Paper ID: TE-07

Production, Characterization and Performance Study of Cottonseed Biodiesel in a Diesel Engine

Md. Wahedul Islam[1], Mafia Naher Afroj[1*], Romana Jannat[1]
[1] Department of Mechanical Engineering, Rajshahi University of Engineering and Technology
**Corresponding Author E-mail: mafianaherafroj@yahoo.com*

Abstract

The energy crisis and environmental concerns of the world has led the researchers to the search of feasible alternatives of fossil fuel. Biodiesel, also known as fatty acid methyl ester is an alternative, nontoxic, biodegradable, harmless and environmentally benevolent fuel. This paper represents an assessment of the production of biodiesel from non-edible renewable cotton (Gossypium herbaceum) seed oil and its characterization and performance. Cottonseed oil was used for biodiesel production by the transesterification process followed by the determination of various fuel properties. The variation of biodiesel production can be caused due to variation in the process parameters. It was observed that for 1% NaOH catalyst, 20% methanol, 58^0C reaction temperature and 60 min reaction heating time yield maximum (96%) biodiesel production. The engine performance test was conducted in a diesel engine using pure diesel and biodiesel blending with diesel in various ratios. Assorted parameters such as speed, fuel consumption and brake power were measured at different loads and their effects were discussed in this paper. From the results achieved it is noticed that cottonseed biodiesel has great potential to be used as alternative fuel in diesel engine.

Keywords: Biodiesel, cottonseed oil, transesterification, properties, performance test.

1. Introduction

Biodiesel is an alternative fuel formulated exclusively for diesel engines. Biodiesel is defined as the mono-alkyl esters of vegetable oils or animal fats, produced by using a bio-chemical method known as transesterification. Biodiesel and its blends with petroleum-based diesel fuel can be used in diesel engines without any significant modifications to the engines. The advantages of biodiesel are that it displaces petroleum thereby reducing global warming gas emissions, tail pipe particulate matter, hydrocarbons, carbon monoxide, and other air Toxics. Biodiesel improves lubricity and reduces premature wearing of fuel pumps [1]. It is important to explore the feasibility of substitution of diesel with an alternative fuel, which can be produced within the country on a massive scale for commercial utilization. At present the potential alternative fuels are Alcohols (Methanol and Ethanol), Liquefied Petroleum Gas (LPG), Compressed Natural Gas (CNG), Hydrogen and Vegetable Oils [2, 3, 4]. The cotton seed oil, a non-edible type vegetable oil is chosen as a potential alternative for producing biodiesel. After ginning process of cotton, cottonseed remains, which is used to produce cottonseed oil. Cottonseed oil is a waste product of cotton industry. Cottonseed oil does not have food value. It is one of the most sprayed crops in the world due the industrial value of cotton. Therefore, there is a plentiful supply of cottonseed as it comes as a byproduct of cotton cultivation [5]. At present 100 percent biodiesel is not used in place of diesel fuel to run the engine, because 100 percent biodiesel cause significant reduction of brake thermal efficiency, higher specific fuel consumption and excessive NOx formation. This problem can be greatly minimized by using diesel biodiesel blend. The most widely used blends are B10 (10%biodiesel, 90% diesel) and B20 (20% biodiesel, 80% diesel). Diesel biodiesel doesn't cause a significant increase of NOx and reduction of brake thermal efficiency. In the meantime the other performance parameter of the engine is similar to that of diesel fuel. In view of the fact that the cost of raw materials accounts about 60–80% of the total cost of biodiesel production, choosing a proper feedstock is very important. The method of production also plays very vital role in its production as the yield differs from process to process. The process parameters have great influence on the yield of biodiesel. That's why the optimum conditions are suggested in this paper.

