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Waste Cooking Oil as a Fuel Source for Diesel Engines*

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Almost all cities and towns in Papua New Guinea are producing tonnes of waste vegetable oils annually, mainly from industrial deep fryers in potato processing plants, snack food factories, fast food restaurants, and institutional dinning facilities. These waste vegetable oils are directed to waterways, rivers, and finally into the ocean which destroys the ocean shores and damages the environment. With increasing population, not only the demand for cooking oil will increase but also the environmental problems caused by the waste cooking oil. Most brands of cooking oil that is used in Papua New Guinea are from locally produced palm oil. Palm oil consists mainly of triglycerides made up of a range of fatty acids and contains other minor constituents, such as free fatty acids and non-glyceride components. This composition determines the oil's chemical and physical characteristics. This is an attempt to improve the waste vegetable oil's chemical and physical characteristics that will allow the oil to be used as an energy source and at the same time reduce the associated environmental problems. It has been observed that the waste cooking oil can be converted into a useful energy source using the transesterification process. The converted fuel has been tested and found its performance to be equivalent to petroleum diesel.

Keywords: vegetable oil, biofuel, biodiesel, renewable energy, triglycerides, transesterification

Introduction

In many cities and towns in Papua New Guinea, there are tonnes of waste vegetable oil that is being produced annually from various commercial dinning facilities at the learning institutions, industrial deep fryers, and fast food restaurants etc. within the major cities and towns. With increasing population, not only the demand for cooking oil will increase but also the environmental problems caused by the waste cooking oil. In many surveys conducted, restaurants may produce more than 1-liter of waste cooking oil per day and most of this oil is likely to be discharged into the sewers and water ways that may finally end up in the ocean that may destroy the ocean shores and damage the environment. If discarded oil can be used as an energy source, it may not only be an alternative energy source but also assist in reducing the cost of waste water treatments and generally assist in recycling of resources.

When the fresh cooking oil is used for deep frying, the oils are generally heated to 160 ℃ -180 ℃, and several changes occur such as oxidation and lowering of molecular weight due to hydrolytic release of fatty acids from the triglycerides and thermal decomposition, and polymerization with formation of cyclic

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compounds (Yusaf, 1998). Some characteristic changes occur such as bubble formation, coloration, and stability against oxidation. The viscosity and the density increases slightly and atomization characteristics deteriorate. However by filtering out suspended matter and taking appropriate cleaning action on the oil in order to improve its quality, waste cooking oil may adequately be used as an energy source, and in this form they may be very attractive, in regard to the cities and towns environmental maintenance and resource recycling considerations. Waste cooking oil's properties can be improved to an equivalent of diesel fuel by using the transesterification process and producing methyl esters.

Like many other universities in the world, the Papua New Guinea University of Technology has more than 1,200 resident students who are fed from the university dinning facilities throughout their residential study period. A large quantity of locally processed palm oil is used annually to prepare students meals, which end up as waste cooking oil. Papua New Guinea is one of the countries in the Asia Pacific region that produces palm oil as an export commodity as well as supplying the local market needs for cooking oil. Palm oil is derived from the mesocarp of the oil palm fruit. Palm oil consists mainly of triglycerides made up of a range of fatty acids and also contains other minor constituents such as free fatty acids and non-glyceride components. This composition determines the oil's chemical and physical characteristics.

This paper reports an investigation that has been conducted to determine if the waste oil produced from the university student's dinning facilities could be utilized as an energy source since the original oil used for cooking is locally produced palm oil by using the transesterification process and producing methyl esters.

Experimentation

Materials and Methods

The materials used for this project are mainly the waste cooking oil as the feedstock, which was supplied by the university's dinning department. The waste cooking oil is produced as a waste after the university's dinning department uses palm oil supplied by the local palm oil manufacturers for the preparation of the food for the students.

