Production of Biodiesel from Waste Cooking Oil Using the *Cruzesterification* Process for Rice Farming Operations

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Abstract: Providing the farmers alternative sources of fuel such as biodiesel produced from waste cooking oil is one possible way of helping them reduce their dependence on fossil fuels. Waste cooking oil (WCO) can be a stable source of feedstock for biodiesel production since it can be easily accessed from restaurants and fast food establishments. If farmers would be able to use biodiesel, not only will they have a cheaper source of fuel for their farm equipment but they will also aid in the reduction of greenhouse gas emission. Moreover, they can have the chance of earning additional income from glycerin, a by-product of the biodiesel processing that could be used to manufacture soap, among other possible products. The utilization of waste cooking oil for biodiesel production could also help solve the problem of its improper disposal which would lead to some serious health issues. This study was therefore conducted to: (1) gather baseline data in the processing of waste cooking oil to biodiesel, (2) develop a system for a large scale processing of waste cooking oil to biodiesel, and (3) test the performance of biodiesel on different rice farming machinery. The *cruzesterification* process developed by Dr. Rico Cruz was adopted in processing the WCO into biodiesel. To account for the varying quality of purchased WCO, each container purchased from local food establishment was subjected to testing to determine the proper amount of KOH to be used per batch of mixing. It was observed that highly reused cooking oil required up to 21 grams KOH per liter of WCO with a conversion rate of 72-75%. WCO which was relatively less degraded on the other hand only required 11-15 grams KOH per liter of WCO with a recovery rate of as much as 92-95%. Using a fabricated micro-processing plant, the production of biodiesel in larger volumes was tried to enhance the system of production and utilization of biodiesel from WCO for farming operations. The processed biodiesel were tested in PhilRice-CES farm machinery in different blends: B20, B50 and B100. B20 and B50 biodiesel blends were tested in a 75hp four-wheel tractor. Moreover, B20, B50 and B100 biodiesel blends were tested in an 8hp diesel engine. One notable difference was that colorless smoke came out of the exhaust pipe in engines run on biodiesel blends as compared to the black smoke emitted in 100% petroleum diesel fuelled engines. No notable performance difference was observed in the engines run in biodiesel blends compared to 100% petroleum diesel.

Keywords*:* biodiesel, biofuel, rice farming, transesterification, waste cooking oil

Introduction

Farmers are the producers of food. In the Philippines, they produce rice, among other crops, which is the staple food for millions of Filipinos. Without them, the Philippines, like any other rice-importing country, would be totally dependent from the rice produced from other countries. Imported rice may not always be available as the risks of crop failure is becoming high due to extreme climate events such as droughts and floods whose frequency and severity has increased in almost all rice-producing countries of the world. With investments in agriculture becoming riskier than ever because of these climate hazards, there is therefore a need to provide support to the farmers in order to produce more rice and ultimately for the Philippines to be able to attain rice self-sufficiency.

One of the supports that could be provided to the farmers is in helping them reduce their dependence on the use of fossil fuels especially during conditions of prolonged drought (El Niño). In rainfed rice areas, farmers are consuming at least 100 liters of diesel per hectare mostly for irrigation. This does not only mean a significant expense on the part of the farmers but also as an added burden on our environment since for each liter of diesel used, a corresponding 2.67 kg of carbon dioxide is released to the atmosphere as greenhouse gas.

Providing the farmers alternative sources of fuel such as biodiesel produced from waste cooking oil (WCO) is one possible way of helping them reduce their dependence on fossil fuels. WCO can be a stable source of feedstock for biodiesel production since it can be easily accessed from restaurants and fast food establishments. If farmers would be able to use biodiesel, not only will they have a cheaper source of fuel for their farm equipment but they will also aid in the reduction of greenhouse gas emission. Moreover, they can have the chance of earning additional income from glycerin, a by-product of the biodiesel processing that could be used to manufacture soap, among other possible products.

