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The Potential of Biodiesel Production from Frying Oil Used in the Restaurants of São Paulo city, Brazil

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This work aimed to produce a biodiesel from oils used in restaurants of São Paulo, Brazil, to discover the power production city and to demonstrate its economical feasibility. For this, it has been researched in the Brazilian market sales prices of glycerin, carbon credit, biodiesel and diesel blend, well as well, the amount of B20 blend (70.1 10^3 m^3/month) used by the bus fleet of São Paulo and the amount of residual oil generated by restaurants. During the collection of frying oil samples used in restaurants, it has applied a standardized questionnaire (1-5 Likert scale) to the manager, in which contained questions about the type of restaurant, the amount of frying oil produced and if he knew the environmental impacts of its disposal. Ethanol was mixed at 1:7 to the samples of cooking oils collected from restaurants and it was transesterified at 60 °C, for 1 h, in order to obtain biodiesel, using NaOH as a catalyst. Results showed that the restaurants had a monthly consumption of 120 L, giving 3.6 10^3 m^3/month; it is equivalent to 48 % of B100 used in bus fleet. A conversion yield of 87 % has found in this work and with its production is possible to reduce US$ 120 million per year the fuel cost. Also it is possible contribute to the reduction or elimination of indiscriminate disposal of oils; of 92 % of sulfur emissions and to acquire the carbon credits which improve the city's image as it becomes an environmentally friendly city.

1. Introduction

According to Diya'uddeen *et al*. (2012), the biodiesel can be defined as a monoalkyl ester of long chain fatty acids derived from a renewable lipid feedstock, such as vegetable oil or animal fat. If it is obtained from other sources are considered as II generation biodiesel (Pirozzi *et al*., 2013). It is sulphur free, non-toxic and biodegradable; it reduces the emission of gas pollutants and global warming; it is economically competitive and may be produced by small companies (Benjumea *et al*., 2008; Lin and Lin, 2007). In terms of productivity biodiesel the first country is Malaysia/Indonesia with 4747 kg/ha from palm oil, followed by Europe/EU with 946 kg/ha from rapeseed and sunflower oil and West Canadian with 809 kg/ha canola oil; but EU is the world's largest producer. The interest of the European Union in the utilization and consumption of biodiesel is based on their greater production of biodiesel, which is estimated at approximately 85 % of the world's total. However, of according to Giraçol *et al*. (2011), there are severe criticisms regarding the production of biodiesel from edible oil, because it may imply a rise in the price of this essential item in food beyond the need to expand the area under cultivation of oilseeds and the possibility of desertification area degraded by agricultural use.
Current, there are a lot of clamours regarding the environment and its sustainability (Rosa *et al*., 2013). Thus used domestic waste oil should be considered as a source of fuel for effective mitigation of greenhouse gas emissions (GHG) as well as for providing environmental benefits and sustainable

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development via waste conversion to energy. Still on attaining sustainability, and in line with the objective of achieving the 2020 and 2030 goal of substituting approximately 20% and 30% of petro-diesel with biofuels in US and EU, respectively, a policy of recovering value from waste has been enforced and this includes waste diversion from landfill. (Diya'uddeen *et al*., 2012; Papageorgiou *et al*., 2009)

With a trend in recent years towards US$ 2.20/kg, as each ton of biodiesel produces over 104.4 kg of glycerol, this by-product alone adds US$ 230 of value to each ton of biodiesel produced. The gain in carbon credits resulting from reduced CO_2 emissions by burning cleaner fuels is estimated at roughly 2.5 t CO_2 / t biodiesel. In the European market, carbon credits are sold at around US$ 9.25/t. Also, it can be negotiated the acquired with other nations with Clean Development Mechanism (CDM) projects, such as Canada, the Czech Republic, Denmark, France, Germany, Japan, Netherlands, Norway and Sweden; based in carbon credits market established Kyoto Protocol (Giraçol *et al*., 2011).

According to Brazilian Association of Food, Hospitality and Tourism (ABRESI, 2013), São Paulo city, Brazil, has over 30.2 thousand restaurants, with 52 types of cookery, which include ethnic foods from around the world. However, this leads to an increase in consumption of food oil to meet the need of these restaurants and as it doesn't know the end destination this oil, it is assumed that the majority will contaminate the soil, rivers and lakes. Giraçol *et al*. (2011) showed how to reduce the impacts of this disposal wrong, through the production of biodiesel for use in the fleet of city buses and the sale of its byproducts (glycerin and carbon credits). Thus, this work aimed to produce a biodiesel from oils used in restaurants of São Paulo, Brazil, to discover the power production city and to demonstrate its economical feasibility.