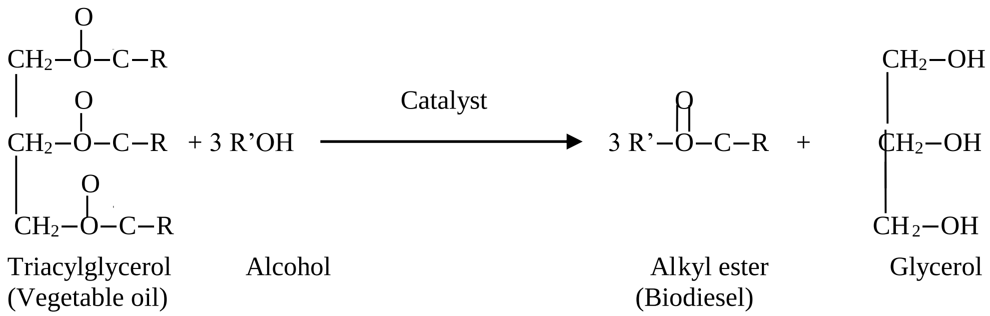
2. Experimental

2.1 Materials and Method

There are various methods of extracting oil from oil producing seeds and these to a large extent determine the quality of the oil. The various methods include; mechanical extraction, pyrolysis, solvent extraction, etc. [6].The raw cottonseed was collected from the Cotton Development Board. The raw cottonseed was dried and then the crude oil was extracted by expeller machine. The cleaned seed meats were first passed through a series of press rolls to produce thin flakes, after which the flakes were cooked under steam pressure, which ruptures the oil cells. Subsequently, the flakes were processed in expellers which remove the oil under high pressure.

2.2 Transesterification

When vegetable oil is mixed with methanol and a catalyst in the presence of heat, it produces methyl ester and glycerol. Biodiesel was prepared from cotton seed oil by alkali catalyzed transesterification. NaOH was used as the catalyst amounting 1.0% on a mass basis and 20% methanol was treated with the cottonseed oil. The oil was preheated and mixed with a solution of 20% methanol and 1% NaOH. The mixture was kept on a magnetic stirrer cum hot plate for proper mixing. The reaction was carried out in 55-60^{0}c for one hour. It was then placed in the separating funnel for separating the layers of biodiesel and glycerin impurities for 24 hours. The upper layer was biodiesel and lower layer was of glycerin. The method was repeated for different percentages of sodium hydroxide. It was found that maximum amount of biodiesel was produced at about 1% of NaOH. Fig.1 represents the flow chart for the transesterification process. The chemical equation of transesterification is below.



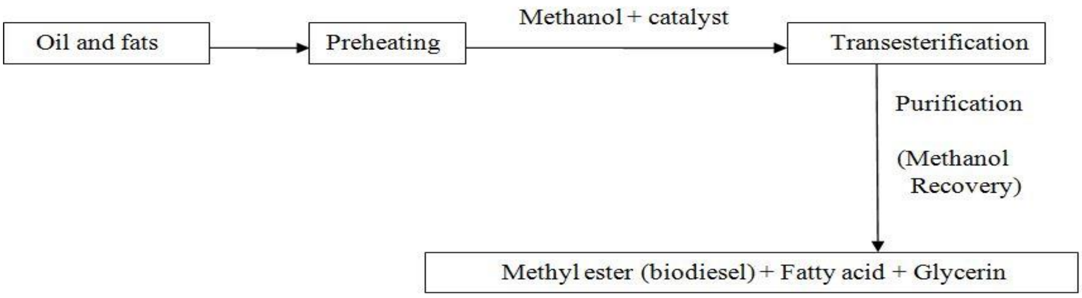


Fig.1. Flow chart for Transesterification process

2.3 Process Variables in Transesterification

Fig.2 represents the variation of % volume of biodiesel with % methanol. As the percentage of methanol increases, production of biodiesel increases. Maximum(96%) production of biodiesel occurs for 20% of methanol. For lower percent of methanol more reaction time is required. For higher percent of methanol biodiesel production decreased due to poor separation of glycerol.