The utilization of WCO for biodiesel production could also help solve the problem of its improper disposal. Studies have shown that recycling used cooking oil for frying food could form a toxin called 4-hydroxy-trans-2-nonenal (HNE). Consumption of foods containing HNE from recycled cooking oils has been associated with increased risks of cardiovascular disease, stroke, Parkinson's disease, Alzheimer's disease, Huntington's disease, various liver disorders and cancer (Ku, et al., 2014).

A Filipino scientist based in the US, Dr. Rico Cruz, had developed a simple method of processing WCO into biodiesel called *Cruzesterification* which has potential for adoption by the farmers because, among other things, it does not require sophisticated equipment and source of external heat unlike in the conventional esterification process.

However, before the technology of processing waste cooking oil to biodiesel can be promoted to the farmers, several issues have to be addressed and verified. Concerns on the sustainability and efficiency of biodiesel from waste cooking oil can be addressed by a more intensive testing of the biodiesel on different farm machineries.

Objectives

- Gather baseline data in the processing of waste cooking oil to biodiesel;
- Develop a system for a large scale processing of waste cooking oil to biodiesel;
- Test the performance of biodiesel on different rice farming machinery;

Review of Literature

Impending global crisis paved way to the search for alternative sources of fuel. Moreover, high costs of petroleum based fuel (fossil fuels) made way for the search of cheaper sources such as biofuel. Biodiesel is defined by the American Society for Testing and Materials (ASTM) as monoalkyl esters of long chain fatty acids derived from a renewable lipid feedstock, such as vegetable oil or animal fat.

It takes 40 million years for fossil fuels to be formed while vegetable and animal oil only takes 3 months to be produced. It is with this difference that several groups moved for the utilization of biodiesel to be used in neat form or mixed with petroleum-based fuel. Several advantages on the use of biodiesel include the following as cited by Zhang et al (2003): a) decreased reliance on fossil fuel imports; b) it is biodegradable and non-toxic; c) it has a more favorable combustion emission profile, such as low emissions of carbon monoxide, particulate matter and unburned hydrocarbons; d) carbon dioxide produced by combustion of biodiesel can be recycled by photosynthesis, thereby minimizing the impact of biodiesel combustion on the greenhouse effect (Korbitz, 1999; Agarwal and Das, 2001); e) it has a relatively high flash point (150°C), which makes it less volatile and safer to transport or handle than petroleum diesel (Krawczyk, 1996); and f) it provides lubricating properties that can reduce engine wear and extend engine life (Von Wedel, 1991).

Biodiesel is mostly processed through transesterification which is a catalyzed chemical reaction involving vegetable oil and an alcohol to yield fatty acid alkyl esters. Recently, a simpler process was developed by Dr. Rico Cruz, termed as cruzesterification. Cruzesterification is the process of reacting the triglycerides or vegetable oils, with alcohol (methanol or ethanol) in the presence of catalysts at room temperature. In addition, this process no longer involves heat application and fuel washing, making biodiesel production easier.

In the Philippines, the use of coconut oil as biofuel source has been explored by the Philippine Coconut Authority (PCA). The project was led by The PCA-Zamboanga Research Center (PCA-ZRC) wherein biofuel was produced through cruzesterification. A pilot plant with a capacity of 130 liters of crude filtered coconut oil per batch was established. From 1995-2000, about 12,000 liters were produced and used at their test vehicles at blends of 40% to 100% coconut biodiesel and small amounts were used in a small generator, hand tractor and irrigation pump.

Wide-scale adoption on the use of biodiesel as alternative fuel has been limited by the availability of cheap feedstock and simple production process. Mostly, biodiesel is produced from food-grade oils (Canakci, 2007) such as rape seed oil, palm oil, sunflower oil and soybean oil (Van Kasteren and Nisworo, 2007). However, these feedstocks are not economically viable because food-grade oils are more expensive than diesel fuel (Canakci, 2007). Over 70% of the total cost of biodiesel production is accounted to oil feedstock cost (Chhetri, Watts and Islam, 2008). Waste cooking oil used as feedstock would be a great aid to lessen the total cost of biodiesel production.

