Proceedings of IOE Graduate Conference, 2015
pp. 233–241

Cost-Benefit Analysis of Biodiesel from Used Cooking Oil

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Abstract

The objective of this study was to perform a cost-benefit analysis of biodiesel from used cooking oil (UCO) within Kathmandu valley. The basic two problems which has triggered for this paper are the ever existing crisis of petroleum fuel supply along with 12 hours of power cuts per day since last few years and the reuse and disposal of used cooking oil. The process of transesterification with potassium hydroxide has been adopted for the production of biodiesel from used cooking oil in this paper. The emission test resulted in the reduction of CO in the blends, B10 and B20 compared to the petro-diesel. Rs.195.17 has been determined as the cost of per liter production of biodiesel in the lab scale during the work. The annual percentage reduction in dependency of petro-diesel has been determined as 4 percent using the blend B20 for running generators in Kathmandu. The cost of biodiesel obtained is though high the benefit from the emission and the elimination of use of UCO has resulted much higher in terms of human health and environment. Hence used cooking oil proves to be a better feedstock for production of biodiesel which supports human health and also is environ ment friendly.

Keywords

Biodiesel – Used Cooking Oil (UCO) – Petro-diesel – Transesterification – B10 – B20

1. Introduction

The energy consumption in the world has been on the rise due to industrializing and use of more energy consuming appliances to make the lives more comfortable which is leading the world towards the state of energy shortage. With many evidences it is clear that energy has taken a central role in the global economic development in the past and will continue to be so in the future.

The world today is going through the phase of energy crisis of which Kathmandu valley is not an exception. The excessive use of fossil fuels, relentless global demand and record high oil prices have triggered an urgent search for an alternative to fossil fuels for a world dangerously dependent on oil supplies and has been deeply alarmed by the effects of global warming. Renewable energy sources, especially vegetable fuel, have appeared as an important alternative in the present context.

Almost more than half of the year there is fuel crisis in the country which has topped the chart of problems faced by the people in the country. Along with the fuel crisis, the country is also affected by the increasing demand and the fluctuating prices of the petroleum products every year. On the other hand hundreds of liters of used vegetable oils are wasted every week by the people in vain. So this paper has made an attempt to amalgamate these two problems and come with a single solution by production of biodiesel from UCO and preparing its blend with the petro-diesel to minimize the consumption of petro-diesel which also tried to optimize the cost of the fuel in context of Kathmandu Valley.

2. Objectives of the Study

The main objective of the research is to perform the cost-benefit analysis of biodiesel from used cooking oil (UCO) in context of Kathmandu Valley. However the specific objectives are the followings:

- To find out the percentage of cooking oil (soybean oil) consumption annually by various businesses (restaurants, hotels, party venues) and households in the valley.
- To find out the percentage of used cooking oil

(used soybean oil) produced annually by those businesses.
- To recycle the used cooking oil from the businesses to produce biodiesel.
- To estimate the percentage reduction of dependency on the petro-diesel annually by the
- To evaluate the cost and benefit of the biodiesel.

3. Limitations

The study has few limitations which have been considered for its completion which are:

- Only the refined and used soybean cooking oil has been considered for the study.
- Only the used frying oil has been considered as used cooking oil for biodiesel production.
- The study has only considered the data of Kathmandu Valley throughout the study.
- Only laboratory production cost of biodiesel has been considered to be determined.
- Labour cost has not been considered for cost determination.

4. Literature Review

4.1 Biodiesel

Biodiesel is advised for use as an alternative fuel for conventional petroleum-based diesel chiefly because it is a renewable, domestic resource with an environmentally friendly emission profile and is readily biodegradable [1]. The amount of greenhouse gas emissions, generating energy from renewable resources is being possessed a high priority gradually to decrease both over-reliance on imported fossil fuels [2].