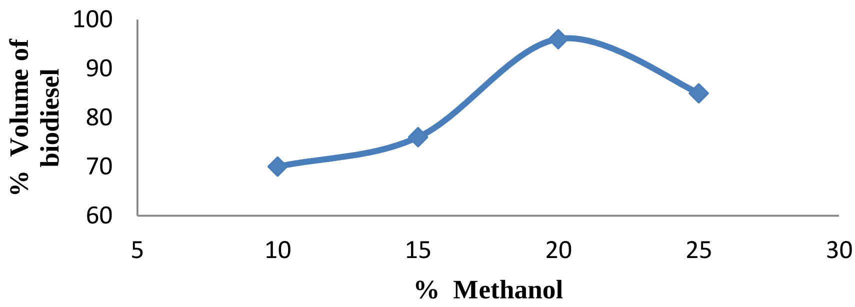


Fig. 2. The variation of % volume of biodiesel with % methanol

Fig.3. represents the variation of % volume of biodiesel with % NaOH. NaOH was used in transesterification. As the percentage of NaOH catalyst increases, production of biodiesel increases. Maximum(96%) production of

biodiesel occurs for 1% of NaOH. Further increase in percentage of catalyst causes reduction of biodiesel production. It was found that higher amounts of NaOH catalyst were required for higher FFA oil.

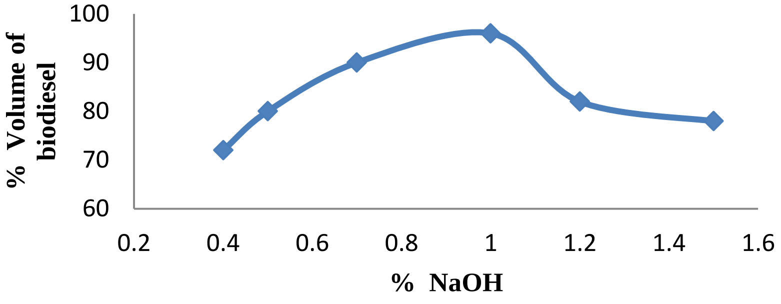


Fig. 3. The variation of % volume of biodiesel with % NaOH.

Fig.4. represents the variation of % volume of biodiesel with reaction time(min). As the reaction time increases, production of biodiesel increases. Maximum (96%) production of biodiesel occurs for 60 minutes of heating time. Further increase in time causes reduction of biodiesel production by producing higher amount of glycerol.

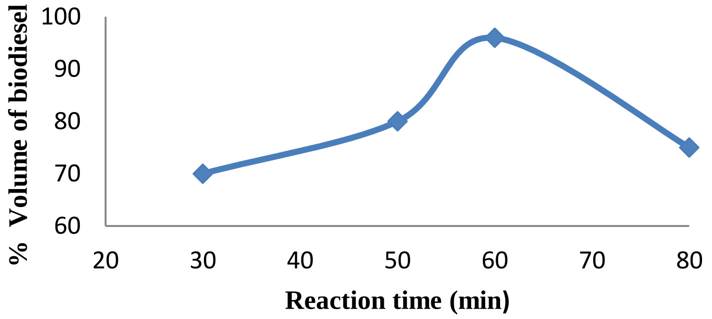


Fig. 4. The variation of % volume of biodiesel with reaction time(min).

Fig.5. represents the variation of % volume of biodiesel with reaction temperature. The rate of reaction is strongly influenced by the reaction temperature. Generally the reaction was conducted close to the boiling point of methanol (50^0C to 60^0C) at atmospheric pressure. As the temperature increases, production of biodiesel increases. Maximum(96%) production of biodiesel occurs at 58^0C. Further increase in temperature causes reduction of biodiesel production.

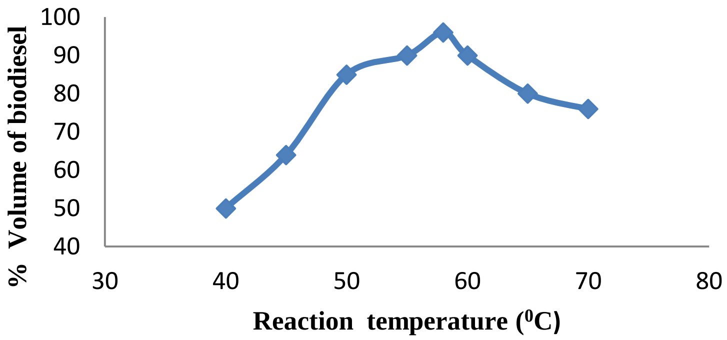


Fig. 5. The variation of %volume of biodiesel with reaction temperature.

