Bio-diesel as an Alternative Fuel (Description, Benefits and Production Process)

Muhammad Arsalan Khan[1,2], Majid Baseer[1] and Dr. Abdul Shakoor[2]
[1]Sarhad University of Science & Information Technology, Peshawar, Pakistan
[2]University of Engineering & Technology, Peshawar, Pakistan
arsal678@yahoo.com

Abstract

The world energy sources are depleting day by day due to declining fossil fuel reserves, global climate changes and government regulation regarding Green House Gases. More over the use of fossil fuel is not enough to meet the increasing energy requirements of the growing population of the world so the alternate and renewable fuel sources available nowadays are becoming more and more important. Although there are a number of different fuel sources available but Bio-Diesel is the most feasible for countries like Pakistan, as it is an agricultural country and possesses suitable climatic and Geographical conditions. The objective of this study is to understand the construction of the bio-diesel plant and all the mechanical challenges involved in it to make it efficient and commercial, also to understand the chemical processes involved in it. The control, operation and working of the plant are also given priority in the objective. The cost of the Bio-Diesel is the issue related to it commercialization, Adoption of continuous transesterification process and recovery of high quality glycerol (by product) are the primary parameters to be considered to lower the cost of Bio-Diesel. The produced Bio-Diesel is also analyzed after the production, to make sure that the Bio-Diesel produced is of the required quality or not. This study consists of all of these processes involved in bio-diesel production along with the benefits that comes with its use, now and in the near future.

Keywords
Bio-diesel, transesterification process, Glycerin, blends, purification of Bio-diesel.

I. INTRODUCTION

World has been confronted with an energy crisis due to fossil fuel depletion and environmental degradation. As the advent of a time when fossil fuel will cease to exist draws near, All the petro heads of the world are tirelessly working on producing a renewable fuel which will not only work as efficiently in an internal combustion engine as the fossil fuels but will be economical as well [1]. Biodiesel is one of the most promising alternative fuels to meet these problems. It is renewable, biodegradable, nontoxic and has almost very close property to that of diesel fuel. Biodiesel fuel blends are one option currently being researched as a pathway to energy diversity and reduced petroleum dependence in the transportation sector. One of the key factors related to the success of biodiesel fuel blends is their compatibility with vehicle components such as fuel systems, combustion parts, and advanced emission control systems [2]. In this regards for diesel engines, Bio-Diesel has been proved to be the best option available yet. All over the world petroleum based diesel is being replaced by the bio diesel blends at an alarmingly (but positively) high rate, the main reason for which is that it can be used in diesel engines without any modifications [3].

It can be produced from vegetable oil as well as animal fats. Oils/fats are basically triglycerides which are composed of three long-chain fatty acids. These oils/triglycerides have higher viscosity and therefore cannot be used as fuel. In order to reduce viscosity, triglycerides are converted into esters by transesterification reaction. By this means, three smaller molecules of ester and one molecule of glycerin are obtained from one molecule of fat/oil. Glycerin is removed as by product and esters are known as biodiesel.

Biodiesel, a renewable fuel, is safe, biodegradable, and produces lower levels of most air pollutants than petroleum-based products [1, 4]. And it is the fastest growing alternative fuel in Europe and the United States. Also the ultimate goal is to build a stronger, more self-sufficient and independent community by using a community-based biodiesel production model. A community-based biodiesel distribution program benefits local economies, from the farmers growing the feedstock to local businesses producing and distributing the fuel to the end consumer. The raw materials for the production of biodiesel ranges from oils produced domestically like soybean oil, to other cheaply available sources animal fats, recycled cooking oils, non-edible oils, etc. [5, 6]. In this way, the money stays in the community while reducing the impact on the local environment; heavy petroleum import expenses and increasing energy security issues [7].

The beauty of biodiesel is its eco friendliness and it's potential for reducing greenhouse gases emission and provision of an efficient performance in existing diesel engine [8]. When burned, biodiesel produces pollutants that are less detrimental to human health. In addition, it provides better lubricity as compared to that of diesel fuel. But, due to its unsaturated molecules and compositional effects, it is more oxidative and causes enhanced corrosion and material.