Biodiesel is a cleaner burning alternative fuel produced from renewable vegetable oil resources such as soy beans, palm and waste vegetable oil (cooking oil) or any other source of organic oil (animal fat) [3]. Biodiesel is miscible in petro-diesel fuel, and can be easily blended with it. Biodiesel in its pure form is referred to as biodiesel or B100 (100 percent biodiesel). When biodiesel is blended with petro-diesel, the resulting fuel is referred to as a biodiesel blend. For example, a blend of 20 percent biodiesel and 80 percent petro-diesel is referred to as B20. Biodiesel blends can be used in diesel engines with no modifications to the engine or fuel system, with similar performance (Kenneth Bickel, 2002).

4.2 Used cooking oil (UCO)

The increasing production of used cooking oil (UCO) from household and industrial sources has been a growing problem in all around the world. Most of the UCO is being poured into the sewer system of the cities all over the world. This practice has aided to the pollution of rivers, lakes, seas and underground water, which is very harmful for environment and human health [4].

Reusing cooking oil has been done for ages. But a recent study found that a toxin called 4-hydroxy-trans-2-nonenal (HNE) forms when such oils as canola, corn, soybean and sunflower oils are reheated. Consumption of foods containing HNE from 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 [5].

4.3 Biodiesel and UCO

Several sources for producing biodiesel have been studied such as rape seed, coal seed, palm oil, sunflower oil, waste cooking oil, soybean oil, etc. Due to the high cost of the fresh vegetable oil, waste cooking oil has come into the light which can be converted to biodiesel and is available with relatively cheap price [1, 6].

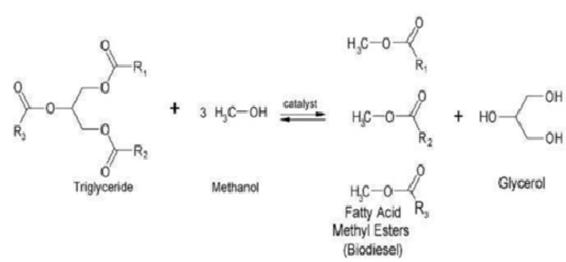

Figure 1: Transesterification reaction of triglyceride and methanol to fatty acid methyl esters (biodiesel) and glycerol

The American Society for Testing and Materials (ASTM) has defined biodiesel fuel as monoalkyl esters of long chain fatty acids derived from renewable lipid feed stocks, such as vegetable oil or animal fat. The most common way to produce biodiesel is by transesterification, which refers to a catalyzed chemical reaction involving vegetable oil and an alcohol to yield fatty acid alkyl esters (biodiesel) and glycerol (by-product) [7].

To carry out the transesterification process, the percentage of free fatty acid (FFA) of the oil from which biodiesel is to be produced should be less than 2%. If the percentage of free fatty acid exceeds 2%, then pretreatment should be carried out to lower the percentage [8].

Transesterification reactions can be alkali-catalyzed, acid-catalyzed or enzyme catalyzed [9]. An excess of methanol is used to shift the reaction to the right side in order to achieve high yield of methyl esters/biodiesel.

5. Testing Apparatus, Methodology and Data Collection

5.1 Chemicals and equipment

Selected chemicals have been used for the experiment comprising of the biodiesel production, its purification and property testing. The major reactant was methanol (CH3OH), the catalyst used was potassium hydroxide (KOH) and the solvent was acetone ((CH3)2C=O) during the production phase. Other chemicals which helped in production and purification were sodium hydroxide (NaOH) and sulfuric acid (H2SO4).

As the experiment took place in the lab scale, the equipment used for this research was limited to those available in Nepal Academy of Science and Technology (NAST) where the experiment was carried out. All the equipment used were run by electricity and the equipment were hot plate with magnetic stirrer, electronic balance, rotary evaporator (Yamato, Japan with water bath BM210 and low temperature bath circulator HS-3005N), centrifugal concentrator (Tomy CC105, Japan), pycnometer, Ostwald viscometer, Bomb Calorimeter (Toshniwal T-480), automotive emission analyzer (Horiba MEXA-584L) and GD216 PMCC flash point tester.