2.4 Economical aspect of producing biodiesel as diesel substitute in Bangladesh

- The Textile industry plays an important role in the economy of Bangladesh. The textile industry in Bangladesh currently accounts for 45% of industrial employment and contributes 5% of total national income. The environment and soil in Bangladesh are very suitable for Cottonseed cultivation. If this crop can be cultivated on large scale production, yielding non-conventional oil that can be usefully converted into biodiesel.

- The country produced a record of 0.152 million bales of cotton in the just-concluded fiscal year (2014-15), marking a 5.47 percent growth as compared to the previous year's production. According to BCDB data, 152,534 bales of cotton were produced from about 42,700 hectares of land. These yield 20064.59 tons of cotton seed which produce 1575 tons of biodiesel [7].
- After the experimental work the net cost of biodiesel production from cottonseed oil was found 50 taka per liter in Bangladesh.
- Cottonseed oil is a wasted product of textile industry. It doesn't have any other significant use. If cottonseed biodiesel can be used as a substitution of diesel fuel it can save around 280 million taka per year in addition of its economical advantage.

2.5 Engine Performance

Performance tests were conducted on a four stroke diesel engine with various biodiesel blends in order to optimize the blend concentration for usage in CI engines. The engine specifications are given in Table 1. To achieve this, three samples of cottonseed biodiesel-diesel blends i.e. B5 (5% cottonseed biodiesel, 95% diesel), B10 (10%cottonseed biodiesel, 90% diesel) and B20 (20% cottonseed biodiesel, 80% diesel) were prepared to be fueled into a diesel engine.

Table 1: Engine Specification

Engine type	4-stroke CI engine
Number of cylinders	one
Bore x stroke	80 x 110 mm
Swept volume	553 cc
Cooling	water cooling
Compression ratio	16.5
Rated pressure	4.476 KW@1800 rpm
Injection pressure	14 Mpa (low speed, 900-1099rpm)
	20 Mpa (high speed, 1100-2000rpm)
Injection timing	24^0 BTDC

3. Results and Discussions

3.1 Properties

Table 2 presents the physicochemical properties of the extracted crude cottonseed oil, produced biodiesel and conventional diesel fuel. The calorific value which shows the energy density in the fuel was found 40562.72 KJ/Kg for biodiesel which is close to diesel. The density of biodiesel is slightly higher than diesel. The cottonseed biodiesel has high viscosity. This is why pure biodiesel is not used in an engine for combustion. It is used in engine after blending with diesel in various proportions. The biodiesel can be directly used in lubrication system. Since the specific gravity and API gravity are related to heat of combustion it has a major effect on engine fuel consumption. The API gravity of hydrocarbon diesel fuel is a reliable indication of the heat energy released when the fuel is burnt [8]. The flash and fire points indicate the temperature below which oil can be handled without danger of fire. High free fatty acid content can reduce the quality and yield of biodiesel production. The amount of FFA value in cottonseed biodiesel is 2.82% which is low. The acid value is a measure of acidic or alkaline contents of oil. The cloud and pour points indicate the temperature below which the flow of fuel will be difficult. These give the temperatures above which oil should be handled in cold environments. Carbon residue content and ash contents is the pointer to the deposit characteristics of the oil. Cottonseed biodiesel has low carbon residue content and ash content which indicates low deposition. But the formation of deposits is strongly affected by the design of the engine, the fuel used, and the operating conditions. The cetane rating of a diesel fuel is a measure of its ability to auto ignites quickly when it is injected into the compressed and heated air in the engine [9].

Table 2: Properties of Diesel, Cotton Seed Oil biodiesel and Cotton Seed Oil (Crude oil)

Properties	Crude oil	Biodiesel	Diesel
Calorific value, KJ/Kg	3056.76	40562.72	44500
Density, gm/cc, at 27.7 ^{0}C	0.94	0.88	0.8445
Viscosity, cP, at 27.7 ^{0}C	70	26.3	7.3
Specific gravity	0.94	0.87	0.84
API gravity	19.03	37.56	34.52
Flash point, ^{o}C	216	97	65