Analysis of the emissions of BD blends showed that its fuel blends reduce the Particulate Material (PM), Hydrocarbon, Carbon Monoxide and Sulphur Oxides. However, NOX emissions are slightly increased depending on Cetane number [9, 10] and Even though Bio-Diesel fuel has a longer Ignition Delay than diesel but the Ignition Delay decreases for blends and depends on the amount of diesel in the blends [13].

Similarly the experimental Study of the Combustion Characteristics of the spray of Diesel and BD Blends in a Direct Injection Common-Rail Diesel Engine of BD5 and BD20 of Soybean oil led to the facts the fuel injection profiles for diesel and BD blends are very similar to the pilot injection i.e. an increase of the blending ratio results in the decline of peak injection rate [14].

They have lower emissions and high flash point (usually >300F), hence they are safer. They are biodegradable and essentially free from Sulphur and aromatics, making it safer to handle and transport [15, 16]. Also the addition of even 2% biodiesel to diesel helps in significant improvement of lubricity of diesel [17, 18].

As a conclusion to an extensive studies based on the different thermal characteristics of biodiesel it was remarked that there exist three stages of combustion namely the Warm-up followed by liquid phase boiling which is later commenced by the Burn-off of the vaporized fuel [2]. Therefore, it is important to conduct more researches to formulate optimal operation conditions as biodiesel is used as fuel.

II. MIXING OF BIODIESEL BLENDS:

Blending of biodiesel with petroleum based diesel may be accomplished by the following three methods

a. Splash mixing:

This is the most commonly used and also the least accurate method of blending biodiesel. Splash blending is done when a truck tanker which is already having diesel at 8 degree Celsius is pumped with biodiesel at 18 to 20 degree [10].

b. In line mixing method

This method involves two storage tanks one containing biodiesel and the other having fossil diesel. Both of the fluids are then passed through a pipe and hose, and mixed in a particular ratio (depending on the type of blend) and then accumulated in a third, tanker [11]. This method is widely used for production of Biodiesel on large scale.

c. Injection mixing method

In this method the blending of fuels is done in tanks at manufacturing points prior to the supply to the tanker truck. Valve controls are used to ensure that monitored quantities of diesel and biodiesel components are injected into the mixing tan to get a specific blend of biodiesel and diesel [7].

Blends of biodiesel and conventional fossil-based diesel are produced by mixing biodiesel and petroleum diesel in suitable proportions under appropriate conditions. Much of the world uses a system known as the "B" factor to state the amount of biodiesel in any fuel mix [11, 12]:

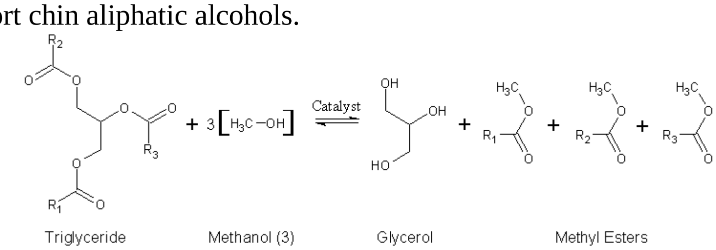
Blends of biodiesel and conventional hydrocarbon-based diesel are products most commonly distributed for use in the retail diesel fuel marketplace. Much of the world uses a system known as the "B" factor to state the amount of biodiesel in any fuel mix.

- 100% biodiesel is referred to as B100, while
- 20% biodiesel, 80% petro diesel is labeled B20
- 5% biodiesel, 95% petro diesel is labeled B5
- 2% biodiesel, 98% petro diesel is labeled B2

Blends of less than 20% biodiesel can be used in diesel equipment with no, or only minor modifications, although certain manufacturers do not extend warranty coverage if equipment is damaged by these blends. The B6 to B20 blends are covered by the ASTM D7467 specification.

III. CHEMICAL PROCESS

Biodiesel production is a process which involves the production of biodiesel, through either the transestertification process or by alcoholysis. It involves reacting vegetable oils or animal fats catalytically with short chin aliphatic alcohols.