5.2 Methodology

The methodology which has been adopted for the completion of this study comprises of following phases:

- Biodiesel generation from used cooking oil (UCO)
- Data collection

5.2.1 Biodiesel Generation from Used Cooking Oil (UCO)

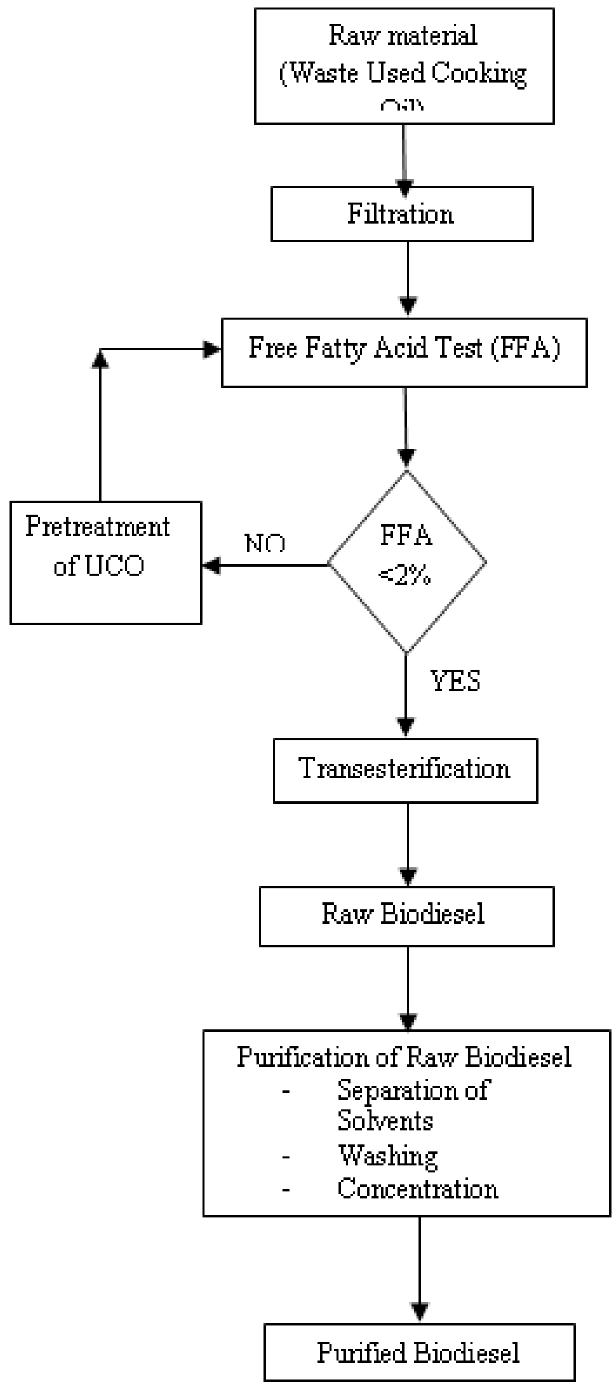

Figure 2: Flow chart of production of biodiesel from UCO

Used cooking oil (used soybean oil) has been used as the raw material to produce biodiesel which was bought from Jai Ganesh Party Venue, Kamaladi at Rs.45/liter.

The entire generation of biodiesel from waste cooking oil included the following processes:

- Production of raw biodiesel
  - Filtration and determination of free fatty acid (FFA)
  - Pretreatment and determination of free fatty acid (FFA)
  - Transesterification
- Purification of raw biodiesel for production of pure biodiesel
  - Separation of solvents
  - Washing of the biodiesel
  - Concentration of biodiesel
- Properties tests of the produced pure biodiesel
  - Specific gravity and density
  - Calorific value
  - Viscosity
  - Emission
  - Flash point
  - Color

5.2.2 Data collection

The data collection was achieved by distribution of questionnaire to various food service providing business and households within Kathmandu valley.