Properties	Crude oil	Biodiesel	Diesel
Fire point,^{0}C	224	112	105
Acid value, mgNaOH/g	11.50	5.61	0.34
FFA value, %	5.75	2.82	0.17
Cloud point	1	2	-12
Pour point	-2	-3	-20
Carbon residue content, %	4.9	0.04	0.05
Ash content, %	1.5	0.005	0.02
Cetane number	49	51	52

3.2 Performance Parameters

3.2.1 Speed Optimization

From the Fig.6 it is observed that brake thermal efficiency of an engine increases with increase of engine speed. After reaching the maximum value the efficiency of the engine also decreases. This is due to the fact that initially with the increase in engine rpm the torque produced by the engine increases, so the efficiency also increases. But at higher rpm(>850) the amount of fuel injected into the engine cylinder per cycle increases and due to higher engine speed this fuel doesn't get sufficient time to burn completely which reduce the efficiency of the engine.

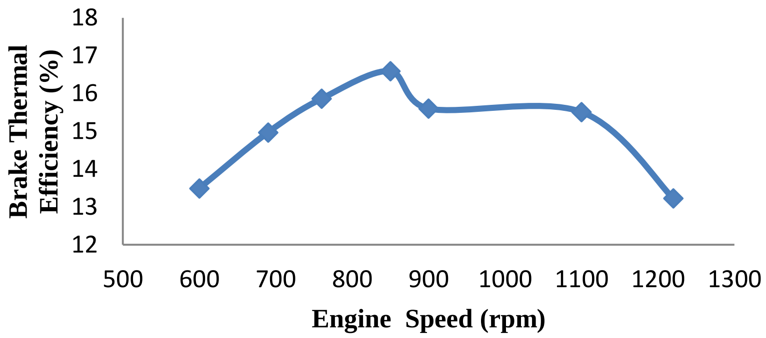


Fig. 6. The variation of brake thermal efficiency with engine speed.

3.2.2 Brake Thermal Efficiency

The change of brake thermal efficiency of the engine with break power output is presented in Fig.7. The brake thermal efficiency of the engine presented very similar affinity for all the fuel samples. It is apparent that the B20 blend shows the nearest break thermal efficiency to that of pure diesel. From the graph it is detected that the brake thermal efficiency increases with the rise in engine load (brake, power) to a maximum point then decrease with the increase in the brake power.

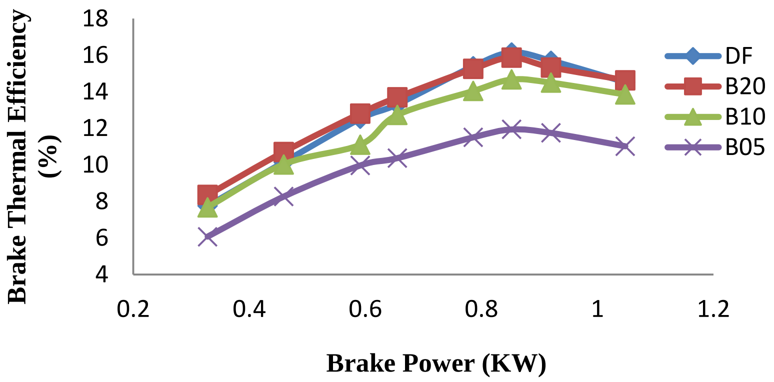


Fig. 7. The variation of brake thermal efficiency with brake power.

From the equation of brake thermal efficiency it can be found that with the increase in engine load the engine brake power increases which increases the thermal efficiency of the engine. At higher loads, i.e. at higher brake power more amount of fuel is injected into the engine cylinder which is not completely burned [8]. It causes higher BSFC and low thermal efficiency. The B20 blend has the highest efficiency among all the blends for the brake power 0.852KW.

3.2.3 Brake Specific Fuel Consumption

In Fig.8 the variation of brake specific fuel consumption (BSFC) with brake power is represented. The BSFC decreases with the brake power increase to a certain point, then again increases with the increase in brake power. The B05 blend has the lowest BSFC among the blends. With the increase in engine load break power increases. As an outcome the brake specific fuel consumption decreases. The BSFC for the same amount of power produced, for biodiesel is slightly higher than that of diesel fuel. This is due to the poor volatility, higher viscosity, higher density and lower calorific value of biodiesel [10].

