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PRODUCTION AND PERFORMANCE OF BIODIESEL AS AN ALTERNATIVE FUEL FOR DIESEL ENGINE

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ABSTRACT
The increasing demand for fossil fuel can be reduced by introducing renewable and environment friendly bio-fuels, obtained from different vegetable oils. In this study, Soybean oil is used for the production of "bio-diesel" through "Transesterification" reaction. Refined vegetable oil like soybean oil contains less than 0.005% free fatty acid which is very effective for bio-diesel production. Thermo-physical properties of bio-diesel are determined and compared with those of conventional diesel. The density and viscosity of bio-diesel are found higher than diesel, which is considered as the main obstacle for using it directly as CI engine fuel. It can be overcome by preheating. In the present study, preheating technique is employed to the biodiesel blends and their effects on engine performance is investigated on an unmodified direct injection 4 stroke single cylinder engine at different load conditions with rated rpm. Specific fuel consumption increases with the increase of percentage of bio-diesel in the blends at 85ºC preheat temperature. Emission quality of the exhaust gas is tested by using IMR2800P Gas Analyzer. CO_2 emission rate shows a decreasing trend with increase of bio-diesel percentage. Unburned O_2, excess air, NOx emission also follows the same trend. Technically diesel fuel can be replaced with preheated bio-diesel but the major obstacle is the high cost of Soybean oil relative to diesel fuel.

Keywords: Biodiesel, Transestarification, Diesel Engine, Preheating, Performance, Emission Quality

1. INTRODUCTION
Majority of the world's energy needs are supplied through petrochemical sources, coal and natural gases, with the exception of hydroelectricity and nuclear energy. Diesel fuel has an essential function in the industrial economy of a developing country and is used in transports, industrial and agricultural goods, etc. An alternative fuel should be easily available, environment friendly and techno-economically competitive. One of such fuels is triglycerides and their derivatives. This paper presents a comparative performance testing of an unmodified 4 stroke single cylinder diesel engine run by preheated biodiesel produced from soybean oil. Performance test was conducted at rated rpm (2400 rpm) for different loading conditions. Initially the engine was run by diesel fuel. Then the experiments were repeated replacing diesel by biodiesel blends at 85^{o}C preheat temperature. In doing so, various engine performances are obtained, analyzed and reported. The potential of bio-diesel produced from soybean oil have been found to be a very promising fuel for diesel engines in a number of studies [1, 2, 3, 4]. Soybean is mainly used for cooking in Bangladesh. Bio-diesels from a number of other vegetations are also being tried out [5, 6]. Using straight vegetable oils in diesel engines causes a lot of deposition inside the engine and hampers long term operation [6]. Blends of bio-diesel with diesel are used for testing the engine performance at different proportions termed as B20, B50, B70, B100 etc. B20 contains 20% biodiesel mixed with 80% conventional diesel by volume. This study compares some performance parameters of B20, B50, B70 and B100 based on short term engine tests. Thermo-physical properties such as flash point, fire point, heating value, viscosity, specific gravity of blended bio-diesel are also determined and compared with those of conventional diesel. Exhaust properties are tested by using IMR2800P Gas Analyzer.

2. PROCESS OF BIO-DIESEL PRODUCTION
In the following chapter, the process for producing biodiesel using soybean oil and methanol with transesterification reaction is described. The byproduct of this reaction is glycerol which can be used in a number of different ways.

2.1 Biodiesel
Bio-diesel is defined as the 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 engines [7]. This name is given to the esters when they're intended for use as fuel.

2.2 Transesterification Reaction
Transesterification [8] also called 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 [9]. This has been widely used to reduce the viscosity of the triglycerides. The transesterification is represented in the following equation:

$$RCOOR_1 + R_2OH \rightleftharpoons R_1COOR_2 + ROH$$

Ester Alcohol Ester Alcohol

Transesterifiacation Process

The major variables affecting the transesterification reactions are:

- The free fatty acid (FFA) and moisture content[10].
- Type of catalysts[11].
- A literature(Freedman et al. 1984) has revealed that, the rate of reaction is strongly influenced by the temperature.
- Murugesan et al. [12] reported that, after completion of the reaction the product is kept for a certain time interval for separation (approx. 24 h) of bio-diesel & glycerol layer.
- Murugesan et al. [13] reported that, washing is a process to remove entrained glycerol, catalyst, soap and excess methanol.