2. Materials and Methods

2.1. Biodiesel preparation

The frying oil samples were collected in all the restaurants that participated in this research (31). As the samples were arrived at the laboratory, which were pre-filtered and mixed before production of biodiesel. In all trans-etherification process were used a 1/6 ethanol/oil volumetric rate and 1 % NaOH dissolved into the alcohol. Solid sodium hydroxide was used as a catalyst to minimize the presence of water after the reaction. A jacketed reaction chamber was used to heat a total volume of 4 L. The volume of reagents in the reaction chamber was 3 L and the reaction occurred at 60 ±2 °C, with constant agitation for one hour. The esterified materials were transferred to a decanting funnel and washed with distilled water to separate the phases. After resting for 1-2 hours, the fractions of biodiesel were separated of glycerin, water and other dross. The following biodiesel have been characterized according ANP (2012) norms. The yield was calculated based on the mean molecular mass was of 835 g/mol for soybean oil and 881 g/mol for the blends of ethyl esters of according to Equation 1 (Barakos *et al*., 2008; Benjumea *et al*., 2008; Giraçol *et al*., 2011; Lin and Lin, 2007).

$$Oil + 3\,Ethanol \xrightarrow{NaOH} 3\,Biodiesel + Glycerin$$

$$Yield(\%) = \frac{V_{Biodiesel} \bullet d_{Biodiesel} \bullet MM_{Oil}}{V_{Oil} \bullet d_{Oil} \bullet MM_{Esters}} \bullet 100 \quad (1)$$

While V is the volume, d is the density and MM is the molecular mass of oil, biodiesel or esters from biodiesel.

2.2 Survey methodology

A questionnaire containing 20 questions standardized according to 1-5 Likert scale was applied to each of restaurant managers who participated in this research (total of 31 interviews). The questions covered the area where the restaurants were located. About frying oil were asked its amounts weekly used, if reuse this oil, which oil type used and other. Also it were asked if the managers know the impacts of the irregular disposal of this oil, if they have some form of treatment or reuse (correct) these oils and if they knew that biodiesel can be made from these oils (Giraçol *et al*., 2011).

2.3 Ecological and production account

The considerations for the determination of the cost of biodiesel manufactured by used cooking oil were following (Giraçol *et al*., 2011; Passarini *et al*., 2014): São Paulo city, Brazil, has over 30.2 thousand restaurants (ABRESI, 2013), these restaurants consume type and different amounts of used cooking oil, f or the proper functioning of the proposal of this work, they should store waste oils. The collect of the frying oil will be made through the use of reservoir attached in the garbage truck. Thus, the costs with logistical planning and with collect of used cooking oil will be considered as zero net. The collect of the frying oil used by the restaurants will be of responsibility of São Paulo City Hall without taxes. The price composition for diesel currently sold, in São Paulo state, will be based in US Dollar of accordance to

FECOMBUSTÍVEL (2012). Thus, the biodiesel costs will be associated to diesel oil price. The biodiesel production had an associated carbon credit (BIODIESEL, 2012). Each 1 t of biodiesel is equivalent to 2.5 t carbon credit, which are sold by 9.25 US$/t. This is a reducing of biodiesel price. The glycerin is a by-product of biodiesel manufacture (BIODIESELBR, 2012). Each 1 t of biodiesel is equivalent to 104 kg of glycerol, which are sold by 2.20 US$/kg. This also is a reducing of biodiesel price, after its sale and the biodiesel has an associated price of sale, which is greater than the price of diesel oil. The calculation of emissions of sulfur will be made according to the data available for FECOMBUSTIVEL (2012) and BIODIESELBR (2012).

2. Results and Discussions

From restaurants who participated in this research were 51.6 % North, 32.2 % South and 16.1 % Central region of São Paulo city. Figure 1 shows some of response of the restaurant managers for first three questions. From this figure, it is noted that about 94 % of restaurants use frying oil in preparing its food which about 58 % and 23 % are soy oil and animal fat, respectively, and more than 93% using 20 or more litter for week.