Studies have been conducted for the use of biodiesel as alternative fuel source. A study on the production and utilization of biodiesel and by-products in Bulgaria spearheaded by Sampo, Inc. has been conducted wherein 282 tons of used cooking oil among other feedstock was processed to biodiesel (Zamfirov et al, 2002). The biodiesel produced by Sampo, Inc. was used in its transport fleets and vehicles while the glycerin by-product was processed by the company for industrial purposes (Zamifrov et al, 2002).

Cruz (2009) presented the simpler production of biodiesel from waste cooking oil and provided accounts on the biodiesel utilization in various blends and in several automobiles such as an old Ford Bronco with a Toyota engine (100% biodiesel), a 2005 Volkswagen New Beetle (5% to 100% biodiesel), and a 10 hp boat engine (100% biodiesel).

An experiment was conducted by Di, Cheung and Huang (2009) on a 4-cylinder direct-injection diesel engine using ultra-low sulfur diesel, biodiesel and their blends to investigate the regulated and unregulated emissions of the engine. In their results, with the increase of biodiesel in the fuel, the brake specific fuel consumption and the brake thermal efficiency increase. Also, the HC and CO emissions decrease while NO_x and NO_2 emissions increase. For the unregulated gaseous emissions, when the biodiesel content of the fuel is increased, the emissions of formaldehyde, 1-3 butadiene, toluene, xylene decrease, however acetaldehyde and benzene emissions increase.

Though waste cooking oil is proved to be a good feedstock for biodiesel production, problems have to be addressed to achieve the optimal benefits of this feedstock. Waste cooking oil contains high levels of free fatty acids (FFA) and moisture, which reduce the efficiency of transesterification in converting this feedstock to biodiesel (Canakci, 2007). A study was conducted by Canakci (2007) to determine the level of these contaminants in feedstock samples. His results showed that levels of FFA varied from 0.7% to 41.8% and moisture from 0.01% to 55.38%. He affirmed that these wide ranges indicate that an efficient process for converting waste grease and animal fats must tolerate a wide range of feedstock properties.

In transesterification, the amount of the catalyst is critical because the older the oil, the more FFA it contains, which competes with the catalyst (Cruz, 2009). Transesterification was studied by Felizardo et al (2006) with the purpose of achieving the best conditions for biodiesel production. According to their findings, an increase in the amount of methanol or catalyst quantity seems to simplify the separation/purification of the methyl esters phase, as shown by a viscosity reduction and an increasing purity to values higher than 98% for methyl ester phase.

Considering the erratic diesel price, exploring a large scale production of biodiesel using a relatively cheaper feedstock such as waste cooking oil and a simpler process like cruzesterification is worth venturing into.

Materials And Methods

I. Gathering of Baseline Data in the Processing of Waste Cooking Oil to Biodiesel

Extensive data collection on the processing of waste cooking oil to biodiesel was conducted to establish baseline data and document the processing itself as well as to develop an efficient system of producing biodiesel from waste cooking oil. Waste cooking oil was subjected to the cruzesterification process. However, to account for the varying quality of the waste cooking oil, cruzesterification process was revised which included subjecting waste cooking oil samples to titration to determine the amount of potassium hydroxide to be applied.

II. Development of a System for Large-scale Processing of Waste Cooking Oil to Biodiesel

Design and fabrication of a micro-processing plant was done to cater a large-scale processing of waste cooking oil to biodiesel. Large scale processing involved fabricating a 100 liter capacity mixer. Design considerations for the processing plant were: it should require less human supervision and minimal exposure to the chemicals.

III. Performance Test of Biodiesel on Different Farm Machinery

Testing of the biodiesel on the different rice farming machinery was done in different blends such as B20, B50 and B100. Data gathered were fuel consumption (L/h) and smoke emission.