2.3 Producing Biodiesel from Soybean Oil

During the esterification process of soybean oil, first 200 ml (99% pure) methanol was mixed with 3.5 gm NaOH (96% pure). The mixture was shaked until NaOH dissolved completely. This solution is added with 1 litre of soybean oil, which was preheated by an electric heater at 60°C(fig. 1). Then the mixture was blended by a fan coupled with an electric motor as shown in fig. 2. After blending for 3 minutes, this is then left for 24 hours to settle down. This mixture gradually settles down into two distinctive layer as shown in fig. 4. The upper more transperant layer is 100% biodiesel and the lower transparent concentrated layer is glycerol. The heavier layer is then removed.

Fig 1. Preheating Arrangement

Fig 2. Blending setup

Fig 3. B100 just mixed

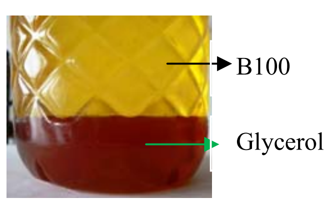

Fig 4. B100 after 24hours

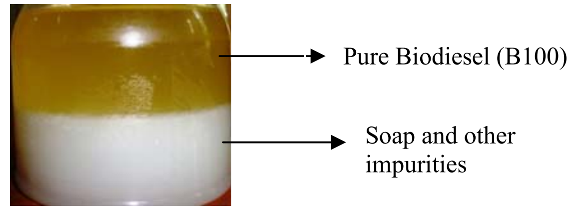

Fig 5. After water washing

3. FUEL PROPERTIES OF BIODIESEL

A number of properties of biodiesel blends (B20, B50, and B100) produced are targeted to be studied. The fuel properties of bio-diesel as listed in Table 1 indicate the property variation between bio-diesel produced and conventional diesel fuel.

Table 1: Comparison of properties of biodiesel produced from soybean oil with respect to diesel fuel

Parameter	ASTM method	Diesel	B20	B50	B100
Flash point(°C)	D - 93	67	86	88	98
Fire Point (°C)	D - 93	72	98	102	120
Calorific Value (MJ/Kg)	D-240	44	43.94	43.88	43.7
Specific Gravity	———	0.836	0.844	0.856	0.86
Viscosity (at 32°C) (centi strokes)	D-445	6.4	7.67	8.74	10.34

4. PERFORMANCE TESTING AND ANALYSIS

Total experimental works of this study is divided mainly into two groups:

- Performance test of Engine
- Exhaust properties

4.1 Experimental Setup

The experimental setup consisted of engine test bed with fuel supply system, different metering and measuring devices along with the test engine. A four-stroke, single cylinder, and water cooled diesel engine was tested at constant speed. Constant speed tests were carried out at rated 2400 rpm for variable loads, extending from 20% to 100% rated load. Preheating was done manually using gas burner. A hydraulic brake dynamometer directly coupled with the engine was used to load the engine. Load was varied by changing the water flow rate to the dynamometer. Fuel was supplied from externally installed tank, allowing volume measurement of fuel consumed. Speed was measured by digital tachometer and temperatures were measured by using K type thermometer. The experimental setup used for this experiment is showed in fig 8. First tests were carried out using diesel fuel. Then, the tests were repeated for B20, B50 and B70 blends.

Fig 6. Experimental Setup

4.2 Performance Analysis

Potentiality of using biodiesels produced from soybean oil as an alternative to diesel fuel is judged in the present study. B20, B50, B70 and diesel was used as fuel. B100 is not used directly to the engine as the engine vibrates rapidly. Fig 7 shows the brake specific fuel consumption results over the load range for diesel with B20, B50 and B70. The break thermal efficiency variation with break horse power is presented in fig. 8. Fig 9 and fig 10 shows the temperature variation of exhaust gases and lub oil with power respectively. All the test results are derated as per BS5514 standard.

