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PERFORMANCE COMPARISON OF DI DIESEL ENGINE BY USING ESTERIFIED MUSTARD OIL AND PURE MUSATRD OIL BLENDING WITH DIESEL

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Abstract *–Energy is indispensable for modern civilization. Fossil fuel is still the main source of energy. But the huge 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, it's an important challenge to search alternative and cost effective fuels, to meet the demand. Diesel engines are more efficient and cost-effective than other engines. This paper estimates the feasibility of mustard oil as an alternative fuel for diesel engine in two state i.e pure form and esterified form. In this study, mustard oil is converted to bio-diesel by well known trans-esterification reaction and made blend with diesel in different proportion named as B20, B30, B50 and B100. 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 has been used. On other hand, pure mustard oil (without trans-esterification) is blended with diesel named as M20, M30, M40 and M50. These blends are tested in a 4 stroke single cylinder diesel engine to determine performance. B20 as esterified and M30 as non esterified blend show the best engine performance among the blends. Finally, a comparison of engine performance for different blends of mustard oil has been carried out to choose the correct blend for different operating conditions.*

Keywords: Bio-diesel, Blend of bio-diesel, Mustard, Renewable alternative fuel, Trans-esterification process.

1. INTRODUCTION

Still in the 21st century, we are much dependent on petrochemical reserve (*i.e.* coal, gasoline, crude oil etc.) to satisfy our energy demand. Among various gasolines fuels, diesel fuel is most widely used as it proved higher energy density (*i.e.* more energy can be extracted from diesel as compared with the same volume of gasoline fuel) than other gasolines [1]. 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 gasolines [2-4]. As a result, the depletion rate of diesel is much higher which subsequently causes higher price. In Bangladesh, we have very limited petrochemical resources. So, for our energy demand we are fully dependent on crude oil import from Middle Eastern countries. Moreover, as Bangladesh imports Arabian Light Crude oil (ALC), so the cost associated with oil refining is also huge [5-8]. 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. 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 [9-10]. 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 Indonesia, coconut oil in Philippines are being considered as substitute to diesel [11]. Bio-diesel production from mustard oil has been found to be a promising alternative to diesel in a number of studies [12]. 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. So our endeavor is to use the surplus mustard oil as an alternative to diesel. This paper shows the prospect of mustard oil as a renewable and alternative source to diesel fuel [13].

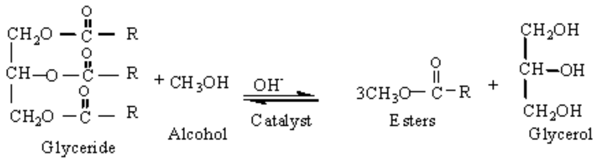
2. BIO-DIESEL VS STRAIGHT VEGETABLE OIL

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 [14].

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.

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 [15]. This has been widely used to reduce the viscosity of the triglycerides. The transesterification is expressed by the following reaction.



4. SYNTHESIS OF BIO-DIESEL FROM MUSTARD OIL

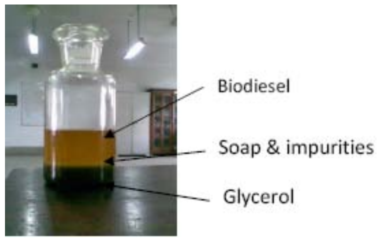
For the transesterification of mustard oil, Dr. Peepers style has been followed in our work [2]. First 250 ml (90% pure) methanol is mixed with 150 ml (1 N) NaOH. This mixture is swirled in a glass container until NaOH is fully dissolved in methanol. As this is an exothermic reaction, so the mixture 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 is added with 1 liter of mustard oil, which is preheated about 55° C. Then the mixture is jerked for 5 minutes in a glass container. After that, the mixture is left for 24 hours (the longer is better) (Fig. 1 (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.Produced bio-diesel is then heated at 110ºC to remove methanol and water (Fig.1(c)).

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 act as a co-solvent for soap in biodiesel; so at higher soap levels the soap 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 is used, other than raw mustard oil to ensure that the vegetable oil contains lesser impurities.

(a)



(b)

(c)

Fig.1 (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. PREPARATION OF PURE MUSTARD OIL BLEND WITH DIESEL

Pure Mustard oil is blended with diesel at different proportion like 20%,30%,40%, and 50% by volume. Those blends are named as M20,M30,M40,M50 and pure mustard oil M100.