Results and Discussions

Gathering of Baseline Data

The methodology used by Dr. Rico Cruz (cruzesterification) was modified to account for the varying quality of oil purchased. It was found out that the recommended 11 grams of potassium hydroxide (KOH) per liter of waste cooking oil is insufficient to convert waste cooking oil to biodiesel when the quality of oil is highly degraded. To account for this varying quality, purchased waste cooking oil was subjected to testing per tin can basis to determine the proper amount of KOH to be used per batch of mixing. It was observed that highly reused cooking oil will require up to 21 grams KOH per liter of waste cooking oil with a conversion rate of 72-75%. Waste cooking oil which was relatively less degraded on the other hand will require 11 to 15 grams KOH per liter of waste cooking oil and will be converted to biodiesel by as much as 92-95%.

A small-scale mixing of used cooking oil (UCO) to biodiesel was conducted to compare the biodiesel produced from newly purchased UCO (less than 3 months in storage) and old stacked UCO (more than a year in storage). The recommended ratio of methanol and potassium hydroxide (KOH) according to Dr. Rico Cruz is: for every 5 L of UCO, 1 L of methanol and 55 g of KOH will be used. From this recommendation, different ratio of methanol and KOH were used as treatments. Table 1 shows the different ratios used and the amount of biodiesel produced from newly purchased and old stacked UCO.

Table 1. Different ratio of methanol and KOH used for each treatment and the amount of biodiesel produced from the newly purchased and old stacked used cooking oil

Used Cooking Oil (mL)	Methanol (mL)	Potassium Hydroxide (g)	Biodiesel Produced from Old stacked UCO (mL)	Biodiesel Produced from Newly Purchased UCO (mL)
500	100	5.5	200	520
500	100	5	175	570
500	100	6	135	560
500	110	5.5	150	540
500	110	5	330	560
500	110	6	110	580
500	90	5.5	190	540
500	90	5	110	540
500	90	6	180	500

From the results shown, newly purchased UCO produced more biodiesel as compared to the old stacked UCO. The 110 mL methanol and 6 g KOH ratio produced the highest quantity of biodiesel at 580 mL. It was observed that biodiesel from newly purchased UCO is lighter in color than the old stacked UCO (Figure 1). For the old stacked UCO, there was difficulty extracting its produced biodiesel because some of the glycerin did not settle at the bottom of the container and this may cause the low quality of the produced biodiesel.

Figure 1. Biodiesel produced from newly purchased (left) and old stocked (right) used cooking oil for the first three treatments.

Development of a Processing System

A micro-processing plant was fabricated for the large-scale processing of waste cooking oil to biodiesel. The set-up for the biodiesel processing plant has a 100 L capacity (Figure 2).

Figure 2. The fabricated and design of the micro-processing plant for biodiesel production

Large-scale mixing was conducted to initially test the micro-plant and at the same time to check if there would be possible revisions in the design. 12 L of newly purchased cooking oil was used as a preliminary testing of the micro-plant. The 110 mL methanol and 6 g KOH ratio was used for this test since this ratio produced the highest quantity of biodiesel basing from the previous test conducted. Separate container was used for the mixing of methanol and KOH to make sure that the KOH was totally dissolved in the methanol. Biodiesel produced from this test was 8 L.

Problems encountered and recommendations:

1. Difficulty was encountered during the hauling of UCO in its container. It is recommended that stairs should be incorporated in the design so that hauling will be easier and accidents will be avoided.
2. Almost half of the UCO were not deposited into the mixing tank because the placement of the valve in the container is high. It is better to lower the valve so as to make sure that no UCO that can still be convertible to biodiesel will be wasted.
3. Filter or screen should be placed in the container for the UCO so that the food morsels in the oil will be removed.

A follow-up test was conducted using the micro-processing plant to process used cooking oil to biodiesel to be used for the test of the different blends of biodiesel. Two batch of 10-L UCO, labeled as A and B were taken from two different cans and were processed. A and B produced 10 L and 10.4 L of biodiesel, respectively (Figure 3).