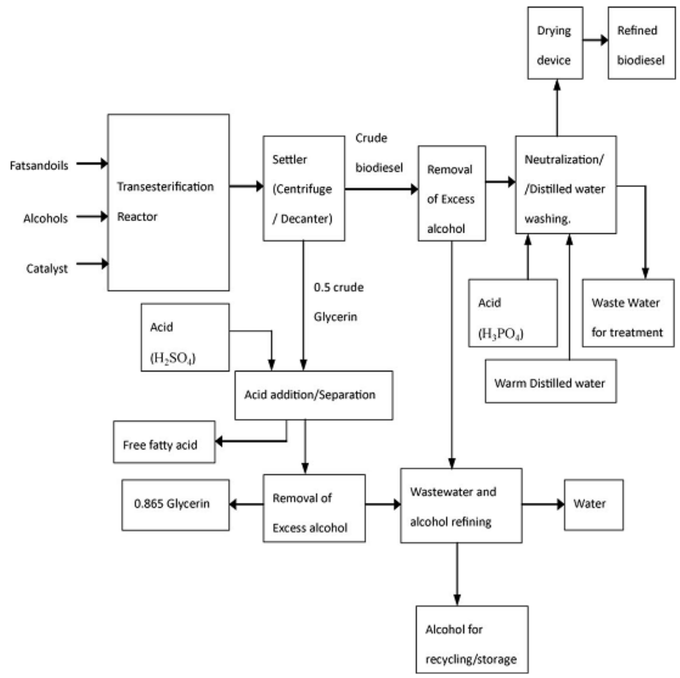


IV. BIO-DIESEL PURIFICATION TECHNOLOGIES

The purification of the crude biodiesel is technically very difficult, greatly contributing to the increase in biodiesel production cost. The purity of biodiesel must be high and generally have to conform to the international biodiesel standard specifications provided by American standard for testing materials (ASTM) and European Union (EU) standards for alternative fuels. According to the European Union (EU) standard specifications for biodiesel fuel water content, free fatty acids, and free and bound glycerin, must be kept to a minimum level and the purity of the fuel must exceeds 96.5% [8].

The crude products of transesterification reaction consist mainly of fatty acid alkyl ester (biodiesel), and other secondary products such as soap, diglycerides, monoglycerides, glycerol, alcohol, and catalyst, etc. in different concentration levels. The main objective in the purification of crude biodiesel is to remove the fatty acid alkyl esters from the mixture, and maintain lower cost of production and also ensure a highly purified biodiesel product. Glycerol, considered as a major secondary product of the transesterification reaction in its purest form can be sold to various commercial manufacturing industries such as cosmetic, food, tobacco and pharmaceutical industries, etc. for different applications. In order to make biodiesel production cost effective removal and resale of glycerol is mandatory. The remaining product mixtures containing other by-products such as alcohols also need to be recovered through either distillation or evaporation process.

However achievement of high conversion rate results in the immediate formation of distinct two liquid phases, with also sharp solid phase when heterogeneous catalyst is employed. The bottom phase of the products consists of glycerol and the upper phase contains fatty acid alkyl esters and alcohol. For cases where by the reaction could not attain complete conversion the unreacted triglycerides and bound glycerol will form solid substance at the bottom phase posing severe difficulty in the separation and purification of crude fatty acid alkyl esters. Refined vegetable oils tend to ease the difficulties encountered during separation and purification of the transesterified products (biodiesel) and provide biodiesel with better physicochemical properties such as viscosity, flash point and densities, etc. However the use of unrefined vegetable oils as raw materials in the production of biodiesel poses great difficulty in the purification processes, leading to low quality biodiesel fuel.



Biodiesel Production and Purification

V. PRODUCTION, ANALYSIS AND UTILIZATION

For the production of Bio-Diesel, we actually perform the transesterification and esterification processes in our plant. This process inside the plant is achieved by the flow of chemicals (oil and MOD) through the chambers where the necessary conditions for the chemical reaction are achieved and the process of formation of Bio-Diesel occurs in the plant in which we have designed various chambers for providing the oil and mixture with the necessary conditions for the process to occur.