5. 1. Fuel Properties of Biodiesel and their Blends

Biodiesel produced from mustard oil has comparable fuel properties with the conventional fossil diesel. A comparative study of fuel properties for esterified mustard oil i.e biodiesel blends and pure mustard oil blends have been carried out in this work to find out the suitable blend. In this study, blends prepared B20, B30, B40, B50, B100 and M20,M30,M40,M50, M100 blend to compare the fuel properties.

5.2 Heating Value

Heating value indicates the energy density of the fuel. In this 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

Fuels	Heating value (MJ/Kg)
Fossil Diesel D100	44.00
Neat biodiesel B100	39.51
B50	41.97
B40	42.18
B30	42.21
B20	42.65
Pure Mustard M100	32.43
M20	41.3
M30	39.00
M40	36.7
M50	34.462

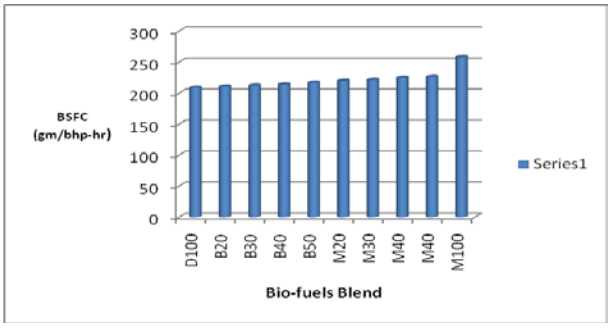


Fig.2: Bsfc for pure mustard and biodiesel blends at 12 Bhp

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.. 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.From fig:2 it is evident that M100 i.e pure mustard oil has the highest bsfc.

5.3. Density

Density is an important property of CI engine fuel. Figure 3 shows density for diesel, biodiesel and their blends.
From Figure 3 it is observed that pure mustard shows the highest density than any other blends,then B100, M50 are closer, and M40,M30,B40 shows closer density eacth other.M20,B20 and pure diesel density is very much closer to each other.Pure diesels density is the lowest among the fuel blends.In comparison with diesel fuel B20 and B30 has same density at room temp.B40,B50,B100 has 1.5,2.5, 5 times higher density than diesel fuel at room temperature (31° C).For pure mustard oil blend M20,M30,M40,M50 and M100 has 1.88,2.66,3.59,4.58,12 times higher density than diesel fuel.Pre-heating does not require for M20 and M30 blend to run the engine.But M40,M50 and M100 requires preheating at 120 ° C to run the engine smoothly. The noise level & vibration of the engine increased remarkably while testing is performed using M100 .

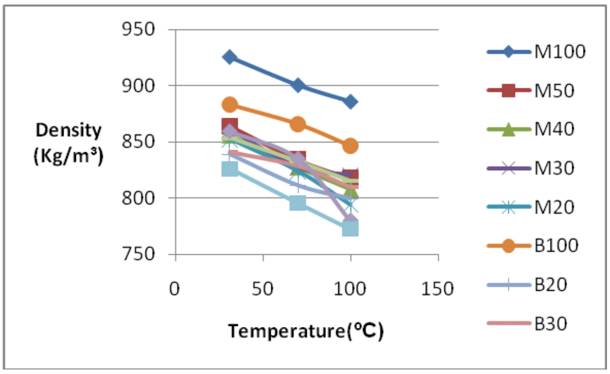


Fig.3: Temperature vs. density curve for diesel, biodiesel and their blends.

5.4.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. A cold engine, with higher viscous oil, discharge will 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 through the leakage of piston and piston wall especially after wear has occurred, which subsequently prevents accurate metering of the fuel.

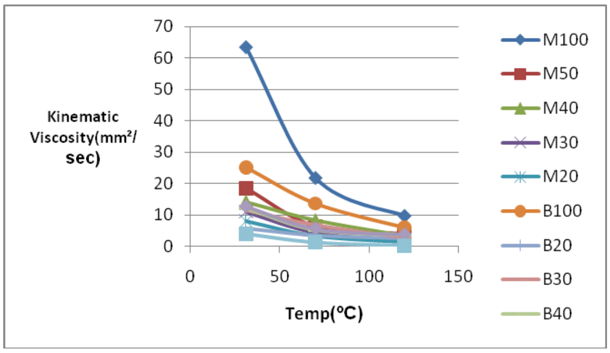


Fig.4: Temperature vs. kinematic viscosity curve for diesel, biodiesel and their blends

from Figure. 4 it is observed that M100 shows the highest viscous fuel.After that B100,M50, shows the 2nd highest viscous fuel. 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.

