

A Clean Biodiesel Fuel Produced from Recycled Oils and Grease Trap Oils (BAQ 2002)

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ABSTRACT

The feasibility of converting recycled oils and grease trap oils from restaurants and food processing industries to clean biodiesel fuel has been studied aiming at reducing the amount of waste oils to be treated and lowering the cost of biodiesel production. This paper presented a novel biodiesel production technology using the waste oils generated from local restaurants. Optimum conditions to achieve maximum yield of biodiesel using the waste feedstock were presented and compared with those produced from a neat vegetable oil. The fuel properties of biodiesel, such as kinematic viscosity and acid value, were examined. The biodiesel produced from recycled oils was further tested with a light diesel van on a chassis dynamometer to explore the vehicle performance under loaded conditions. The engine power and pollutant emissions characteristics under different biodiesel percentages were studied. Experiments demonstrated that using the biodiesel produced could reduce smoke and HC emissions significantly while the NO_x emission changed slightly. There is an unnoticeable drop in the maximum engine power output even at 100% biodiesel.

Keywords: Biodiesel, Transesterification, Emission, recycled oils, Grease trap oils

1.0 INTRODUCTION

Biodiesel is a mono alkyl ester (methyl or ethyl ester) of long chain fatty acids derived from renewable lipid such as vegetable oils and animal fats. Biodiesel can be used in any compression ignition (diesel) engines without the need of modification and is therefore a good substitute for diesel fuel. It possesses several distinct advantages over petro-diesel in the following safety, biodegradability and environmental aspects:

- A renewable fuel with a net gain of energy producing it;
- Higher flash point makes its safer in transport and storage
- Greatly reduces particulate matter and carbon monoxide emissions
- Lowers ozone forming potential of hydrocarbon emissions;
- Reduces carcinogenic polycyclic aromatic hydrocarbons (PAH) and nitrated PAH;
- Contains essentially no sulfur, therefore greatly reduces sulfur dioxide emissions from diesel vehicles;
- Biodegrades as fast as dextrose;

In a recent report released by USEPA [1], it is found, after a comprehensive analysis on the emission impacts of biodiesel using publicly available data, that neat biodiesel fuel can reduce particulate matter, unburnt hydrocarbons and carbon monoxide by 47%, 67% and 48% respectively but at the same time increase nitrogen oxides emission by about 10% as compared to petro-diesel. Due to its potential benefits in reducing vehicular emissions and greenhouse gases, biodiesel has become more and more popular in many countries in Europe and North America. Plenty of studies have been conducted on biodiesel production and emission testing in the past two decades. Most of the current challenges are targeted to reduce its production cost, as the cost of biodiesel is still higher than its petro-diesel counterpart. This opens a golden opportunity for the use of waste or recycled oils as its production feedstock. Everywhere in the world, there is an enormous amount of waste lipids generated from restaurants, food processing industries and fast food shops everyday. Current practice of removing these oily wastes in Hong Kong is to dump them to municipal landfill sites. There are also some illegal dumping of them to public sewers causing various kinds of plugging and damaging problems. Reusing

of these waste greases can not only reduce the burden of the government in disposing the waste, maintaining public sewers and treating the oily wastewater, but also lower the production cost of biodiesel significantly.

The objective of this project is to study the feasibility of producing a clean biodiesel fuel using waste lipids as feedstocks of production. This paper described the laboratory procedures of producing biodiesel by transesterification of waste oils (grease trap oils and recycled oils) with methanol in the presence of a catalyst (sodium hydroxide). Through optimizing the process variables that affect the yield and purity of biodiesel, optimal transesterification conditions that produce maximum biodiesel yield could be obtained. The fuel properties of the biodiesel produced, such as kinematic viscosity, were examined. Finally, the biodiesel produced was tested in a real diesel vehicle on its engine power, smoke level and pollutant concentrations under different biodiesel/diesel blending ratios.

2.0 PRODUCTION METHODOLOGY

2.1 Feedstocks

Two types of oils from local restaurants were collected and used as feedstocks of the biodiesel production. One is the recycled oils which mainly contained used frying oils and animal fats produced after repeated cooking and deep frying of food. The other is the oils collected by a grease trap specially designed for separating oils and grease from wastewater of restaurants and food processing industries (Figure 1). They are mostly oily wastes obtained from utensils washing, floor and stoves cleaning, food residues, etc. and have no commercial value. While the recycled oils can still be usable, mainly for the production of soap, they are usually deposited due to its low resell value and the limited space for storage. Commercial grade edible canola oil was also used to produce a reference neat vegetable oil based biodiesel fuel for comparison.