Table 1: Total number of food service providing businesses in Kathmandu valley

Hotels registered in HAN	132
Restaurants registered in REBAN	96
Party places registered in EVA Nepal	84

Table 2: Total number of household in Kathmandu valley

Kathmandu	4,36,344
Lalitpur	1,09,797
Bhaktapur	68,638
Total	6,14,777

5.2.3 Mathematical Formula for Determining the Sample Size

According to Gupta S.P (1984), the reliable mathematical formula for determining the sample size is as the following equation.

$$CS = \frac{Z^2\Pi(1-\Pi)}{e^2} \tag{1}$$

where,
CS = calculated sample size
Z = value of specified level of confidence or desired degree of precision
Π = estimate of true population
e = error margin

Table 3: The Z values and error margin for different confidence level

Confidence Level	Z value	Error Margin
99%	2.576	0.01
95%	1.96	0.05
90%	1.64	0.1

Source: Gupta S.P, 1984

Thus, the formula to determine the actual sample size of a finite population can be calculated using the following formula:

$$n = \frac{CS}{1+\frac{CS-1}{pop}} \tag{2}$$

where, n= actual sample size
CS= calculated sample size
pop= total finite population.

6. Results and Discussion

Following the methodology, there has been results and findings regarding the per liter production cost of biodiesel from UCO in the laboratory, various properties of the produced biodiesel and the comparison of those properties with those of petro-diesel, total soybean oil consumption in the valley and consumption of the oil by each sector. There has also been the finding of the waste cooking oil generated by the valley and by each sector in the valley. The electricity required by the valley, petro-diesel consumed and the consumption of petro-diesel for diesel generators are other findings of this thesis paper using various primary and secondary data.

6.1 Production Process

The production of the biodiesel from UCO has been carried out by following the transesterification process. From the process the percentage yield of the biodiesel was obtained to be 80 percent. As the yield was determined for the first trial of the experiment during the study period, it appeared to be less in value. The yield percentage can increase more than 96 percent if performed more effectively with fewer errors when repeated several times (Aworanti, et al., 2013). Hence the lab scale yield of the biodiesel from UCO can be increased up to 96 percent or more.

6.2 Property Test

The obtained result of property test have been compared with the standard properties of biodiesel and petro-diesel set by American Society for Testing and Materials (ASTM) and also the results have been compared with the results of property test of biodiesel from UCO produced in the pasts which were performed in Ladoke Akintola University of Technology, Ogbomoso, Nigeria.

Table 4: Property test result and comparison with ASTM standards

Fuel Property	Biodiesel from UCO	Biodiesel ASTM D6571
Specific gravity	0.88	0.88
Density at 40°C, g/ml	0.87	0.875 – 0.9
Calorific value, MJ/kg	43.80	38.378
Viscosity at 40°C, centistokes	3.45	1.9 – 6
Color	Light yellow	
Flash point, °C	126	100 – 170

Source for ASTM Standards: U.S. Department of Energy, Biodiesel Handling and Use Guidelines, March 2006.

Table 5: Comparison of property test of biodiesel from UCO with that from Nigeria

Fuel Property	Biodiesel from UCO	
	Study	Nigeria
Density at 40°C, g/ml	0.87	0.89
Viscosity at 40°C, centistokes	3.45	4.10
Flash point, °C	126	162
Biodiesel yield, percent	80	94.102

Table 6: Property test result of biodiesel and standard values of petro-diesel

Fuel Property	Biodiesel from UCO	Petro-diesel ASTM D6571
Specific gravity	0.88	0.81-0.96
Density at 40°C, g/ml	0.87	0.85
Calorific value, MJ/kg	43.80	44.80
Viscosity at 40°C, centistokes	3.45	3.97-6.78
Color	Light yellow	Clear Bluish Green
Flash point, °C	126	60-800

Source for ASTM Standards: U.S. Department of Energy, Biodiesel Handling and Use Guidelines, March 2006.

It can be seen that the property test results which were acquired lies within the range of standards set by ASTM which proves that the final product which has been obtained is biodiesel which can be used as the alternative fuel for the petro-diesel either in pure form or can be used in blends. Also the comparison made with the result from Ladoke Akintola University of Technology, Ogbomoso, Nigeria showed that the biodiesel produced during this stydy has values of properties close to those of the biodiesel from the university which clearly justifies the production of the biodiesel from UCO for this thesis.