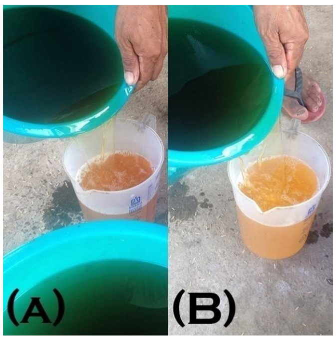

Figure 3. Biodiesel produced by batch A (10 L) and batch B (10.4 L)

Performance of biodiesel in different farm machinery

Initial processing of waste cooking oil to biodiesel was conducted to test the viability of the technology for adoption. Processed biodiesel were tested in PhilRice-CES farm machinery in different blends such as B20, B50 and B100. B20 and B50 biodiesel blends were tested in the Kubota M7530 four-wheel tractor. Moreover, B20, B50 and B100 biodiesel blends were tested in a Kubota RK80 engine. No engine performance difference was observed in the engines run in biodiesel blends compared to 100% petroleum diesel. One notable difference however is that colorless smoke came out of the exhaust pipe in engines run on biodiesel blends instead of the usual black smoke emitted in 100% petroleum diesel fuelled engines.

B20, B50 and B100 were tested on a RK-60 diesel engine (Figure 4) and a load was not considered in this test. 2 L of the biodiesel blend was filled in the engine and was run for 1 hour. After each run, the oil left was measured for the computation of fuel consumption. Before the next run, the engine was cooled down for 1 hour. The biodiesel used for the blends was batch B (processed from the previous testing).

Table 2. Fuel consumption of B20, B50 and B100 blends of biodiesel (average of three replications)

BLEND	FUEL CONSUMPTION (L/h)
B20	0.16b
B50	0.17b
B100	0.30a

Means followed by a common letter in the same column do not differ significantly at 5% level of significance using DMRT

Figure 4. Kubota RK-60 diesel engine used for the test on the different blends of biodiesel

According to the results shown (Table 2), the three different blends performed well and colorless smoke came out of the exhaust pipe which proved that biodiesel is environment-friendly. In terms of fuel consumption, B20 and B50 showed no significant difference, however, B100 showed significant difference when the treatment means were compared statistically.

The different blends of biodiesel were also tested on a centrifugal pump (Figure 5). Table 3 shows the specifications of the pump and engine used for this test. Same blends were used (B20, B50 and B100) and petroleum diesel was added to serve as control. The pump was run for 1 hour and for every run, 2 L of the biodiesel blend was filled in the engine. After every run, the fuel left was measured and recorded for the computation of fuel consumption. Before the start of the first run, the engine was started and run for 15-30 minutes so as to allow the engine to warm up.

Table 3. Specifications of the pump and engine used for the test

PUMP SPECS	ENGINE SPECS
Centrifugal Pump	Kubota RK-80
Size: 4 in	Maximum Output: 5.97 kW
Maximum Capacity: 550 GPM	Speed: 2400 RPM
Maximum Total Head: 60 ft.	Continuous Output: 5.22 kW
Speed: 1800-2400 RPM	Speed: 2200 RPM

Figure 5. Pump used for the testing on the different blends of biodiesel

As shown in the results (Table 4), B20 consumed the most fuel followed by B100 at 0.5 L/h and 40 L/h, respectively. However, when the means of each treatment were statistically compared, it showed no significant difference. Hence, there was no difference in the performance when the pump was run on different blends of biodiesel compared to 100% petroleum diesel. The difference however, as proven from the initial tests conducted, is that colorless smoke came out of the exhaust pipe when the pump was run on the different biodiesel blends instead of the black smoke emitted when petroleum diesel was used.