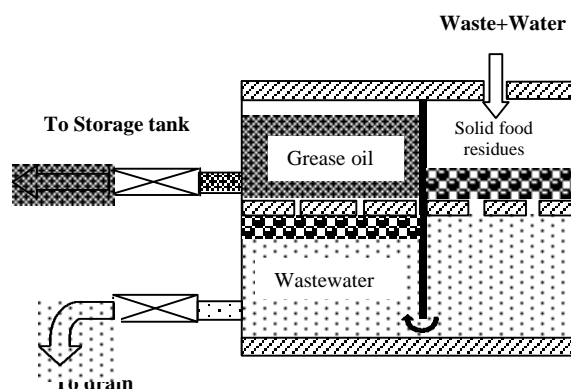


Figure 1. Schematic diagram of the grease trap used for waste/oil separation in local restaurants.

In the present study, the oils were first filtered to remove food residues and solid precipitate in the oils, and heated up to about 130°C for 10 minutes to remove trace water in the raw oils. It was then stored in a container as feedstock for experimental use. Methanol-NaOH solution (sodium methoxide) was prepared freshly during experiment in order to maintain the catalyst activity. Standards of various fatty acid methyl esters were obtained to facilitate the use of a gas chromatography for composition analysis.

2.2 Methodology

Sample of raw oils was weighted and placed in a container equipped with a magnetic stirrer and a thermometer. With the oils stirred and heated to 70°C on a hot plate, freshly prepared sodium methoxide solution was added into the container. The mixture was maintained at 70°C and stirred continuously for a predetermined reaction time. Small amount of glacial acetic acids was added to stop the reaction by neutralizing the residue NaOH in the mixture. The container was then removed from the hot plate and the products of reaction were allowed to settle for several hours to produce two distinct liquid phases. The top phase (crude ester) was separated from the bottom phase (glycerol) by decantation, and then washed with warm deionized water (50 mL) several times to remove the excess catalyst until the wash water became clear. The excess methanol and water in the ester was then removed by evaporation at atmospheric pressure. The ester phase was finally dried over anhydrous sodium sulphate (Na_2SO_4), and the final product, biodiesel, would be obtained as a clear, light yellow liquid. The above procedures were applied to all the test feedstocks with different oil/methanol ratios determined before the production.

3.0 RESULTS AND DISCUSSIONS

3.1 Analysis of transesterification products

The weight percentage of methyl ester in the product was determined using a HP 6890 Series II Gas Chromatograph installed with a flame ionization detector and a 3365/IIIGC-ChemStation. A HP-INNOWax (Cross-Linked PEG) capillary column, which has a length of 30m, a film thickness of 0.5 μ m and an ID of 0.32mm, was used. One micro-liter of each biodiesel sample was injected manually. The internal standard quantitative calculation was chosen. The content of free fatty acid in raw oils and biodiesel was analyzed by a well established experimental titration procedure. The kinematic viscosity of the raw oils and biodiesel was measured at 40 $^{\circ}$ C using an Ubbelohde glass capillary viscometer.

3.2 Reaction and purification conditions

The experiment mainly investigated the feasibility of converting the waste oils from restaurants to biodiesel fuel and if feasible, the optimal operation conditions to produce maximum yield and purity of the product. In all the experiments, reaction temperature was fixed at 70 $^{\circ}$ C at which a shorter reaction time can be possible. The best combination of operation parameters was shown in Table 1, corresponding biodiesel yield and its purity were listed in Table 2.

It can be seen from Table 1 that because of the difference in fatty acid composition, the optimal transesterification conditions varied with the types of feedstock used for the production. Also, due to the presence of more impurities more washing effort was required for biodiesel produced from waste oils.

Table 1 Optimal reaction conditions for maximum biodiesel yield.

Optimum reaction condition	Feedstocks		
	Grease trap oils	Recycled oils	Edible canola oil
Acid value in raw oils	4.1	0.9	<0.5
Molar ratio of methanol to raw oils	6:1	7.5:1	6:1
Catalyst concentration (based on weight of raw oils)	1.0wt%	1.07wt%	1.0wt%
Reaction time	30 minutes	30 minutes	35 minutes
Reaction temperature	70 $^{\circ}$ C	70 $^{\circ}$ C	70 $^{\circ}$ C
Washing	Sodium chloride solution+ warm deionized water	Sodium chloride solution + deionized water	Deionized water

Table 2 Experimental results under optimal reaction conditions.