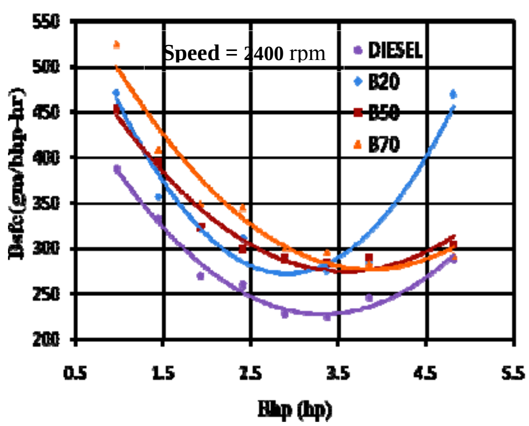

Fig 7. Variation of Bsfc with Bhp for different fuels

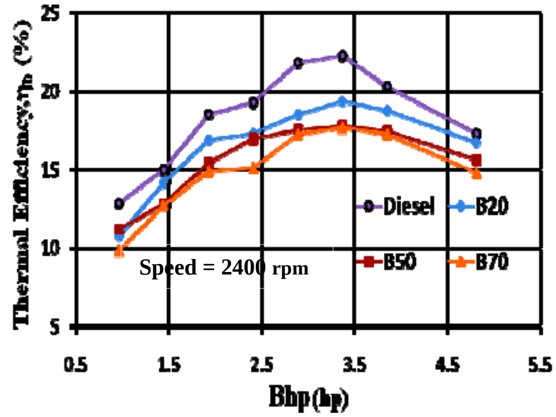

Fig 8. Variation of thermal efficiency with Bhp for different fuels

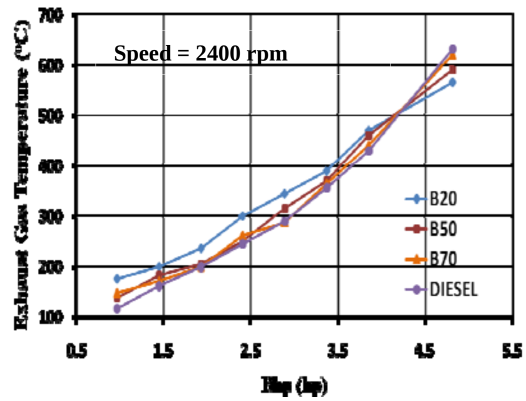

Fig 9. Variation of Exhaust gas temperature with Bhp for different fuels

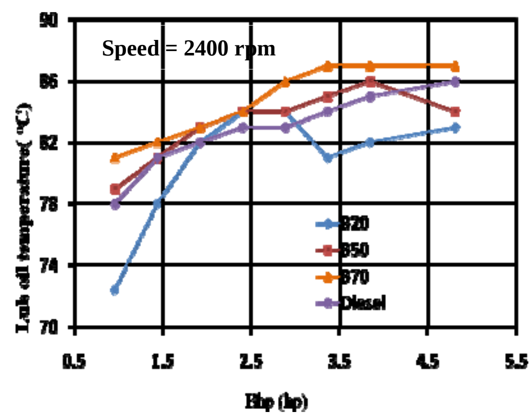

Fig 10. Variation of Lub oil temperature with Bhp for different fuels.

Fuel consumption rates and break thermal efficiency (η_b) are present respectively in fig 7 and 8 for different fuels and for different loading conditions at 85°C preheat temperature. Without preheating, the operation of the engine was very difficult. This is a major constraint of using biodiesel on unmodified CI engines. For diesel, the break specific fuel consumption was viewed to vary from 387.91 gm/bhp-hr at near 20% load and reduce to 224.5 gm/bhp-hr at rated capacity which is at 68% loading condition achieving thermal efficiency of 22.28%. Values are typical for diesel engines of this category and the maximum power attained was only slightly less than the manufacturer's specification. Using B20 did not show much difference in rated load performance and thermal efficiency. The bsfc at rated load was 272 gm/bhp-hr for B20 with thermal efficiency of 17.8%. At rated capacity, the bsfc for B50 was 275 gm/bhp-hr and bsfc for B70 was 280 gm/bhp-hr. The thermal efficiencies for B50 and B70 are 17.8% and 17.67% respectively. Results show very little deviations at rated rpm (2400) and rated load. From these figures, it is evident that the specific fuel consumption values are always higher for all biodiesel and in case of thermal efficiency it is always lower for all biodiesel than diesel. One of the reasons could be that, biodiesel has a heating value lower than diesel. Again high viscosity of biodiesel causes poor atomization and mixture formation and increases the fuel consumption rate to maintain the power. Maybe for these reasons, the bsfc for biodiesel was higher than that of diesel and thermal efficiency is lower.

Fig 9 and fig 10 shows the variation of temperature of exhaust gages and lub oil respectively. From fig 11, the exhaust gas temperature for diesel rises tremendously from 116^{0}C to 632^{o}C. The biodiesel blends (B20, B50, B70) also follows the same trend. At starting condition, the exhaust temperature was higher for all three blends. Higher exhaust temperature but lower power output indicates late burning to the high proportion of biodiesel. This would increase heat losses making the combustion a bit less efficient. But for higher loading condition, the exhaust gas temperature for diesel is higher compared to biodiesel blends. But, in case of B20, at starting, the exhaust temperature was higher than the other threes and it also deviates at full load condition. At full load, whereas the other two blends have exhaust temperature higher than diesel, the exhaust gas temperature of B20 is lower than diesel. From fig 10, the lub oil temperatures shows similar characteristics for diesel and biodiesel blends, as for biodiesel blends, the lub oil temperature is much higher. With an increase of proportion of biodiesel, the lub oil temperature also increases. One of the reasons could be the preheating treatment of biodiesel needed to run the engine. Exact preheating temperature is not known yet and it needs further investigation.