Table 4. Fuel consumption in L/h of the different blends of biodiesel and petroleum diesel run on a pump (average of three replications)

BLEND	FUEL CONSUMPTION (L/h)
B20	0.50a
B50	0.37a
B100	0.40a
DIESEL	0.38a

Means followed by a common letter in the same column do not differ significantly at 5% level of significance using DMRT

Summary and Conclusion

This study was conducted to: (1) gather baseline data in the processing of waste cooking oil to biodiesel, (2) develop a system for a large scale processing of waste cooking oil to biodiesel, and (3) test the performance of biodiesel on different rice farming machinery. The *cruzesterification* method developed by Dr. Rico Cruz was verified to account for the varying quality of oil purchased. The purchased waste cooking oil was subjected to testing per tin can basis to determine the proper amount of KOH to be used per batch of mixing. A 100L capacity micro-processing plant was also fabricated for processing of waste cooking oil to biodiesel in larger volumes for actual use by farm machines using different blends. From the results of the study, the following conclusions could be drawn:

1. Under actual farming conditions, the biodiesel production from WCO using the *cruzesterification* process is more practical to use than the traditional transesterification process as no external heat is needed;
2. Newly recovered WCO is best for processing into biodiesel. For old stock, there is a need to adjust the amount of KOH. The older the stock, the more KOH is needed. Stocks older than __ months are not recommended for use.

3. Farm machines operating using the WCO processed in this study had clear emission in contrast to those using the petrodiesel in terms

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References

[1] Canakci, Mustafa. The potential of restaurant waste lipids as biodiesel feedstocks. Bioresource Technology 98.1 (2007): 183-190.
[2] Cherati, F. E., Bahrami, H. and Asakereh A. 2011. African Journal of Agricultural Research Vol. 6 (11), pp. 2565-2570.
[3] Chhetri, Arjun B., K. Chris Watts and M. Rafiqul Islam. Waste Cooking Oil as an Alternate Feedstock for Biodiesel Production. Energies (2008): 3-18.
[4] Cruz, R. O. 2009. Biodiesel from waste cooking oil for heating, lighting or running diesel engines. In: Dumroese, R. K.; Riley, L. E., tech. coords. 2009. National proceedings: Forest and Conservation Nursery Associations – 2008. Proc. RMRS-P-58. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 22-25. Online: http://www.fs.fed.us/rm/pubs/rmrs_p058.html.
[5] Dangers in reusing cooking oil. http://easterndish.blogspot.com/2010/01/danger-in-reusing-cooking-oil.html
[6] Di, Yage, C. S. Cheung and Z. Huang. Experimental investigation on regulated and unregulated emissions of a diesel engine fueled with ultra-low sulfur diesel fuel blended with biodiesel from waste cooking oil. Science of the Total Environment 407 (2009): 835-846.
[7] Felizardo, Pedro, et al. Production of biodiesel from waste frying oils. Waste management 26.5 (2006): 487-494.
[8] Ku, S.K., Muhamad Ruhaifi, M.S., Fatin, S.S., Saffana, M., Taty Anna, K., Das, S., and Kamsiah , J. 2014. The harmful effects of consumption of repeatedly heated edible oils: a short review. Clin Ter: 165(4):217-221
[9] Santos, G., Baylon, G. and Cruz, R. 2002. Pilot production and demonstration of Cruzesterified coconut biodiesel. http://www.uiweb.uidaho.edu/bioenergy/Bioenergy2002conference/pdffiles/papers/155.pdf
[10] Van Kasteren, J. M. N. and A. P. Nisworo. A process model to estimate the cost of industrial scale biodiesel production from waste cooking oil by supercritical transesterification. Resources, Conservation and Recycling 50.4 (2007): 442-458.
[11] Zamifrov, N., Pavlova, M., Zamifrov, D., and Cruz, R. 2002. Production and utilization of biodiesel and by-products in Bulgaria. http://www.uiweb.uidaho.edu/bioenergy/Bioenergy2002conference/pdffiles/papers/148.pdf
[12] Zhang, Y., Dube, M. A., MacLean, D. D. and Kates, M. 2003. Biodiesel production from waste cooking oil: 1. Process design and technological assessment. http://www.mybiofuels.net/Pubs/2003_BD_Prod_WVO.pdf