We used Jatropha oil for the production of Bio-Diesel. For the sake of simplicity let us consider the oil to be cooking oil. Major steps in the production of Bio-Diesel from cooking oil and jatropha oil are same. However, there is an additional step for jatropha oil that will be discussed in the later section of this article. The production of Bio-Diesel inside the plant occurs in the following steps

a. Preheating of Oil in Storage Chamber

We start our production process with the pre-heating of oil in the storage chamber. For the single batch we took 5 liters of cooking oil. We preheat the oil for at least 15 minutes. The purpose of preheating oil is to lower the viscosity of oil.

b. Pretreatment of Jatropha oil

The oils with fatty content higher than 1% are required to be pretreated before the transesterification process. If the oil is used without the pretreatment, the result is the formation of dense gel and the reaction does not result in the formation of Bio-Diesel. The jatropha oil has a fatty content of 15%. So, pretreatment is required in the case of jatropha oil. Pretreatment of higher fatty acid content oils is done by performing an addition step after the preheating of oil. The oil is reacted with the mixture of methanol and H_2SO_4. The methanol is used in the same ratio as used for MOD solution with respect to the oil. The H_2SO_4 used is 1% w/w of oil. The reaction parameters are similar to the transesterification process. The product is then separated in the separation chamber, with the lower layer of pretreated oil and the upper layer of methanol containing the fatty contents of the oil. This pretreated oil can then be processed in the manner similar to that of cooking oil.

c. MOD Solution Preparation

While the oil is in the storage chamber for preheating, we make the MOD solution inside the MOD chamber. We will pour 1320 milliliters of methanol with 30 grams of NaOH in the MOD chamber. The MOD mixer is turned on for five minutes for complete dissolution of methanol and NaOH. Here we will notice that we are using the twice the amount of methanol theoretically required for Bio-Diesel. For the completion of reaction, we will double the amount of methanol required. However this methanol is recoverable from the final product.

Fig (a) Transesterification reaction, (b) Control panel

d. Start of Reaction in Reaction Chamber

After the preparation of MOD solution and the preheating of oil in the storage chamber, the oil and MOD solution is shifted to the reaction chamber. Depending upon the oil, the reaction parameters are set. In this case we will set the heating up to 55ºC and the required time for the completion of this reaction is 55-60 minutes. As soon as the reaction parameters are set, we turn on the circulating pump and heater to start the process. The electric heaters provide a controlled heating to the mixture and the circulating pump performs the mixing/stirring of the mixture by sucking it from the bottom of the container and spraying back from the top. This process is continued for the specified time. After this process is completed, the product is transferred to the next chamber known as the separation chamber.

e. Separation of the mixture in the Separation Chamber

After the reaction is completed in the reaction chamber, the product is shifted to the separation chamber through the same pump. Here the mixture is given a separation or settling time for the separation of Bio-Diesel and glycerin. Depending upon the oil used for the production of Bio-Diesel, the time of separation varies from 30 minutes to 2 hours. In cooking oil case, it takes almost 40 minutes for complete separation of Bio-Diesel and glycerin. When the separation occurs, the lower layer is of glycerin and the upper layer is of crude Bio-Diesel. The glycerin is extracted by opening the nozzle at the bottom of the separation chamber. We are only left with the crude Bio-Diesel in the separation chamber.

f. Washing of Crude Bio-Diesel

After the separation of two layers, the crude Bio-Diesel is washed inside the separation chamber with the help water and air bubbles from the air compressor. Washing is the removal of soap content from the Bio-Diesel to make it pure Bio-Diesel. Water is introduced in to the crude Bio-Diesel from the top through water storage chamber while the water bubbles are introduced from the L-shaped nozzle through the air compressor. The washing makes the Bio-Diesel milky. The soap water mixture is settled at the bottom of the container and is then discharged. Finally, what we have is the final desired product, the Bio-Diesel.

