Analysis of the Potential Use of the Anaerobic Digester to Treat the Food Waste at KDU Cadets' Mess

SAAAK Athukorala#, RMPS Bandara and MSR De Soyza

Department of Mechanical Engineering, Faculty of Engineering, General Sir John Kotelawala Defence University, Sri Lanka

#athukorala.saaak@kdu.ac.lk

Abstract— The global energy demand is on the rise while the resources are depleting in an equally high rate. Hence, it is of paramount importance to take measures to ensure that future generations have access to affordable and sustainable energy sources. "Biogas" is a clean and renewable source of energy that has the potential to reduce (especially in the rural sector) the use of fossil fuels that are depleting at a rapid rate, causing serious environmental problems. Furthermore, it provides a feasible option to reduce dumping of garbage without making any use of the same. Being a developing country, Sri Lanka could save foreign exchange outflow due to importation of petroleum products promoting renewable energy sources such as biogas. In this study, the biogas potential from different substrates found in the daily food waste from the Officer Cadets' Mess of General Sir John Kotelawala Defence University (KDU) was investigated. The total waste generated has been found to be 351.9 kg per day, and the average biogas yield was estimated as 33,518.13 l/day. The average energy potential from biogas was identified as 724.032 MJ/day that would save the consumption of 16.84 kg of LPG on daily basis. Furthermore, it has also been identified that 40,000 kg of liquid bio fertilizer can be obtained from the existing 40 m^3 digester installed at the University. It is estimated that the total potential savings per annum from the biogas plant for KDU is LKR 1,223,881.90 as per present economic status.

***Keywords**: waste, anaerobic digester, biogas, LPG, savings*

I. INTRODUCTION

The fossil fuels have largely catered for the global primary energy demand with 84% contribution in 2019 (*BP's Annual Review*, 2020) and it is estimated that fossil fuel resources will deplete by 2060 (Jackson Howarth, 2019). The potential for biogas production on a global basis is considerable and with biogas being considered as a renewable fuel, it will have a major role to play in the future energy mix, not only as a fuel for transportation but also as a fuel for domestic cooking. Being a CO_2-neutral and renewable source, biogas can address the GHG emission issues in a better way. Also, bio-manure generated after decomposition can be used successfully as fertilizer. A sustainable circle of nutrients and energy is thus created between consumers and producers (Anders Mathiasson, 2015).

Sri Lanka as a developing country, has always made attempts to mitigate emissions and adverse impacts due to climate change. Being a biodiversity hotspot on earth, it has many natural resources to be utilized for renewable energy production. Sri Lanka possesses experience with biogas systems for a long period of time. The potential of biogas as a feasible option in the energy sector was identified a long time back. This is a highly feasible and a desirable option for Sri Lanka, as a significant segment of the population are struggling for energy. This resulted in a program of the United Nations that adopted a resolution as Colombo Declaration back in April 1974 after holding a convention in Colombo, which emphasized that one of the urgent priorities in the region is Energy from renewable sources. (Barnett et al. 1978)

The main component of a biogas plant is the digester, which is an airtight container in which bacteria break-down organic waste through a process of anaerobic fermentation and generates a gas (biogas) that is mostly comprised of Methane and Carbon Dioxide (CO_2), which can be used for cooking and heating, or it can be used to generate electricity. As more waste material is added to the digester, a liquid waste (slurry) is also produced, which can be used as a fertilizer (Heezen et al. 2016). Biogas can be mixed with other fuels such as natural gas, which is a fossil fuel, and used as a source of energy for domestic purposes. Given that the Carbon Dioxide in air is absorbed by plants in the process of photosynthesis, biogas gives no net increase in Carbon Dioxide emissions compared to fossil fuels.

Biogas is produced as a result of anaerobic digestion of organic substances by a consortium of microorganisms through a serious of metabolic stages such as hydrolysis, acidogenesis, acetogenesis and methanogens. The methane-producing bacteria operate best under neutral to slightly alkaline conditions. Once the process of fermentation has stabilized under anaerobic conditions, the pH value will normally take a figure between 7 and 8.5. If the pH value drops below 6.2, the medium will have a toxic effect (Schwarz, 2007). Combustible biogas content includes about 50-70% of Methane, 30-40% of Carbon Dioxide, Hydrogen Sulfide, water vapour, Nitrogen and other impurities. The energy content of biogas will mostly depend on the Methane content of biogas and the average calorific value of biogas is about 21.6 MJ/m^3 (Minde, Magdum and Kalyanraman, 2013).

As a whole, anaerobic digestion provides a proper way of utilizing food waste to avoid contamining the environment, and-also will help to reduce GHG emission by reducing the usage of liquified petroleum gas (LPG). Utilization of biodegradable food waste to produce bio methane in an anaerobic digester reduces the environmental impacts, which could occur from emission of Methane due to open garbage dumping.