Table 7: Result of emission tests petro-diesel and blends of biodiesels at 50% load

Type of Emission	Diesel	B10	% red	B20	% red
CO (% vol)	0.065	0.055	15.38	0.054	16.92
O2 (% vol)	16.7	18.00	-7.75	15.88	4.91
HC (ppm vol)	46.17	35.64	22.81	36.5	20.94
NO (ppm vol)	105.75	59.25	43.97	124.82	-18.03
CO2 (% vol)	2.29	1.935	15.50	2.69	-17.47
Air Fuel Ratio (Lamda)	5.427	7.25	-33.74	4.34	19.94

The final property test was the emission test which has been carried out for three fuels; petro-diesel, biodiesel blends B10 and B20. The results for B10 and B20 have been compared with those of petro-diesel and the percentage reduction and increments for various components have been achieved.

Here, % red is the percentage reduction and the negative sign indicates % increment in emission

Table 8: Comparison of emission test result with that of EPA

Types of emission	% reduction	% increment of emission
	EPA B20	UCO B20
Total unburned HC	-20%	-20.94%
CO	-12%	-16.92%
NO	2%	18.03%
PM	-12%	Not found
Sulfates	-20%	Not found

Source for EPA B20: National Biodiesel Board, USA, 2005

The results clearly showed that the carbon monoxide has reduced significantly in both the biodiesel blends where the reduction percentage is even better in case of B20 which is almost 17%. Although in the fuel B10 most of the compounds emission has reduced, the increase in the oxygen level and air fuel ratio showed that there exists incomplete combustion of the fuel which in turn has effects on the emission reduction percentage of CO, HC, NO and CO2. However with all emission reduced there is increment in the percentage of NO and CO2 in case of B20. The main reason for the increment of carbon dioxide is that both the UCO and methanol are the organic compounds with long carbon chain which in complete reaction with oxygen has to produce CO2.

The property test result for B20 has been compared with that of result published by EPA. The comparison showed that the percentage reduction in emission of HC were similar in both the cases whereas the percentage reduction in CO was higher in the study result which valued 16.92%. But the emission of NO was much higher in the UCO biodiesel test than that of EPA test. Also due to the inability of the emission test analyzer, the emission result for PM and sulfates could not be determined.

6.3 Sample Size Calculation

Table 9: Sample size for the data collection

Businesses	Population size	Sample size obtained (n)
Restaurants	96	29
Hotels	132	32
Banquets	84	28

Also by using various mathematical formula, the collected data from the survey and from the data available from World Food Program Nepal, K.L Dugar Group, Nepal and Department of Food Technology and Quality Control (DFTQC), Annual consumption of cooking oil and production of UCO with in Kathmandu valley has been determined.

