Performance Analysis of Biodiesel Generated Continuously by Using Newly Developed PLC Processor

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Abstract: Under the ever-looming threat of energy crisis, production and use of biodiesel promises a relievable and environment friendly solution. In this light, design and construction of an automated biodiesel plant can crank up and simplify the production process. Extraction of biodiesel from vegetable oil is time consuming and requires human involvement to perform and keep track of chemical titration, stirring and washing the product for each batch of production. A well-designed system can significantly eliminate human interaction and expedite the whole process. For meeting our energy demand, Bangladesh is mostly dependent on natural gas and import of fossil fuels from foreign countries. This dependency leaves our economy vulnerable and susceptible to international market. The concept of using biodiesel is still in its infancy in Bangladesh though she grows many different kinds of crops suitable for bio fuel production. Construction of an inexpensive automated biodiesel plant can help produce biodiesel in large scale and make a breakthrough in our economy as no such effort has been undertaken so far. It is a novel endeavor that seeks to make biodiesel production cheaper, easier and popularize in our country. To achieve the desired aim this paper focuses on implementation of the construction of a cheap, compact and automatic system that will exhaustively reduce human interactions as well as the processing time and increase the biodiesel yield. For this reason an automated biodiesel processor was designed and built utilizing a programmable logic controller (PLC) in conjunction with pumps, solenoid valves, level sensors, temperature sensors, etc. Upon the completion of a full cycle the plant delivers certified biodiesel and the leftover byproducts are collected for further recycling. Different batches of biodiesel were produced and a comparative study of the physical properties of the fuel and the performance characteristics of the diesel engine by these fuel samples were analyzed and shows satisfactory result.

Keywords: Biodiesel, Vegetable Oil, Alternative Energy, PLC processor, Blend.

1 INTRODUCTION

The inevitable depletion of fossil fuel based energy sources combined with global warming and radical climate change motions a grim fate for all of us which has compelled the researchers to look into more viable and environment friendly sources of energy. As a consequence biodiesel production has come under the limelight with a hope to replace the dwindling fossil fuels. Though an entire replacement might not be possible but a suitable blend of biodiesel and petroleum diesel can significantly reduce environment contamination. A major challenge is to invent a way to make the production process cheaper and faster.

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The conventional process is called Transesterification process in which vegetable oil is reacted with a monohydric alcohol in the presence of a catalyst. The Transesterification is expressed by the following reaction. [1, 2]

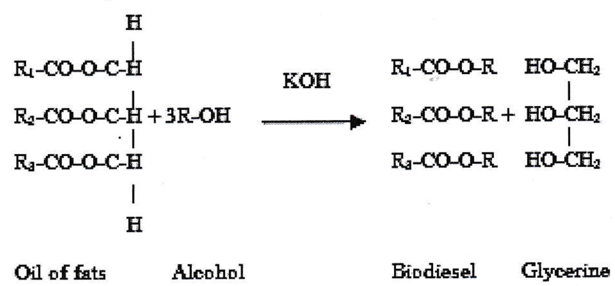

Fig. 1 A schematic representation of the transeterification of triglycerides (vegetable oil) with methanol to produce fatty acid methyl esters (biodiesel)

The entire process requires a human operator to run and monitor the Transesterification system and interfere whenever needed. In order to make the process faster an advanced and smart system is required. Amir et al. produce biodiesel using a stirred batch reactor where waste cooking oil is used as storage of vegetable oil and meth oxide. Middle section of the plant consists of the reactor, separator, washing tank, Control electronics and a blending tank. Bottom part of the plant contains a Diesel storage tank, Biodiesel storage tank, pressure pumps and methanol recovery unit. A functional description of different components is described in the following subsections.

TABLE 1

Summary of the sections in the portable-biodiesel-processing-unit

Sections	Components
Top	Vegetable oil Storage tank MeOH storage tank
Middle	Reactor Control electronics Separation Washing and drying Heat exchanger Blending
Bottom	Pressure pumps Diesel Storage Biodiesel Storage Methanol Recovery

Filtration of Waste Cooking Oil

For separating impurities and suspended particles, at first the waste cooking oil is passed through a fine strainer network manually. As the liquid passes through the strainer the particles are collected because they are not small enough to pass through the holes on the screen.

For the removal of water content oil is heated to 60 ° C and kept at this temperature for 15 minutes and kept for 24 hours to settle down. The advantage of this technique comparing with direct evaporation is reduction of free fatty acids production.