The other secondary materials used in this project are small (1-2 mm) Pearl Caustic Soda are 99% + (Sodium Hydroxide-NaOH) or lye and 100% Methanol or Methyl Alcohol (CH_3OH). Sodium hydroxide was used as a catalyst in the transesterification process and it is hygroscopic—it absorbs water from the atmosphere and fresh sodium hydroxide or lye is essential and it has to be kept in a tightly sealed container. Similarly, methanol is required to convert triglycerides (fats and oils) into esters (biodiesel)—the "methyl" portion of methyl esters. Both of these chemicals are toxic and hazardous and it was handled and stored with great care and cautious.

Test Apparatus

The biodiesel laboratory processor unit with a capacity of about 76-90-liters per batch consists of a single, multi-use tank system that is used to process, separate, wash, and filter the fuel. It is facilitated with a powerful, heavy-duty pump which serves as both as mixer and a transfer system as shown in Figure 1. The processor is also facilitated with an electric heater that is used to heat the water before the hot water is circulated through the heating copper coil tubes in the processor to heat the waste cooking oil or the biodiesel to remove moisture.

The biodiesel fuel produced from the waste cooking oil was tested for performance using a sisson single cylinder direct injection (DI), water-cooled diesel engine with a bore of 114-mm and a stroke length of 127-mm as shown in Figure 2. The engine is rated at a power capacity of 4.1-kW and a speed of 750-rpm with a Bryce Single piston injector pump and a pintle injector. The engine is coupled to a brake dynamometer for loading purposes with friction brake and graduated cylinder for measuring the fuel used.

Figure 1. Biodiesel laboratory processor unit.

Figure 2. Fuel performance testing apparatus.

Test Procedures

Unlike fresh oil, waste-cooking oil supplied from the university's restaurant contained a lot of dirt and solid waste materials that required a through cleaning and filtering. After vigorously cleaning and filtering the waste cooking oil, the clean oil was then poured into the processor for processing using the transesterification process.

Because of the feedstock being waste cooking oil, it was important to determine the correct amount of catalyst to use to crack the fuel from the oil. In order to determine the accurate amount of catalyst required, a titration method was used. Using the detail titration procedures found in other literature (The Papua New Guinea University of Technology, 2007), the required amount for sodium hydroxide (NaOH) was determined to be about 5.5-grams per litre of waste cooking oil and about 0.23-liter of methanol (CH_3OH) per litre of waste cooking oil. The required amount of methanol and sodium hydroxide was mixed in the polyethylene methoxide tank creating a sodium methoxide ($Na^+CH_3O^-$) solution that was to be used to convert about 10-gallons of waste cooking oil. This is a strong chemical that is intended to crack the transfatty acid into glycerine and also the methyl ester chains or biodiesel fuel.

The sodium methoxide was then injected into the processor with the waste cooking oil. Immediately after the injection of the methoxide, the circulation pump was used to vigorously mix the waste cooking oil with the methoxide for more than three hours before letting it settle overnight for the process to complete its reaction. After the reaction has completed, there was a clear distinct layers between the fuel and the glycerine as shown in Figure 3.

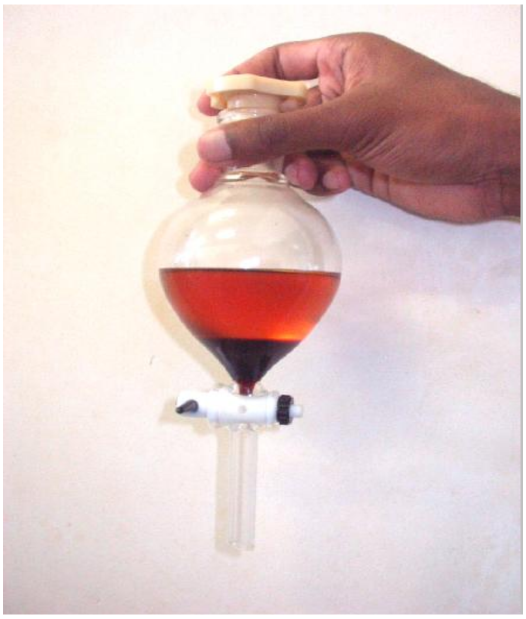

Figure 3. Flask with two distinct layers of biodiesel and glycerine.