Feedstocks	Biodiesel yield wt%	Biodiesel purity wt%	Biodiesel kinematic viscosity at 40 $^{\circ}$ C cSt	Acid value in biodiesel
Grease trap oils	77.3	97.7	4.1	0.21
Recycled oils	91.0	95.6	4.0	0.15
Edible canola oil	91.0	98.0	3.6	0.08

Table 2 showed that the yield and purity of the biodiesel produced from the recycled oils were quite high and the separation and purification steps were also processed without any difficulty. For grease trap oils that have a higher content of free fatty acids (2%), experiment confirmed that it could also be converted into biodiesel with a yield of 77%. It was comparatively more difficult to separate the ester from glycerin and water (during washing) due to additional soaps formed (significant amounts of free fatty acids would react with an alkaline catalyst). As a result, biodiesel yield was reduced markedly and more water and longer time was needed for

product purification as compared with that of higher-quality canola oil and recycled oils. It is inevitable that among the three feedstocks, the edible canola oil was the best with the highest biodiesel purity and yield. The grease trap oils, on the other hand, has the lowest yield due to its higher acidity and more impurities. Further studies on using grease trap oils are underway in our laboratory to improve the technique that enhances the product purification, consequently achieve higher biodiesel yield, and further reduce the production costs of biodiesel.

The kinematic viscosity of biodiesel derived from the transesterification of grease trap oils, recycled oils and canola oil all met the German Biodiesel Standard (3.5-5cSt) and US National Biodiesel Standard (1.9-6.0cSt)[6]. Their acid values also met the German (0.5max) and US standard (0.8max)[6].

3.3 Emissions testing

The biodiesel produced from recycled oils was tested in a 1998 FORD light goods van with a 4-stroke four cylinders water-cooled diesel engine [7]. Its capacity is 2.5 litres with a rated engine power of 59 kW. The van was tested in a Clayton Industries Chassis Dynamometer Model ECCT 500108. Two loadings (12 and 29 kW) were applied onto the vehicle and constant speed was maintained during the emission testing. A IGD TOCSIN 310 Portable Emission Analyzer was used to measure the CO and NO_x concentrations while a Beckman 420A HC analyzer was used to determine the HC concentration. A dieseltune-SPX Smokemeter model DX230 was used to measure the smoke opacity level of the van during the test.

Figure 2 showed the maximum engine power variation of the van with different biodiesel blending percentages. A linear decreasing trend of maximum engine power with biodiesel percentage can be observed. However, the power variation was small for all biodiesel blending percentages tested. For example, there is only a 6% reduction in power for 100% biodiesel. Such a small change would not be noticeable during driving.

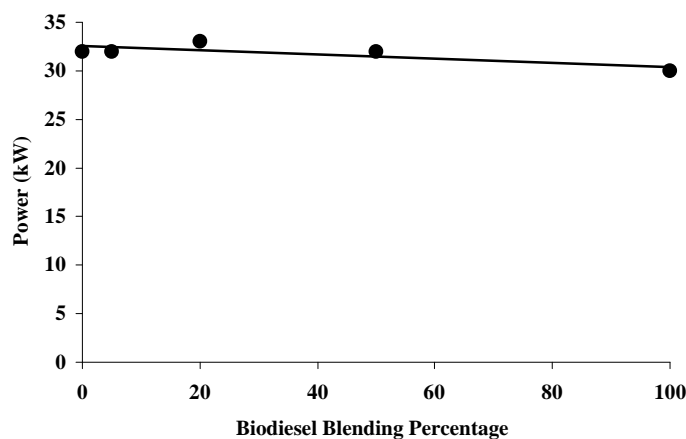


Figure 2. Maximum engine power at different biodiesel blending percentages.

Figure 3 indicated the smoke opacity of the van with different biodiesel blending percentages under a diesel lug down test. The result of the free acceleration simulation (FAS) test has similar trend. All the measured smoke levels decreased with increasing biodiesel blending percentage, which is consistent with the results in literature. A maximum reduction of 83% in smoke opacity has been recorded for 100% biodiesel usage. However, it should be noted that the high percentage may be due to the small smoke opacity value of the vehicle tested.

