
T	:	temperature, ° C
η_b	:	brake thermal efficiency, %

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Lab support: Fuel testing lab, Heat engine lab.

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