The glycerine was drained from the processor into other contains for further processing. The remaining fuel in the processor was washed using the fine water mist from the misting head installed in the centre of the processor lid. The water mist washing was necessary to remove soluble elements such as salts, soap, catalyst, and alcohols in the fuel. After washing, the fuel was left to settle into layers of water and fuel. After setting, the water is then drained and the fuel is dried by heating the fuel to about 50 ℃ using the heating system of the processor and holding it there for a period of time. This allows any excess water in the fuel to drop freely out and then drained out of the bottom of the processor. The final fuel is then pumped through a filter into a storage container for further testing.

Fuel Performance Testing

The sisson single cylinder engine was started using biodiesel fuel from the supply tank and allowed to run for at least 30 minutes to warm up the engine with no loading before testing the fuel with loading as per the laboratory manual (The Papua New Guinea University of Technology, 2007). After the engine was warmed up, the engine was loaded by increasing the tension in the brake rope until the tension in the tight side reached the maximum loading of about 180-N.

The governor was then adjusted in order to maintain the engine speed steady at 600-rpm. The biodiesel fuel supplied from the main tank was turned off and the time taken by the engine to use the 100-cc of biodiesel fuel in the calibrated cylinder was measured. The valve was carefully turned back to open immediately after the 100-cc of fuel was used, as the engine may cut out if the main fuel supply from the supply tank is not reconnected. The tension in the tight side of the rope was reduced with increments of about 20-N and repeated the procedure until the tension reached the minimum loading of 60-N. All necessary measurements were taken and recorded for further processing.

Results and Observations

The biodiesel fuel produced from waste cooking oil appeared to be having some similarities with petroleum diesel fuel in terms of bubble formation. Moreover, when the fuel was tested in the engine, the engine started without any difficulties and it continued running smoothly even after loading. Clean colourless gases were observed to be coming out of the exhaust at loads less than 100-N. However, more light clean blue gases were observed to be coming out of the exhaust as the loads were increased.

Using the data collected from the experiment, the brake power of the engine was determined for each loading. The results were plotted against the load as shown in Figure 4 for the three different types of fuel, 100% diesel fuel (DF), biodiesel blended with diesel fuel (B20), and 100% waste cooking oil biodiesel (B100) for comparison. When the curves are compared, it appears from this linear relationship that there is a negligible difference between the three fuels tested.

Similarly, brake thermal efficiencies were determined for each loading and plotted against its loading as shown in Figure 5. Brake thermal efficiency is the ratio of the brake power over the rate of energy released from the fuel. When the curves are compared, it appears that the brake thermal efficiency for all fuels increased as the loading increased to a specific loading before declining. The declining efficiency appears to be about 100-N for the blends and the 100% waste oil biodiesel (B100) but for the 100% diesel fuel, the declining efficiency appears to be about 125-N. Blended (B20) fuel has the highest brake thermal efficiency followed by 100% diesel fuel and then 100% waste oil biodiesel.

Also, the specific fuel consumption was determined for each loading and plotted against its loading for the three different fuel types for comparison as shown in Figure 6. Note that specific fuel consumption is the mass of fuel consumed by the engine to produce one unit of power per hour (kg/kWh). The curves generally appear to be decreasing as the load increases until it reaches a loading of about 100-N when it begins to increase to its maximum load. When the curves are compared, it appears that the specific fuel consumption of the 100% waste oil biodiesel (B100) is the lowest at maximum load with the 100% diesel fuel being the next lowest and blends (B20) having the highest.