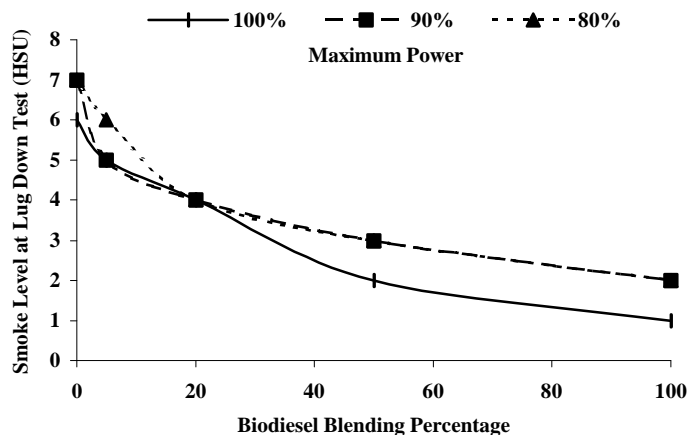


Figure 3. Smoke opacity level at different biodiesel blending percentages.

The hydrocarbon concentration of the van under the two different loadings was shown in Figure 4. It can be observed that the HC concentration decreased first with increasing biodiesel percentage, reached a minimum at about 30% and increased afterwards. The HC concentrations at all biodiesel blending percentages were less than the neat petro-diesel. The CO concentration (not shown here), exhibits similar trend as the HC curves except that the changes are not so dramatic.

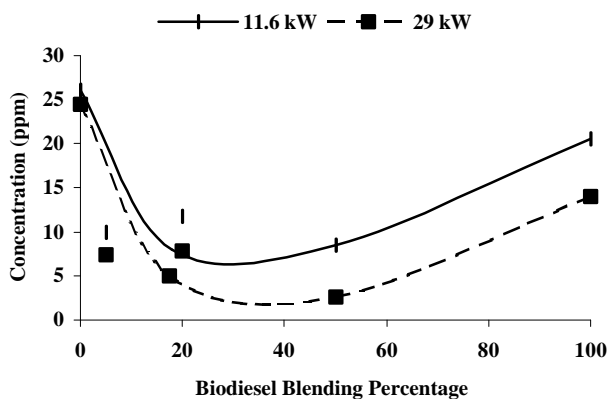


Figure 4. HC concentration at different biodiesel blending percentages.

The nitrogen oxides concentration of the van under the two different loadings was shown in Figure 5. It can be observed that the NO_x concentration only varied slightly for the two loadings at the full range of biodiesel tested. It should be noted that all the NO_x variations were less than 8%, which is consistent with most published results in literature [1].

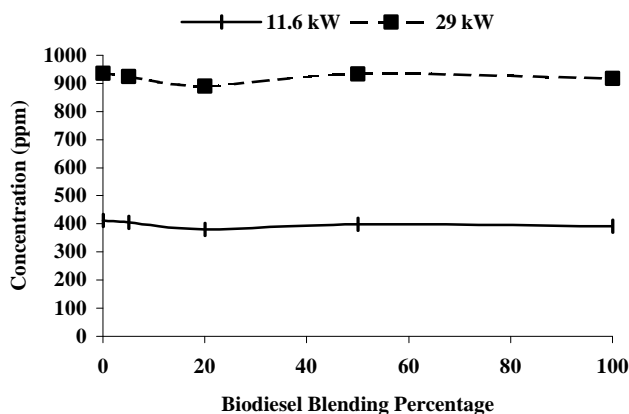


Figure 5. NO_x concentration at different biodiesel blending percentages.

4.0 CONCLUSIONS

The transesterification of waste cooking oils (grease trap oils and recycled oils) with methanol to produce biodiesel was successfully performed with a maximum biodiesel yield of 77wt% and methyl ester purity of 98% for grease trap oils, a maximum biodiesel yield of 91wt% and methyl ester purity of 96% for recycled oils. The optimal conditions and biodiesel yield may vary in terms of the quality of raw oils. For grease trap oils that have a higher acidity, its purification was more difficult than that of recycled oils and edible canola oil with a lower acidity. Further study on grease trap oils conversion is underway in our laboratory to improve the technique that enhances the product purification process, consequently achieves higher biodiesel yield, and further reduces the production costs of biodiesel.

The fuel properties of biodiesel derived from grease trap oils, recycled oils and canola oil, kinematic viscosity and acidity, all met the German Biodiesel Standard and US National Biodiesel Standard.

The biodiesel produced was successfully tested on a light van under a chassis dynamometer with different biodiesel/petrol-diesel blending percentages. Experiments demonstrated that using the biodiesel produced can reduce smoke, and HC emissions significantly while the NOx emission changed slightly. There is no obvious change in the engine power output even at 100% biodiesel.

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