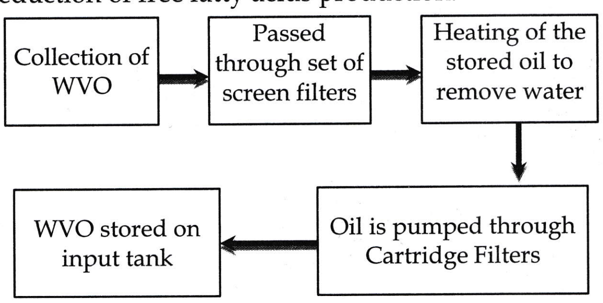

Fig. 2 Process flow diagram of filtration of waste cooking oil

The system is also designed with an automated filtration system to remove impurities from the WVO and moisture before future processing to biodiesel. It consists of taking the strained, heated oil and pumping it through two filters. The first filter is a 15-micron water block that is designed to remove water from the oil, while the second filter is a 10-micron filter that is designed to take out dirt and impurities in the oil (Figure 2). This process may be run twice so that will be able to produce a better overall biodiesel.

Reactor

Reactor is the sole part of the process in biodiesel production on which chemical reaction takes place. Batch and continuous reactors can be divided into two categories. Batch reactors simply made of a tank which equipped with stirrer. Tank is filled with the reactants (in this case waste cooking oil, alcohol, and catalyst), and then stirrer acts for a while. After the time required has elapsed, reactor contents drained and further processing is done. Beginning the process with the reactive substances and then leaving the processed materials is the main feature of batch reactors.

The tank designed for reactor has capacity of 10 liters and the tank is built from 3 mm sheet of stainless steel. The heating system for each tank is equipped with a 1000 W heater element, a temperature sensor and a digital thermometer for monitoring and temperature adjustment. Electrical signals from sensor because heater switched on or off. In the power transmission system, an electrical motor with power of the 1.5 kW (2 HP) was used to stir up the mixing. Two electro pump of 0.37 kW (0.5 HP) were used to transport raw materials (reactants) and products between tanks.

Separation, Washing and drying unit

After the proper mixing the mixture is transferred to Separator/Wash tank by a 0.5 HP pressure pump. The Tank is similar to reactor tank having capacity of 10 liters fabricated with 3 mm sheet of stainless steel. It has a stirrer attachment on the top of the vessel and three different solenoid valves at the bottom for disposing pure biodiesel, glycerin and waste water. There is a 1000 W heater element to heat the biodiesel to remove water from it.

The mixture is given time to react and settle into separating layers of Biodiesel and glycerin.

The glycerin formed settles to the bottom of the mixing tank and is removed from the tank by a hose that leads to a glycerin storage tank by opening feedstock and methanol as alcohol with molar ratio of 1:6 in the presence of potassium hydroxide as a catalyst with 1% by weight of waste cooking oil [3].

Highina, et. al used batch reactor to produce biodiesel from Jatropha oil. The paper concluded that, 93% of triglycerides have been converted to the methyl esters as a result of using batch reactor [4]. Leevijit et al. performed a simulation to optimize a mixing presentation of a permanent reactor for producing saleable Biodiesel from palm oil and to predict required residence times at the elected purities for transesterification of palm oil in optimized reactor [5]. Ghazi et al. discussed the concept of an incessant process in producing Biodiesel from Jatropha oil by using an oscillatory flow Biodiesel reactor [6]. Ghobadian et.al designed, fabricated and evaluated a novel biodiesel processor system with 70 liters capacity of batch type stirred tank reactor (STR).For efficient mixing both mechanical and hydraulic mixing has been incorporated. Also vacuum distillation method for methanol recovery, electrostatic coalescing method for glycerin separation and ion exchange dry wash is provided to increase the production capability and purity of biodiesel [7].

This project is an attempt to build an automated system that will reduce operator interaction as well as to make the system affordable and completely portable. The system also has some options to change a few operating parameters such as time, rpm and temperature so that the final product can be studied for further optimization. Therefore, the primary aim of the project is to explore for better and faster alternatives of biodiesel production and its commercialization.