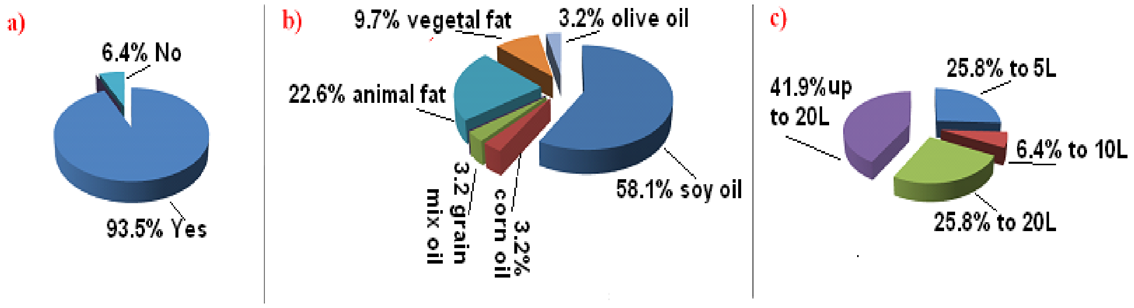

Figure 1: Response of the restaurant managers for questions: a) Do your restaurant uses oil in food preparation? b) What type of oil used in your restaurant? c) Which the weekly amount of used oil?

Figure 2 shows some of response of the restaurant managers for seguint three questions. From this figure, it is noted that about 62 % of oil is used in frying processes and 51 % of the restaurant managers have been affirmed that not reuse these oils in new frying processes, however, they come in conflict, for about 70 % of managers answered that had reused more 1-time the cooking oil in the new frying.

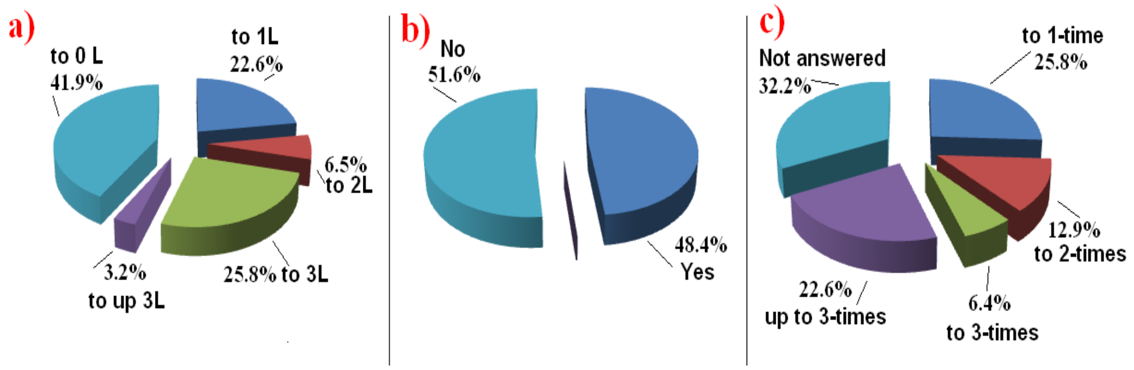

Figure 2: Response of the restaurant managers for questions: a) Where the amount of the oil that is used in frying? b) Your restaurant reuses oil in new frying? c) How many times you reuse the oil?

Figure 3 shows the responses for other questions of the survey. On respect to most of the questions, the restaurant managers have not demonstrated any knowledge on the subject, sense their answers well diversified, which generated 3-time or down in Likert scale (indecision or discordance). However, with respect to the item that refers to the storage of oil over 80 % agreed. Furthermore, they also know that biodiesel is a fuel and can replace the other, but 77.5 % feel that your trade price is greater than the alcohol (which is not true). About 45 % of managers are concerned that the collection of frying oil is a public company, 6.0 % for outsourced and 29.0 % for private companies. On the impacts, they cited: water and groundwater pollution and contamination of vegetables. Where biodiesel is used, they cited: engines, machinery, truck and industry. On the frequency, 74 % preferred it to be a weekly, a fact that is good, because garbage collection is also weekly and it would be done in parallel with collecting oil.