4.3 Emission Characteristics of Biodiesel

In this thesis, emission characteristics such as, excess O_2, CO, CO_2, excess air and heat losses are measured by using IMR 2800P. The NOx emission does not show any regular pattern.

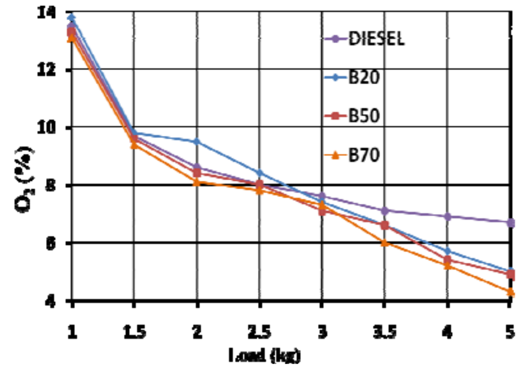

Fig 11. Variation of excess O_2 (%) with load for different fuels

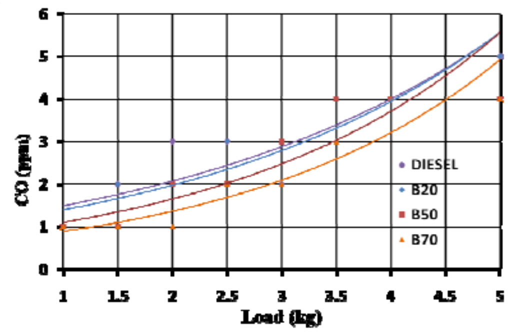

Fig 12. Variation of CO (ppm) with load for different fuels

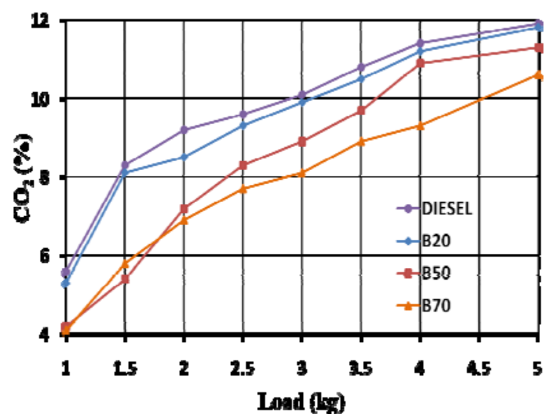

Fig 13. Variation of CO_2 (%) with load for different fuels

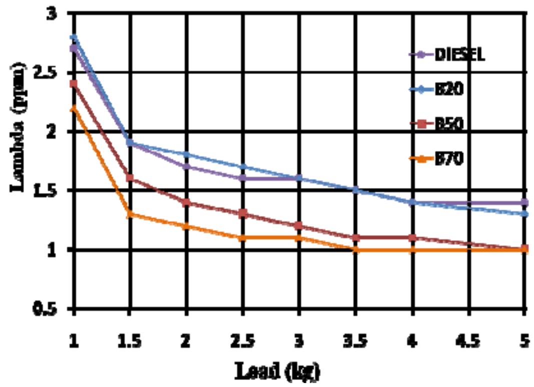

Fig 14. Variation of excess air (ppm) with load for different fuels

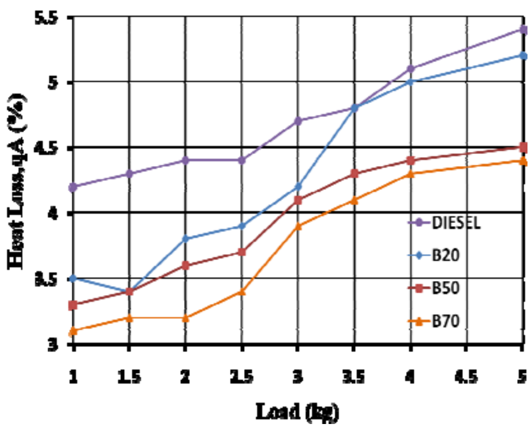

Fig 15. Variation of heat loss (%) with load for different fuels

During experiment the gas probe was inserted at the end of a six feet long exhaust pipe. It was difficult to insert the probe in the actual exhaust port of the engine due to high temperature and vibration. The experimental data such as percentage of O_2, CO_2, Heat loss etc varies from the actual data because of this distance from the exhaust port of the engine. The aim of the experiment is to show the trend of the graphs and the comparison of different bio fuels with the diesel fuel.