VI. ANALYSIS AND CONCLUSION

The produced Bio-Diesel was then analyzed after the production, to make sure that the Bio-Diesel produced is of the right quality or not. For analyzing, the following properties of Bio-Diesel were considered:
Cetane Number – is the number of combustion quality of diesel fuel during compression ignition.
Flash Point – is the lowest temperature of the volatile material at which it can vaporize to form an ignitable mixture in air.
Pour Point – is the lowest temperature of a liquid at which it becomes semi solid and loses its flow characteristics
Calorific Value – is the quantity of heat produced by the complete combustion of a given mass of a fuel
Specific Gravity – is the ratio of the density (mass of a unit volume) of a substance to the density (mass of the same unit volume) of a reference substance.
Viscosity - is a measure of the resistance of a fluid which is being deformed by either shear stress or tensile stress
These properties were individually calculated for Fossil Diesel, Standard Bio-Diesel, Jatropha Bio-Diesel, Mustard Bio-Diesel, and Cooking Oil Bio-Diesel and are stated in the tabulated form as shown below:

VII. COST ANALYSIS

The cost analysis is based on four (4) liters batch

Total Cost= Cost of Oil + Cost of Chemicals (i.e. NaOH, Methanol, H_2SO_4) + Cost of Electricity

a. Waste Cooking Oil

Cost of Waste Cooking Oil per liter = Rs. 40
Cost of Electricity per batch = Cost of Electric Heaters + Cost of Circulating Pumps + Cost of MOD Mixer + Cost of Air Pump = 1.6476 KW = Rs 12
Cost of Chemicals = Cost of Methanol + Cost of NaOH = Rs 144

Total Cost = 160 + 12 + 144 = Rs 316

Cost per litre of Biodiesel = Rs 84.2

b. Jatropha Oil

Cost of Waste Cooking Oil per litre = Rs 30
Cost of Electricity per batch = Cost of Electric Heaters + Cost of Circulating Pumps + Cost of MOD Mixer + Cost of Air Pump = 1.6476 KW = Rs 19
Cost of Chemicals = Cost of Methanol + Cost of NaOH + Cost of H_2SO_4 = Rs 272

Total Cost = 120 + 19 + 272 = Rs 411

Cost per litre of Biodiesel = Rs 103

Table: Comparison of Properties of Fossil Diesel, Standard Bio-Diesel, Jatropha Bio-Diesel, Mustard Bio-Diesel, and Cooking Oil Bio-Diesel

Properties	**Fossil Diesel**	**Standard Bio-Diesel**	**Jatropha Bio-Diesel**	**Mustard Bio-Diesel**	**Cooking Oil Bio-Diesel**
Cetane Number	45 - 55	47 - 65	49	47.8	51
Flash Point	60 to 90ºC	130 to 170ºC	185ºC	192ºC	180ºC
Pour Point	-35 to -15ºC	-15 to 10ºC	-8ºC	-5ºC	-10ºC
Calorific Value	45 to 46 MJ/Kg	38 to 43 MJ/Kg	41.5 MJ/Kg	40.3 MJ/Kg	42.6 MJ/Kg
Specific Gravity	0.85	0.88	1.03	1.10	1.09
Viscosity	1.3 to 1.4 mm^2/s	1.9 to 6.1 mm^2/s	4.8 mm^2/s	5.3 mm^2/s	4.6 mm^2/s

REFERENCES:

[1]. Jinlin Xue Et Al. “Effect of Biodiesel on Engine Performances and Emissions” renewable and sustainable energy reviews journal 15 1098-1116. (2011)

[2]. Anthony lam and Andrzej Sobiesiak, “Biodiesel Droplet Combustion Journal of Kones Powertrain and Transport” Vol 13, no. 2. Pg.267-274.

[3]. Ali Reza Valipour “Experimental Combustion Analysis Of Biodiesel Fuel Spray With Hot Surface Ignition” Volume 2, issue 1, January 2014 ISSN 2321-6441

[4]. M.J.Thornton, T.L.Alleman, J. Luecke, and R.L.Mccormick “Impacts Of Biodiesel Fuel Blends Oil Dilution On Light-Duty Diesel Engine Operation” conference paper NREl/cp-540-44833 August 2009

[5]. M. Renksizbul and M. Bussann “Multicomponent Droplet Evaporation At Intermediate Reynolds Numbers”, Hear Mass Transfer.Vol. 36, no. Li, pp.2827-2835, 1993.