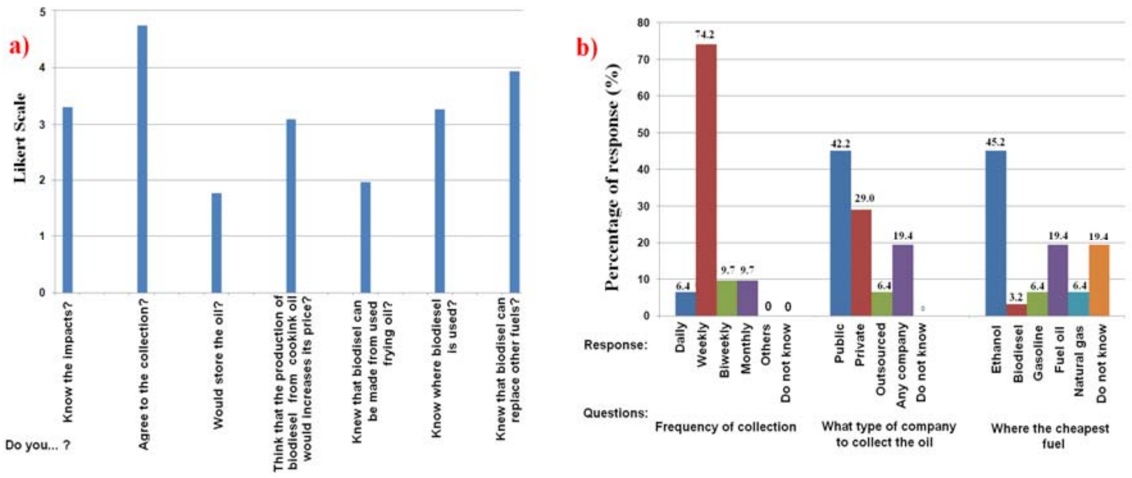

Figure 3: Responses of restaurant managers for some questions. a) Likert scale, b) in percentage.

Figure 4.a shows the responses of restaurant managers for weekly quantity of frying oil used. For 13 restaurants, which used more than 20 L per week, it was asked to managers the real volume used and they have been cited volumes between 25 and 120 L, which generated an average 50L. From the data showed in this Figure 3, it can be seen that the overall mean weekly frying oil is used 28 L/restaurant, giving 120.27 L/restaurant or by multiplying this value by the total restaurant 3,632,350.30 L frying oil per month is obtained. This quantity can generate more than 47 % of biodiesel monthly need for bus fleet of São Paulo city. Figure 4.b shows a photo of the biodiesel samples into tubes. The biodiesels obtained as oil from restaurants possessed a large amount of flour, from various fried foods, it was necessary that they pass by a new filtration process. Tubes 1 and 5 are samples de biodiesels of frying from oils restaurants, in which it is possible to note the presence of the flour decanting at the bottom of the tubes. Tubes 4 are the same samples after the filtration process.

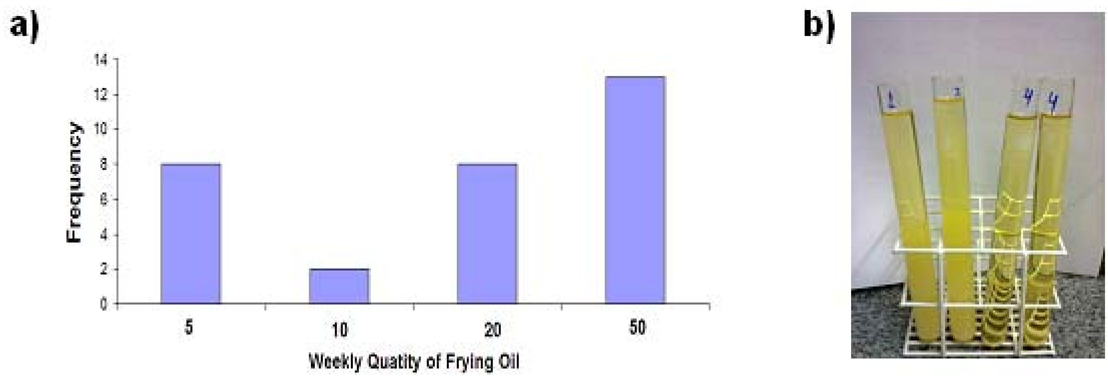

Figure 4: a) Responses of restaurant managers for weekly quantity of frying oil used, b) Photo of biodiesel from restaurant frying oils before and after filtration

Table 1 shows the results for biodiesel obtained in this work. The mean of the biodiesel yields of 86.91 % from 12 frying oil conversions all of which are within the ordinary range yield (55-90 %) as mentioned by Diya'uddeen *et al*. (2012). After the filtration processes of biodiesels a less in the yield of 1.18 % was found. Also there are variations in density of biodiesels, however, not there were significant differences among the samples and all samples are close into Brazilian standard for biodiesel.