Fig. 11 shows the variation of excess O_2 present in exhaust gas with load for different fuel. The O_2 present in the exhaust gas for the biodiesel blends are lower than that of the diesel fuels at all loading conditions. The percentage of O_2 decreases with an increase of biodiesel in the blends.

Fig. 12 shows the variation of CO emission with load for different fuels. The CO emissions for the biodiesel blends are lower than that of diesel fuels, though the characteristics show that the increase or decrease of CO emission is very small. This also maintain the same characteristic as excess O_2, as the CO emission is higher for lower number biodiesel blend and is lower for higher number.

Fig. 13 shows the variation of CO_2 emissions with load for different fuels. Actual percentage of CO_2 emission is much higher than the experimental data. The reason behind this variation is the distance of the gas probe from the exhaust point. It is observed that all the CO_2 emission of diesel fuel is higher than that of blended fuels. This may be because the biodiesel blends contains oxygen elements the common context is relatively lower in the same volume of fuel consumed at the same engine load, consequently, the CO_2 emissions from the biodiesel blends are lower.

Fig. 14 shows the variation of excess air present in the exhaust gas with load for different fuels. The excess air present in the exhaust gas decreases with increase in load and biodiesel percentage present in the fuel.

Fig. 15 shows the heat losses by exhaust with load for different fuels. This heat loss does not represent the actual value as the data were collected from a certain distance from the exhaust point. This data does only represent the idea how the heat losses varies with load for different fuels. From the fig, it is clear that heat loss increases with the increase in load. The diesel fuel has higher values for heat loss and it decreases with increase in biodiesel percentage present on the fuel for the same load.

In view of environmental considerations, bio-diesel is considered Carbon neutral because all the CO_2 released during consumption had been sequestered from the atmosphere for the growth of vegetable oil crops. The combustion of bio-diesel has reported to emit lesser pollutants compared to diesel. This indicates that the engine exhaust contains no SO_2, and shows decreasing emissions of CO, HC, soot and aromatics. The NOx emission is reported to be in the range between ±10% as compared to diesel depending on engines combustion characteristics [14].

5. COST ANALYSIS

The present costing of running a diesel engine with biodiesel blends derived from soybean oil are given at the following table:

Table 2: Cost of running engines with different fuels

Fuel	Cost (tk/litre)	At rated load Tk/bhp-hr (Tk/kW-hr)
Diesel	45	10.1 (12.98)
B20	64	17.4 (23.34)
B50	92.5	25.4 (34.1)
B70	111.5	31.2 (41.85)

From Table 2, it is clear that, running diesel engine with biodiesel is costly compared to that of diesel. The main contribution for high cost of per litre biodiesel is the high price of edible oil and high cost of methanol which are used for transesterification reaction. The fuel cost is about 1.4, 2.05 and 2.5 times more expensive compared to diesel for B20, B50 and B70 respectively. Regarding cost of per kWh mechanical power generation, this is about 13 tk/kW-hr for diesel, 24 tk/kW-hr for B20, 34 Tk/kW-hr for B50 and 42 tk/kW-hr for B70 at rated load.

The costing shows that using biodiesel is still very expensive with current market price of diesel, but this situation may change with unavailability of fossil fuel or sharp rise of conventional fossil fuel prices.

6. CONCLUSION

Experiments were conducted on a small four stroke, single cylinder, water cooled diesel engine and performance characteristics of the engine was studied using diesel and diesel-biodiesel blends as fuels. The following conclusion can be drawn from this experimental study:

i). Bio-diesel can be produced from soybean oil using transesterification process.

ii). It was possible to run the diesel engine with biodiesel blends as the fuel.

iii). The density and the heating value of bio-diesel from soybean oil were found to be close those of diesel.

iv). Brake specific fuel consumption for biodiesel increases with increase in its amount in the blend.

v). The CO, CO_2, excess O_2 and excess air emissions are reduced with increase in its amount in the blend.

vi). The B20 seems to be the best alternative fuel for diesel. Because the break specific fuel consumption of B20 (272gm/bhp-hr) is close to diesel (225gm/bhp-hr) and the emission quality is better than diesel.

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8. NOMENCLATURE

Symbol	Meaning	Unit
T	Temperature	(^oC)
λ	Excess air	(ppm)
q_A	Heat loss	(%)
Q	Calorific value	(MJ/kg)
A/F	Air Fuel ratio	[-]

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