[6]. Chandrasekhar “Effect Of Biodiesel, Jet Propellant (Jp-8) And Ultraslow Sulphur Diesel Fuel On Auto-Ignition, Combustion, Performance And Emissions In A Single Cylinder Diesel Engine Journal Of Engineering For Gas Turbines And Power”, , vol. 134 /022801-pp. 1-11 by ASME. February 2012

[7]. Jayashri Nair, J. Deepthi, k. SIVA Kalyani “Study Of Biodiesel Blends And Emission Characteristics Of Biodiesel” ISSN: 2319 issue 8, August 2013

[8]. Y.X. Li, N.B. McLaughlin, B.S. Patterson and S.D. Burt “Fuel efficiency and exhaust emissions for biodiesel blends in an agricultural tractor” CANADIAN BIOSYSTEMS ENGINEERING Volume 48 2006

[9]. Clean cities, a review, U.S. Department of energy, energy efficiency and renewable energy, fact sheet, April 2008. . Viewed on 20th November 2014

[10]. J.P.Szybist, J. Song, M. Alam, A.L.Boehman. ”Biodiesel Fuel Combustion, Emissions and Emission Control Process.Technol. 88 679–691.2007.

[11]. Peterson, C.L., J.L. Cook, J.C. Thompson and J.S. Taberski. “Continuous flow biodiesel production” Applied Engineering in Agriculture 18(1): 5-11. 2002

[12]. C. H. Wang, X. Q. Liu, and C. K. Law, “Combustion and Micro Explosion of Freely Falling Multicomponent Droplets” Combustion and Flame 56: 175-197 (1984) 175,

[13]. NREL/TP-540-43672.

[14]. Laurencas Ras Lavičius & Donates Markšaitis “Research into Three-Component Biodiesel Fuels Combustion Process Using a Single Droplet Technique” transport, vol. XXII, no 4, pp. 312–315. (2007)

[15]. Jyotirmoy Barman et al. “Experimental Investigation Of Bio-Diesel Droplet Ignition”, International Journal Of Oil, Gas And Coal Technology, Vol.1, No.4, pp.464 – 477. 2008

[16]. R.K.Malhotra, “Biodiesel as Blending Component for Diesel Fuel & Its Applications and Benefits”, Biodiesel Conclave, November 5, 2005.

[17]. V.A.N.Gerpen, “Biodiesel Processing and Production, Fuel Process”. Technol. 86 1097–1107. (2005)

[18]. K.Tapan Gogoi, T.Shovana, C.Debendra, Baruah, "Comparative Analysis of Performance and Combustion of Koroch Oil and Jatropha Methyl Ester Blends in a Diesel Engines," world renewable energy congress, Sweden 2011.
[19]. "Pakistan Energy Year Book 2004" by Ministry of Petroleum and Natural Resources, Govt. Of Pakistan.

Biography

Muhammad Arsalan Khan is a post graduate student at the Mechanical Engineering department of University of Engineering and Technology, Peshawar, Pakistan and also working as a Lab-engineer and technical assistant at Sarhad University of Science and Information Technology, Peshawar, Pakistan. He earned B.S. in Mechanical Engineering from University of Engineering and Technology, Peshawar, Pakistan, also Masters in Materials engineering from the said university. His research interests include manufacturing processes, engineering materials, failure analysis, and renewable energy resources. He is a member of ASME, SAE, PEC and SMEP.

Majid Baseer is currently a fulltime assistant professor at the Mechanical Engineering department of Sarhad University of Science and Information Technology, Peshawar, Pakistan. Mr. Majid Baseer holds a Bachelor of engineering degree in Mechanical engineering from University of Engineering and Technology, Peshawar, Pakistan, and MS in Engineering Management from UTS, Sydney.

Dr. Abdul Shakoor is currently working as an Associate Professor at the Department of Mechanical Engineering of University of Engineering and Technology, Peshawar, Pakistan. He did MS in Manufacturing Engineering from Loughborough University, U.K and also PhD in Materials Composites from the said university. He is the president of University of Engineering and Technology Teachers Association, a syndicate member of the university and other numerous executive bodies.