Table 1: Results for yields and density of biodiesels

Sample	Density (g/cm^3) ±σ				Yield (%) ±σ		Volumetric less (%)±σ	
	Before		After					
Frying oil	0.8779	0.0270	-	-	-	-	-	-
Biodiesel	0.8902[a]	0.0444	0.9130[a]	0.0212	86.91	6.22	1.18	0.62

Table 2 shows the composition of the price of biodiesel used in the bus fleet of São Paulo city by the data supplied by FECOMBUSTÍVEL (2012), making the considerations presented in methodology. Current, biodiesel blend used in São Paulo is composed of 20 % pure biodiesel (B100) and 80 % diesel oil. Considering that the amount of biodiesel is at least equal to the amount of frying oil obtained from restaurants (in reality frying oil can yield up to 105.5 % of its volume in biodiesel). By the calculations, an annual cost of US$ 98.1 million was obtained.

Table 2: Cost of biodiesel production from restaurant frying oil

Composition of B20 Cost	Quantity (L/month)	Acquisition costs (US$)	Cost (US$/month)
Diesel (80%)	14,529,401.20	0.56	8,099,954.90
B100 (20%)	3,632,350.30	0.00	0.00
Other chemicals	3,632,350.30	0.02	72,647.01
Biodiesel production cost (US$/month)			**8,172,601.91**
Annual production cost with biodiesel (US$)			**98,071,222.86**

Table 3 shows the before and after implantation of biodiesel production from restaurant frying oil. In accordance with the city of São Paulo, the bus fleet consumes monthly 37,900,000 L of biodiesel. This table is noted an annual cost reduction of about US$ 109 million with fuel acquisition.

Table 3: Calculation of cost with fuel for bus fleet of São Paulo for current a future situation

Situation	Oil fuel Volume (L/month)	Acquisition cost (US$)	Fuel purchase (%)	Cost (US$/year)
Current	37900000*	0.95	100.00	**432,060,000.00**
Future	19738249	0.95	52.08	**225,016,032.90**
Total New annual cost with fuels (biodiesel+ fuel oil) (US$)				**323,087,255.77**
Annual cost reduction with fuel (US$)				**108,972,744.23**

*Varela (2011)

Table 4 shows the results of calculation of profits for byproducts. This table is noted a possibility of cost reduction or profit from the sale of by-products of US$ 11.4 million. Table 5 presents the results of the evaluation of sulfur emissions. It is noted a reduction of 92 is reached when using the combination of biodiesel with diesel S-50, but in absolute quantity still need to improve this efficiency, since more than 1,500 ppm are released monthly in atmosphere.

Table 4: Calculation of profits from byproduct of biodiesel production

Pure glycerin (kg/month)	Glycerin 80% purity (kg/month)	Price (US$/t)	Annual profit (US$)
341,383.206	426,729.008	2.20	11,265,645.81
CC per biodiesel (t)	Total CC (t/month)	Price (US$/t)	-
2.50	8,172.788	9.25	98,073.46
Total profit from the sale of byproducts			**11,363,719.27**
Total cost reduction (Byproduct sale+cost reduction with fuel)			**120,336,463,50**

Note: CC is carbon credit and glycerin rate is 10.44% biodiesel conversion (92/881)

Table 5: Sulphur emission reduction by biodiesel use

Fuel	S Diesel (ppm)	S Biodiesel (ppm)	Emission (t/month)	S Reduction (%)
Diesel S-500	500	N	18.950	0
Biodiesel diesel (80%S50+20%B100)	40	0	1.516	92

Note: the current biodiesel diesel in Brazil is composed of 80% diesel S-50 and 20% of B100. Fuel volume = 37900 m^3/month.

Advantages of biodiesel production from restaurant frying oil by city hall of São Paulo are: reduction of about 48 % fuel purchase; an annual cost reduction with the fuel acquisition of about US$ 110 million; a total cost reduction of about US$ 120 million per year; the reduction or elimination of indiscriminate disposal of oils; the reduction of sulfur emissions by up to 92 %; a gain 98,073 carbon credits; an improves city image and the partial autonomy in fuel consumption.

3. Conclusions

After an analysis of data from this work, it is possible concluded that: is possible to obtain a biodiesel from frying oils used in restaurants of São Paulo city closed into Brazilian norms and a yield of 87 %. The survey showed that managers of restaurants have little knowledge about the reuse of the frying oil and the evils it causes. However, it was to use the survey that was obtained 120 L as average monthly amount of frying oil used in restaurants. It is possible to reduce in 48 % fuel purchase for bus fleet and to reduce US$ 120 million per year the total cost with the fuel acquisition. Also it is possible contribute to the reduction or elimination of indiscriminate disposal of oils; of 92 % of sulfur emissions and to acquire the carbon credits which improve the city's image as it becomes an environmentally friendly city.

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