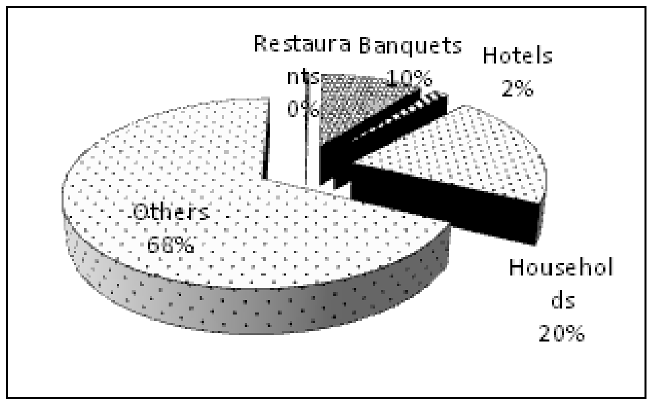

Figure 3: Percentage of annual consumption of cooking oil in Kathmandu valley

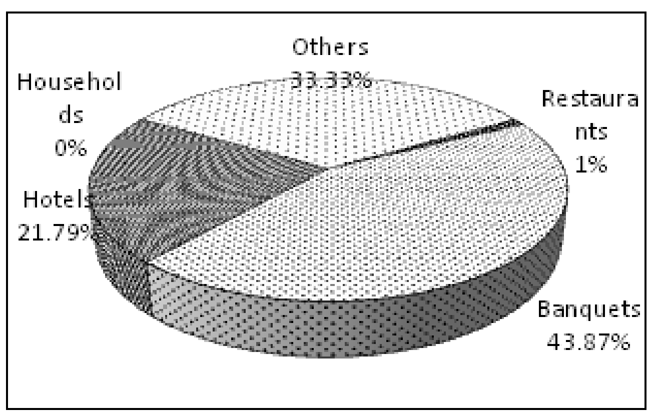

Figure 4: Percentage of annual production of UCO in Kathmandu valley

6.4 Cost Analysis

For the cost analysis some assumptions have been made to calculate the cost of chemicals used, the equipment used, the electricity cost and raw material cost (i.e. cost of UCO) to determine the cost for the production of 1 liter of biodiesel in the laboratory scale.

Table 10: Calculated cost of per liter of biodiesel produced

Factors required	Cost per liter production (Rs.)
Raw material	45.00
Equipment used	10.97
Electricity consumed	14.87
Chemicals used	124.33
Cost per liter of biodiesel produced (Rs.)	195.17

Even though the cost per liter of biodiesel produced which is Rs. 195.17 seems to be higher than the cost of per liter of petro-diesel in the market, its cost becomes beneficial as the biodiesel would only be used in the diesel blends of B10 or B20. Also the cost become of less importance as the emission from the biodiesel blends reduce which supports the health of humans as well as the environment.

6.5 Annual Consumption and Reduction of Petro-Diesel in Kathmandu Valley

From the secondary data obtained from a report of Sustainable Nepal, it was found that the average daily consumption of diesel is 700,000 liters only for Kathmandu valley (Sustainable Nepal, 2013). Another report published by Clean Energy Nepal has declared that 65% of the total diesel consumption is for the generation of electricity from the diesel generator (Rai, 2014). Based on these two secondary data and the data from survey, the annual consumption of diesel in Kathmandu valley and the consumption of diesel in generators by different sectors have been determined. Also with these information the reduction on dependency have also been calculated when blend of B20 is used in the generators.

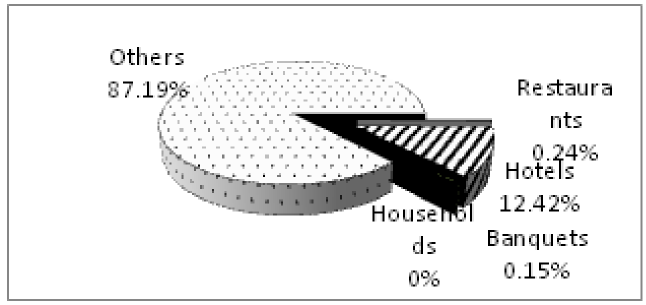

Figure 5: Percentage annual consumption of petro-diesel for generators in Kathmandu valley by different sectors

Table 11: Calculated percentage reduction in dependency of petro-diesel

Description	Values
Percentage of Biodiesel that meets regular diesel for generators	4%
Total B20 blend that can be made from produced biodiesel (kL)	30,484.69
Percentage of petro-diesel that would be required if B20 is not made	19%
Total petro-diesel required for B20 (kL)	24,387.75
Percentage petro-diesel required in generators if B20 made	15%
Percentage reduction in dependency of petro-diesel	4%

Table 12: Calculated cost of reduced dependency of petro-diesel for generators in Kathmandu valley

Description	Cost (Rs.)
Cost per liter of petro-diesel as per NOC without subsidy	109.81
Cost per liter of biodiesel produced in lab	195.17
Total savings in diesel annually if biodiesel is made	66,95,04,805.70
Total cost of B20 if made from all available UCO	38,67,958,690.34
Petro- diesel cost if biodiesel is not made	33,47,524,028.52
Reduced/Increased Cost	5,20,434,661.82

6.6 Findings Regarding Current Disposal of UCO

With the help of the survey questioner, it has been found that most of the party banquets, a few restaurants and very few hotels sell the wasted used cooking oil generated by them to the vendors who are called kabadis. These vendors collect the UCO from different food service providing businesses and again sell those oils to other organizations for various purposes. The oils which are not sold are directly discarded into the drainage system.