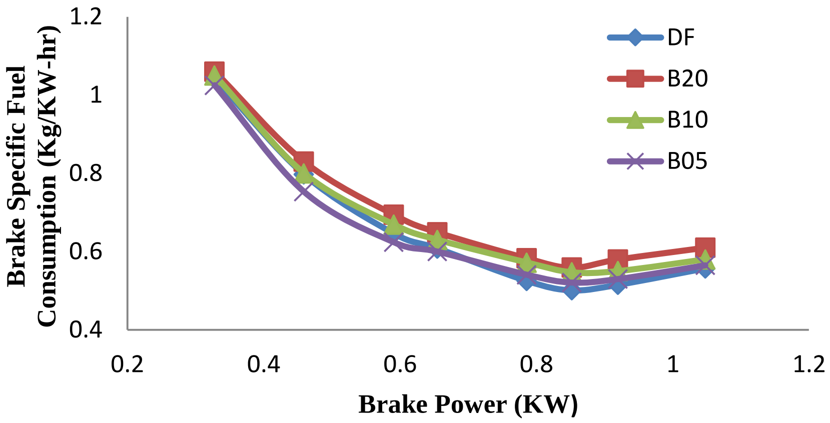


Fig. 8. The variation of BSFC with brake power

4. Conclusion

The following conclusions could be drawn according to the analysis and summary of the current investigational work:

1. The cost analysis of the cottonseed biodiesel production process shows that it is more economical than conventional diesel fuel. According to the production of cotton in the year 2014-15, if the waste cottonseed oil can be converted to biodiesel it can save around 280 million taka per year.

2. The maximum production of biodiesel from cottonseed oil came up with 1% NaOH and 20% methanol in the transesterification process.

3. The optimum temperature for transesterification process is 58^0C with 60 min of heating time.

4. Although the brake specific fuel consumption is slightly higher than the diesel for 20% biodiesel and 80% diesel blend, but it shows the nearest brake thermal efficiency of that of pure diesel.

5. References

[1] Joshi Rushang M. et al. "Flow properties of biodiesel fuel blends at low temperatures", *Elsevier*, Vol. 86, No. 1-2, pp.143- 151, 2007.

[2] K. VinuKumar, "Production of bio-diesel used in diesel engines", *Innovare Journal of Engineering & Technology*, Vol.1, No.1, 2013.

[3] Syed Ameer Basha , K. Raja Gopal, S. Jebaraj, " A review on biodiesel production, combustion, emissions and performance", *Renewable and Sustainable Energy Review*, Vol.13, No. 6-7, pp. 1628–1634,2009.

[4] A.S.Ramadhas,S Jayaraj, C. Muraleedharan, "Use of vegetable oils as I.C. engine fuels—a review", *Renewable Energy*, Vol. 29,No.5, pp. 727– 742,2004.

[5] Fangrui Ma[a], Milford A. Hanna[b], "Biodiesel production: a review", *Bioresource Technology,* Vol. 70, pp. 1-15, 1999.

[6] Orhevba Bosede Adelola [1] and Efomah Andrew Ndudi [2] "Extraction and Characterization of Cottonseed (*Gossypium*) Oil", *IJBAS,* Vol. 01, No. 02, Oct 2012.

[7] www.thefinancialexpress-bd.com/2015/07/10/99910/print, 2015/10/10.

[8] MN Nabi, MM Rahman, MS Akhter, "Biodiesel from cottonseed oil and its effect on engine performance and exhaust emissions", *Applied Thermal Engineerin*g, Vol. 29, No. 11,pp. 2265-2270,2009.

[9] M.L.Mathur, R.P, Sharma, Internal Combustion Engines, *Dhanpat Rai Publications*, 2011-2012, pp.306-307, 503.

[10] Dr.V. Naga prasad naidu, Prof. V. Pandu rangadu, "A Comparative Study of Performance and Emission Characteristics of Four Stroke Diesel Engine with Mahua and Cotton Seed Biodiesel Blended with Diesel", *IJITR,* Vol. 2, No.5, pp. 1223 – 1227, 2014.