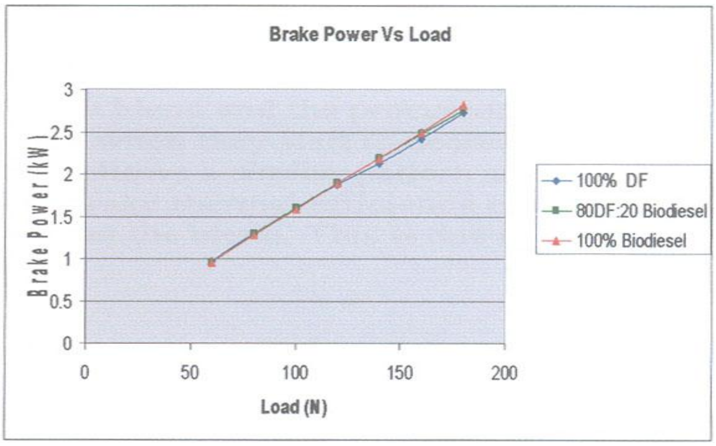

Figure 4. Brake power vs. load.

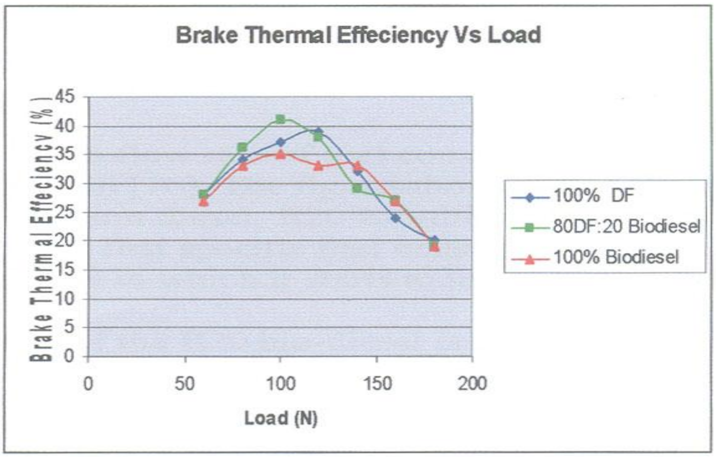

Figure 5. Brake thermal efficiency vs. load.

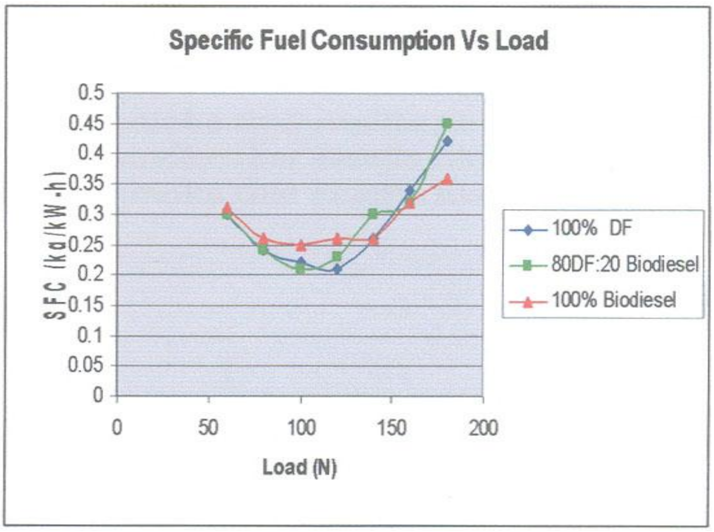

Figure 6. Specific fuel consumption vs. load.

The results of the three different fuel types appear to indicate that there is a negligible difference at low and high loads but there is a slight difference at loads ranging from 80-N to about 145-N. This may be due to the difference in the viscosity and heating value of the three different fuel types. Generally, it appears that the biodiesel fuel produced from waste cooking oil is compatible with petroleum diesel and it can be used in a diesel engine without any modifications.

Conclusions

A successful attempt has been made to make use of the waste cooking oil from the student's dinning facilities as an energy source. The results are summarized as follows:

1. The waste cooking oil has been successfully converted as an energy source.
2. The biodiesel fuel produced from waste cooking oil is comparable with petroleum diesel.
3. Visual inspection of the exhaust gases indicates clean and environmentally friendly emissions being released from the exhaust system without any thick smoke.

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