Besides, M20 has 2.04 times higher,B30 has 2.78 , B40 has 3.56 and B50 has 4.67 times higher viscosity than the fossil diesel at room temperature. But a slight preheating would cause to achieve comparable viscosity as that of diesel fuel.
On the other hand, M100 is a much viscous fuel, and its viscosity is about 16 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 M100 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.
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6. ENGINE PERFORMANCE TESTING AND ANALYSIS

Pure mustard blends and t he 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	S 195 G
Method of starting	Hand starting
type	Single Cylinder,Horizontal,Four-stroke,
Cylinder dia	95 mm
Piston stroke	115 mm
Nominal speed	2000 rpm
Rated power	9.00 KW
Cooling system	Water Cooling Evaporative
Fuel Injection Pressure(MPa)	12.75+/-0.5 kgf/cm²
Fuel filter	Present
Lube oil filter	present

6.1. Experimental Setup

The experimental setup (Fig.5) consist of engine test bed with fuel supply system and different metering and measuring devices with the engine. A water brake dynamometer is coupled with the engine. Load is varied by means of flow control of the dynamometer. Fuel is supplied from an external source. Preheating of fuel is done manually by gas burner. B40,M40 blend was preheated at 55 ° C and B50,M50 blend is preheated at 60 ° C, B100 & M100 is preheated at 120 ° C.Engine speed is measured by digital tachometer. Lube oil temperature and exhaust gas temperature is measured by K-type thermocouple. Operating condition of the engine is given in table 3.

Table 3**:** Engine operating conditions

Engine speed	2000 rpm
Engine load	6 kg to 15.5 kg
Fuels tested	100% diesel, B20, B30, B40, B50, M20, M30, M40, M50, M100
Lube oil used	SAE-40

Fig.5**:** Experimental setup

6.2. Performance Analysis

Figure 6 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.M100 shows the highest bsfc all load condition. M30 and D100 show the minimum bsfc at higher and lower load condition respectively 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.

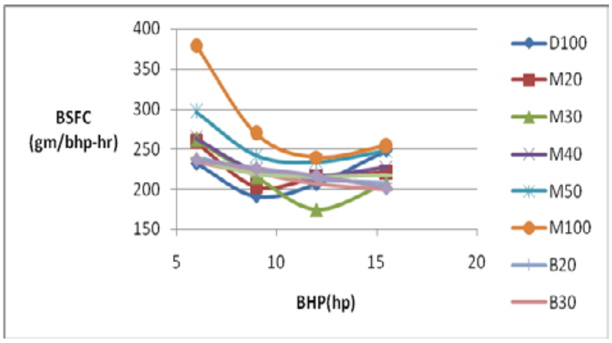

Fig.6. Variation of Bsfc with Bhp for different fuels

Figure 7 shows the relation in between Bhp and brake thermal efficiency η_b for different fuels.Minimum η_b shows for pure mustard at all load condition.Maximum η_b shows for diesel fuel and B30 blend.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 7, it is evident that Bsfc for biodiesel blends is always higher and η_b is always lower than that of diesel fuel. 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.

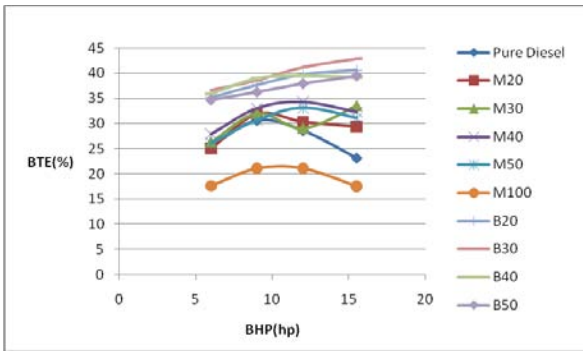

Fig.7. Variation of thermal efficiency η_b with Bhp for different fuels

Figure 8 depicts about variation in exhaust gas temperature with Bhp for different fuels. From the curve it is observed that pure mustard blends shows higher exhaust gas temperature at higher load condition than the esterified fuels.Esterified blends shows lower temp at higher load condition than the pure mustard. except B30 and M30 , all other biodiesel blends have higher exhaust gas temperature than diesel fuel at higher load condition. 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.