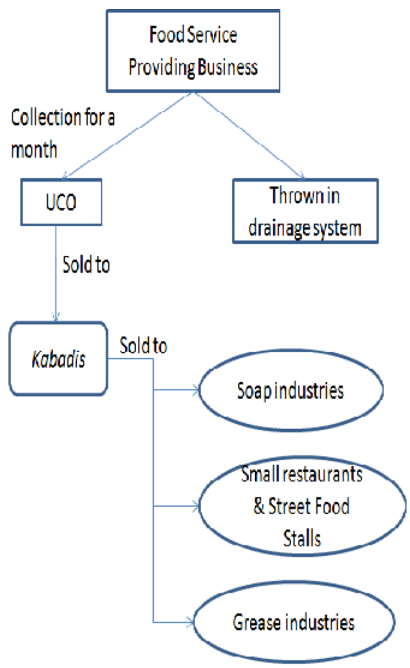

Figure 6: Current trend of channel of disposal of UCO in Kathmandu valley

7. Conclusions and Recommendations

7.1 Conclusions

The experiment performed and the surveys made during period of the study have helped to accomplish the objective of the study. The experiment phase was for the production of biodiesel from the used cooking oil collected from different food service providing industries and used the process of Transesterification. From this experiment, the percentage yield of biodiesel produced from UCO was found to be 80% which can be further improve and reached up to 96% or even more.

The results of the property test has concluded that the produced fuel during the experiment is biodiesel as it lies under the range of the standard property test values of biodiesel rested by ASTM. Also the fuel is justified as its property test results are very near to those values performed by people in some other part of the world.

From the result of the calculation of costs of raw material, equipment used, electricity charge and chemicals used for production of biodiesel from UCO per liter biodiesel cost was determined to be Rs. 195.17 for the laboratory scale. Also the calculation of diesel consumption by generators in Kathmandu valley has lead to the determination of percentage reduction in the consumption of petro-diesel if biodiesel is produced from all the available UCO produced in the valley. This has resulted in 4% reduction in the consumption of petro-diesel to run the generators in the valley. Although the consumption has been reduced, the cost of blending to make B20 has increased. This is due to the cost of lab production which is higher than Nepal Oil Corporation (NOC) diesel price.

7.2 Recommendations

At present there is no systematic provision of UCO collection. If biodiesel industry is to be established, there could be a proper flow of UCO from the food service providing industries to production of biodiesel to the flow of biodiesel back to the food service providing industries. This recommendation can be generalized in the following figure:

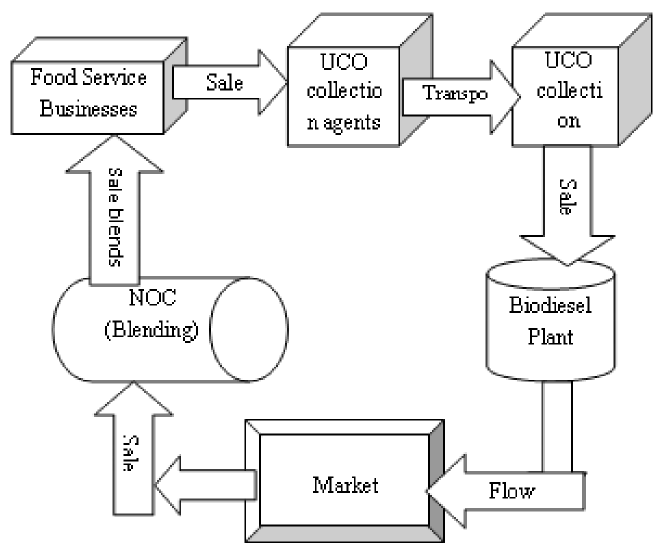

Figure 7: Recommended flow of UCO and biodiesel

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