2 The Process Design

This project aimed at constructing an inexpensive and automated biodiesel plant that would help mass production of biodiesel without manual [8, 9] observation. This is the first attempt ever undertaken in Bangladesh to produce biodiesel in an automated production system. The plant is about five feet high, completely portable and can fit into any corner. It's powered by 220V AC supply and can be used in both home and industries to produce biodiesel. The plant has different compartments for different raw material input. After all the inputs are given, it only requires turning on the machine. A standard time and temperature for reaction is preset but it can be changed as per the requirements. Currently the plant in its miniature form has the capacity to produce 10 liters of biodiesel in 24 hours which includes the waiting time after trans-esterification reaction and water wash time for 4 hours. The complete final product can be extracted after 20 hours and the byproduct glycerin is also extracted out separately. It can be used again to recover methanol for further biodiesel production. The plant has simple construction geometry and can be built locally and it's very much on the budget. In Bangladesh biodiesel was conventionally produced in laboratory for research purpose, but this plant can be used to produce biodiesel for both research and commercial purpose conveniently.

A process flow diagram of biodiesel production by the automated biodiesel plant is shown in the figure 02.

In a 10L chemical tank, the methanol and lye were mixed to produce the sodium methoxide. This reaction is exothermic, which produces heat, and results in the formation of sodium methoxide.

Operators should avoid standing over the tanks from this point on as any vapors released can be harmful or fatal.

In the first step, the sodium methoxide is added to the vegetable oil. First, the oil is reheated between 50°- 65 °C and then sodium methoxide is added. The mixture is maintained at this temperature and mixed for one hour using a stirrer. Then the mixture is allowed to cool to room temperature. Afterwards it is pumped to the settling/wash tank and allowed to settle for approximately 12 hours. The glycerin was separated and settled into the bottom of the wash tank and is drained off to methanol recovery unit.

The final step in the biodiesel process is to remove any soap, water, methanol, and other contaminants from biodiesel that were inadvertently created during the processing. Traditionally, a wet wash system is used for this process. It requires several wash cycles with water, and each cycle requires 4 hours of settling/separation time. Then the contaminated water must be properly disposed of.

3 Design and Construction of Biodiesel Processor

The portable biodiesel processing plant is divided in three separate sections (Table 1).On top of the plantthe two stainless steel tank is situated for the solenoid valves (valve#01) at the bottom of the Separating tank.

Once the glycerin is completely removed, the water inlet valve (valve#02) is opened and the biodiesel is washed to remove any soap, water, methanol, and other contaminants from biodiesel that were inadvertently created during the processing. After washing, biodiesel is heated up to 110 C to remove any leftover water on the biodiesel.

Storage Tank for Vegetable oil and Methoxide

Vegetable oil and methoxide storage tank is situated on the topmost section of the processor having capacity of 22L and 10L. Both of the tanks have a 24v submersible pump to pump out desired amount of oil and methoxide to the reactor.

Storage Tank for Diesel and Biodiesel

Diesel and Biodiesel storage tank is situated on the bottom section. Both the tank is made with 3mm stainless steel having capacity of 200L and 30 L respectively.

Methanol Recovery unit

Methanol is the most expensive input for the biodiesel process. The price is of Methanol is tied to the price of oil, and as such is at risk of instability as crude prices rise.

The glycerin by-product is poured in to a stainless steel container through a flexible pipe attached with the lid. The container must be sturdy and air-tight. An electric heater heats the glycerin to the methanol boiling point of 66 °F. The vapors rise through the bucket and into a length of copper tubing. The copper tubing then coils as it enters a condenser. Cold tap water passes through the condenser, cooling the methanol vapors to a liquid. The liquid falls through the copper tubing where it is collected at the bottom. Once the liquid methanol stops flowing, the process is completed and the glycerin is drained from a tap.

Blending Unit

Biodiesel can be blended and used in many different concentrations. They include B100 (pure biodiesel), B20 (20% biodiesel, 80% petroleum diesel), B5 (5% biodiesel, 95% petroleum diesel), and B2 (2% biodiesel, 98% petroleum diesel). The most common biodiesel blend is B20, which qualifies for fleet compliance under the Energy Policy Act (EPAct) of 1992. Blends of 20% biodiesel and lower can be used in diesel equipment with no, or only minor modifications [10]. The B6 to B20 blends are covered by the ASTM D7467 specification [11]. Biodiesel can also be used in its pure form (B100), but may require certain engine modifications to avoid maintenance and performance problems [12].

By the two separate 0.5 HP pump diesel and biodiesel is transported on the blending tank situated on the middle section of the plant. The tank is also a 3mm thick stain

less steel tank having capacity of 10L. Over the tank a stirrer is attached to mix the diesel and biodiesel uniformly.