KDU presently has a biogas plant of 40 cubic meter capacity, which was constructed in 2012. The plant provides biogas for the cadets' mess kitchen for cooking and heating purposes.

The KDU Cadets' mess kitchen is providing meals for nearly 600 cadets daily, where considerable amount of food waste is generated on daily basis. This wastage is treated in an anaerobic digester to produce biogas and utilized in the Cadets' Mess kitchen as an alternative energy source for cooking where it can save substantial amount of energy. The effluent output of the plant is used as fertilizer for flowerbeds and trees in the KDU premises that contribute to monetary savings for the KDU. Furthermore, the effluent fertilizer promotes the proper growth of plants who do not need any additional chemical fertilizer. The main objective of this project is to estimate the potential of the biogas plant in order to cater for the energy requirement of the KDU Cadets' mess.

II. METHODOLOGY

Data related to the daily food waste were collected for few weeks in order to obtain an average value of the same. However, it was observed that the same food menu is repeated on a weekly basis and hence the analysis was done for an average value recorded per day. Mass of the leftover meals of the previous day was measured in the cadets' mess. Values obtained were used to calculate potential biogas yield of food waste per day separately. The average daily biogas potential was calculated by using reference data (Dilhani, Alwis and Sugathapala, 2012) of food wastes. It was assumed that cadets' appetite stayed the same for each menu and the menus were not changed during the period of data collection.

The potential of biogas was compared with that of LPG and was analyzed critically on the basis of economic and environmental aspects. The possible GHG emission reduction per annum was also calculated. It was assumed that the food waste and water were added with a 1:3 ratio in order to achive optimal thermophilic digestion conditions in the biogas digester at KDU.

III. ANALYSIS

Food waste data on daily basis in the cadets' mess were collected as shown in Table 1.

Table 5. Mass of daily food waste in kilogrammes

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Mixed Waste	180.9	224.6	196.4	194.5	184.6	193.2	207.6
Beans	12.5	-	14.6	-	11.8	-	-
Fish	-	32.4	28.4		29.3	-	33.6
Chicken	34.6	-	-	30.7	-	28.4	-
Leaks	-	-	14.6	-	-	12.4	-
Tomato	15.1	15.9	14.6	13.4	12.6	11.7	15.4
Onion	10.2	12.4	11.8	10.7	9.6	12.1	11.3
Banana	25.8	-	-	28.4	-	22.5	32.7
Banana Peel	46.4	-	-	44.3	-	46.8	49.6
Lady's Fingers	32.4	-	-	-	24.6	-	-
Orange Peel	-	26.4	-	-	-	28.4	-
Beets	-	24	-	-	-	-	-
Carrot	-	-	12.5	-	-	-	18

Potatoes	18.6	22.4	21.7	19.5	20.3	24.7	-
Total	376.5	358.1	314.6	341.5	324.3	380.2	368.2

Table 6: Methane yield from different substrates

Sample	Total solid %	Volatile Solids (%)	Ultimate methane yield (l/kg of Vs)
Carrot	9.5	91.3	309
Potato	19.0	91.9	267
Tomato	7.5	98.1	384
Ladies fingers	12.3	91.9	350
Onions	82.4	88.2	400
Beet	22.5	81.4	231
Brinjals	8.39	91.1	396
Banana Peels	18.3	91.7	314
Banana	12.8	94.3	274
v. Orange Peels	22.6	94.7	455
vi. Beans	18.0	92.8	383
vii. Meat	17.0	93.1	241
viii. Mixed	13.7	86.0	472

Source: Dilhani, Alwis and Sugathapala (2012)

Average quantity of daily waste was found to be 351.9 kg. Mass of volatile solids and the respective yield of biogas for different substrates were also calculated. Table 2 provides the ultimate Metane yield for different substrates as presented by Dilhani et al. (2012). Table 3 shows the calculated values of average volatile solid mass and average biogas yield on Mondays. Similarly, the same was calculated for other days of the week as presented in Table 4.

Table 7: Total volatile solid mass & Average methane yield on Mondays

	Total Volatile Solid Mass (kg)	Average Methane Yield
Mixed Food Remains	21.17	9995.07
Beans	2.08	799.70
Meat/Fish	5.47	1318.27
Banana	3.11	853.23
Banana Peel	7.78	2444.81
Potatoes	3.24	866.94
Brinjals	1.32	522.72
Onion	7.41	2965.21
Tomato	1.11	426.24
Ladies' Fingers	3.66	1279.61
TOTAL	56.35	21471.80

Table 8: Daily average total volatile solid mass & daily average methane yield on weekly basis

	Daily Average of Volatile Solid Mass (kg)	Daily Average of Methane Yield (l)
Monday	56.35	21471.80
Tuesday	52.51	21842.54
Wednesday	44.54	18581.21
Thursday	50.74	19639.01
Friday	49.35	18942.04
Saturday	51.67	20031.24
Sunday	51.75	20268.32

According to the data, the daily average mass of volatile solid waste was calculated.