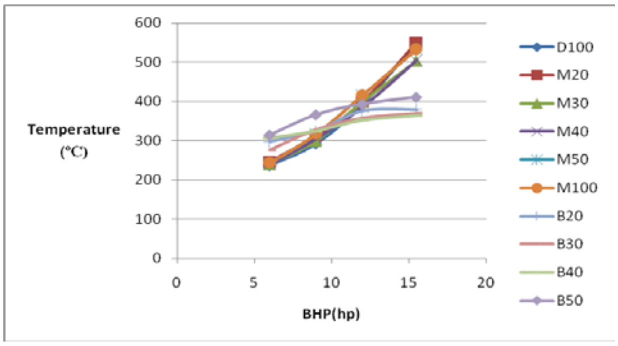

Fig.8.Variation of exhaust gas temperature with Bhp for different fuels

Figure 9 shows the relation in between lube oil temperature and Bhp for different fuels. The blends of pure mustard shows lower temperature than the esterified fuel blends in all load condition. 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.

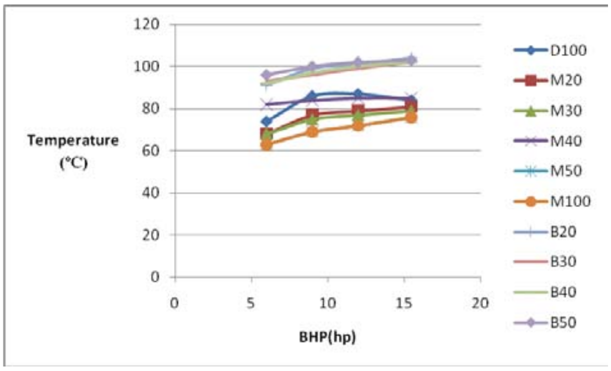

Fig.9. Variation of lube oil temperature with Bhp for different fuels

Figure 10 indicates that for the engine load conditions tested, it is found that the trend of BMEP does not seem to be changed that much whether the fuel is diesel or bio-diesel or pure mustard blend. The regular shape of the curves indicates that proper combustion of the fuels has done inside the cylinder.

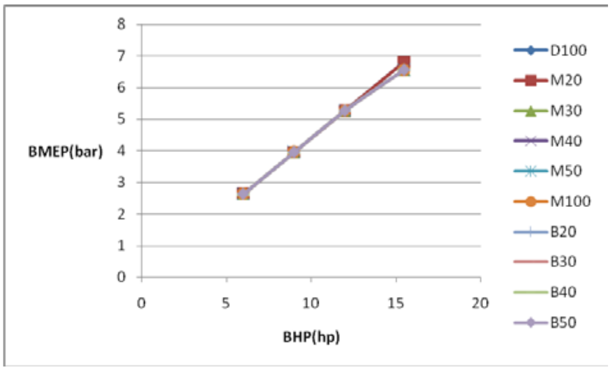

Fig.10. Variation of BMEP with Bhp for different fuels

7. CONCLUSION

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

- Diesel engine can be run by mustard oil both in pure form and esterified form.
- Biodiesel can be produced from mustard oil using transesterification reaction.

- **B**SFC for pure mustard blend is higher than the esterified fuels i.e biodiesel because of glyceraol which is responsible for high viscosity.
- BSFC 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.
- Interms of BSFC B20 as esterified and M30 as pure mustard blend shows the best engine performance.

8. NOMENCLATURE

Symbol	Meaning	Unit
M	Blend of pure mustardoil	% by volume(liter)
B	Blend of esterified Mustard	% by volume(liter)
D100	Pure Diesel	liter
BTE	Brake Thermal Efficiency	%
BMEP	Brake Mean Effective Pressure	bar
BSFC	Brake Specefic Fuel Consumption	gm/bhp-hr
BHP	Brake Horse Power	horse power(hp)
LV	Lower Heating Value	MJ/Kg
T	Temperature	°C(Celcius)
η_b	Brake Thermal Efficiency	% (Percentage)

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