Programmable Logic Controller Programming

The last step involved is writing a PLC program to control different process. The biodiesel processor uses Siemens S7-200 CPU 222 PLC controller. The Siemens S7-200 CPU 222 PLC controller was selected because it is currently widely used in industry. It has multiple inputs and output capabilities and is easy to program. In addition, the PLC will allow the operator to add a vast array of items to the process, such as flow meters, temperature gauges, timers, solenoid valves, and pumps quite easily. The processor works on an input/output basis for each action to occur. Once an input signal/signals are received (a given temperature, elapsed time, etc.) the controller sends an output signal (begin mixing, turn heater on, etc.).

There are three buttons on the PLC panel; a green start button, a red stop button, and a clear green reset button. The red stop button can be pressed at any time to stop the processor. The reset button can also be used to stop the program, and it must be pressed after the stop button is pressed in order to reset the counters in the program. Ladder programming language is used to program the PLC for this biodiesel production.

The operator has to press the Start button on the PLC panel and this will start the pump #1 for 5 min to fill the reactor with 5L of oil. After that heater #1 and stirrer motor #1 should be switched on for 15 minutes to ensure all of the oil is thoroughly heated.

Once the temperature of the oil in the reactor reaches at 50° C (via a thermometer attached to the tank) and also 15 minutes are up, pump #2 will start and begin pumping the sodium methoxide from the tank into the 10L reactor. It takes 1 min to deliver 200 ml sodium methoxide to the reactor.

The mixture is maintained at 50° C temperature and mixed for one hour using a stirrer. Then the mixture is transferred to settling/Wash tank by switching on pump #3.On the settling tank the mixture is kept for 12 hours and the glycerin was separated and settled into the bottom of the settling tank and is drained off to methanol recovery unit by opening valve #1.

Then for wet wash of the biodiesel Valve #2 will open for 2 min and continue to stir the biodiesel and water at a very low RPM and about 2 min. After 4 hours passes, valve #3 will automatically open to drain waste water from the wash tank. Then the heater#2 of the wash tank will be switched on and heated to remove water of the oil. Afterwards valve #4 will open to drain biodiesel to storage tank.

In the different storage tank four fluid level sensors are there for the indication of empty tank. Once Fluid Level Sensor #1 (located in the bottom of the sodium methoxide small tank), Fluid Level Sensor #2 (located in the bottom of the vegetable oil storage tank), Fluid Level Sensor #3 (located in the bottom of the Diesel storage tank), Fluid Level Sensor #4 (located in the bottom of the Biodiesel storage tank) reads empty, a red indictor will be lit to inform the operator.

4 CHARACTERIZATION OF BIODIESEL

The properties of biodiesel (methyl esters) made from waste cooking soybean oil is quite comparable to that of diesel fuel. Transesterification reaction improves the desirable fuel properties of oil like density, kinematic viscosity, flash point, fire point, cloud point, pour point and calorific value.

Viscosity was measured by using Saybolt viscometer. Flash point and fire point were measured by closed cup apparatus whereas calorific value was determined using bomb calorimeter. The table II shows the comparison on fuel properties of waste cooking oil, bio-diesel blends and diesel.

TABLE 2

Properties of waste cooking oil, biodiesel, diesel and their blends

Fuel Type	Density (gm/cm³)	Kinematic Viscosity (mm²/sec)	Flash point	Calorific value (MJ/kg)
Waste cooking Oil	0.93	32.5	286	37.3
Diesel	0.84	4.05	65	45.8
B100	0.92	5.6	172	37.9
B40	0.89	5.2	82	41.3
B20	0.87	4.9	78	42.8

The comparisons show that the biodiesel has fuel properties relatively closer to diesel fuel. The viscosity was substantially got reduced from a value of 32.5 to 5.6 mm2/sec. The flash and fire point of waste cooking biodiesel were higher than that of conventional diesel. A small percentage of biodiesel addition with diesel can definitely improve the flash point of resultant blend, hence this blend is safe to store and transport.

5 PERFORMANCE TEST ON AUTOMOTIVE DIESEL ENGINE

Experimental set up consisted of engine bed, water brake dynamometer, load indicator, supply tank and fuel input measuring system, air intake measuring system, digital panel board etc (Fig. 3). K type thermocouples are used to measure the temperature of exhaust gas and lubricating oil.The specification of the engine used for experimentation is given in table 3. The set-up enables the study of engine brake power, fuel consumption, air consumption, heat balance, thermal efficiency, volumetric efficiency etc.

TABLE 3

Engine specification

Item	Specification
Absolute Maximum Power	3.5 kW (4.8 hp) at 3600 rev. min⁻¹
Continuous Rated Power	3.1 kW at 3000 rev. min⁻¹
Bore	69 mm
Stroke/Crank Radius	62 mm/31 mm
Connecting Rod Length	104 mm
Engine Capacity	232 cm³ (0.232 L) or 232 cc
Compression Ratio	22:1
Oil Type	Multi grade SAE 5 W - 40
Oil Capacity	2.6 Liter

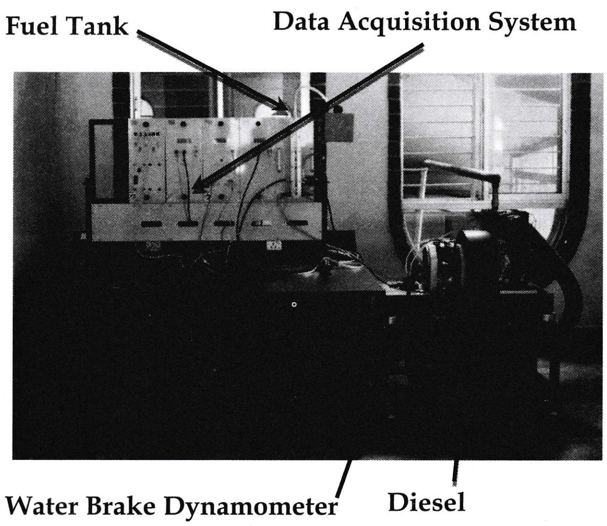

Fig. 3 The single cylinder CI engine with water brake dynamometer and data acquisition system

6 Results Analysis and Discussion

Variation of Bsfc and thermal efficiency with power produced are shown in the figures4 and 5 respectively. Bsfc was found to be highest when the engine is running with low power. This decreases when engine power approached the rated power of the engine and then slightly increases at the end. Since the density and heating values of diesel and the two blends are different, the real comparative picture is exhibited in the variation of thermal efficiency. The thermal efficiency of diesel found to be highest for diesel and slightly lower for B20 and B40.

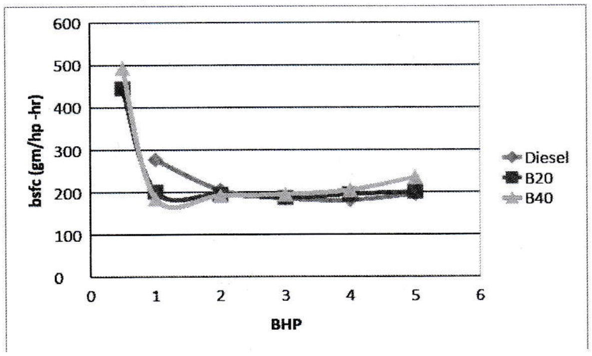

Fig. 4 Comparison of Bsfc with respect to BHP for different biodiesel and diesel

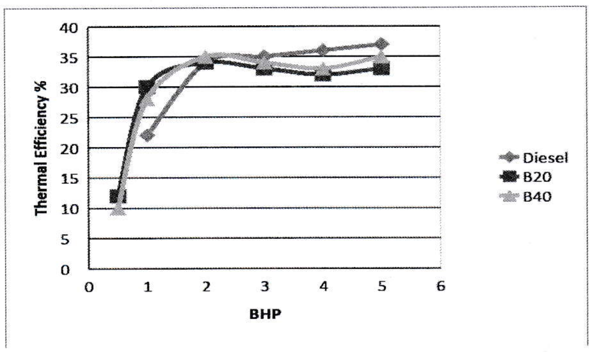

Fig. 5 Comparison of thermal efficiency with respect to BHP for different biodiesel and diesel

7 Conclusion

The ultimate goal of this project is to design and produce an automated biodiesel processor to minimize the processing time and increase the biodiesel yield with very limited operator interaction. The biodiesel produced was analyzed and meets ASTM standards and used successfully in running a diesel engine.

The system also have some options to change a few operating parameters such as time, rpm and temperature so that the final product can be studied for further optimization.

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