Average total volatile solid mass per day

$$= \frac{\sum \text{Daily Average of volatile solid mass}}{7} = 50.98 \text{ kg}$$

Average methane yield per day:

$$= \frac{\sum \text{Daily Average of yield of methane}}{7}$$

$= 20110.88$ litres/day

Average Biogas yield per day assuming methane content in biogas as 60%

$$= \frac{20110.88}{0.6}$$

$= 33{,}518.13$ litres/day

Calculation of potential energy yield from biogas was calculated subsequently. The average calorific value of biogas was assumed to be 21.6 MJ/m^3 (Minde, Magdum and Kalyanraman, 2013)

Hence, average energy yield from biogas produced per day = 33.52 x 21.6 = 724.032 MJ/day

Continuous feeding of the digester is proposed and it is suggested to have an alternative feed during the vacation. It can be fulfilled by garden waste from KDU premises. Since the cadets are not at KDU during the vacation, biogas requirement also will be less. Hence, the full quantity of feed will not be required and only the minimum feed required to keep the continuity of biogas production in the digester will be needed.

A. Comparison between LPG and Biogas

Liquefied Petroleum Gas (LPG) is used for cooking purposes in the KDU cadets' mess kitchen. Cooking process consumes up to 5–6 Cylinders of LPG per day. As per calculations above, daily average energy yield of biogas is estimated as follows:

Daily average energy yield of biogas = 724.032 MJ

Calorific value of LPG = 43 MJ/kg

Total mass of LPG that can be saved per day

= 724.032/43

= 16.84 kg

A medium size LPG cylinder contains 12.5 kg of LPG. Hence, it is evident that the daily supply of biogas saves almost 1.3 gas cylinders per day. Given that the current price of a LPG cylinder in the market is Rs. 1495.00, the monetary saving can be calculated as:

Monetary saving per day

$$= \frac{16.84 \text{ x } 1495.00}{12.5}$$

= Rs. 2014.06

Annual Saving = 2014.06 x 365 days

= Rs. 735,131.90

B. Saving from bio-fertilizer (digestate)

Anaerobic digester can provide 1000 kg of liquid bio-fertilizer per m^3 of a biogas plant per year. According to the present market price, liquid bio-fertilizer can be valued for Rs 5 per kg.

Hence, bio-fertilizer yield from a 40 m^3 plant=40000 kg

Annual income =Rs.200,000

C.Potential saving by the utilizing of garbage

The government allocates Rs. 2500.00 per ton of garbage for dumping. By assuming 330 days per annum (excluding vacations, during which the cadets' mess does not function):

Degradable waste generated per day = 0.35 tons

Degradable waste generated per year = 115.5 tons

Savings from disposing degradable waste in the digestor

= Rs. 115.5 x 2500

= Rs. 288,750

D. Monetary saving potential of the biogas plant

Total potential savings per annum from the biogas plant

= 288,750.00+200,000.00+735,131.90

= Rs 1,223,881.90

Total expenditure on LPG per year

= 6 x 1495 x 330

= Rs 2,960,100.00

Annual Percentage Saving of Biogas plant

$$= \frac{1{,}223{,}881.90 \times 100\%}{2{,}960{,}100.00}$$

= 41.35%

E. Reduction in GHG Emissions

Possible saving in LPG consumption annually

= 16.84 × 330 = 5557.2 kg/yr

Annual possible GHG emission reduction Since the GHG emission per LPG kilo grams is 2.9kgCO (IPCC, 1996).

= 2.9 × 3333 = 16.116 tons/yr

IV. DISCUSSION

Based on calculations 16.84 kg of LPG could be saved daily and 41.35% of an annual monetary saving could be achieved by direct and indirect savings. Proper utilization of the biogas plant will enable generation of energy from bio-degradable food waste, which could have dumped without any use. The effluent, which contains higher nutritious level, could be used to reduce the consumption of commercial fertilizer.

It is important to note that, in order to achieve the above objectives, the plant must be continuously fed. If the feeding process continues without any issue, the biogas yield will be maintained at a constant level with only negligible fluctuations. It is required to add waste and water in a ratio of 3:1 in order to facilitate the growth of bacteria and to ensure the generation of biogas is maintained at an acceptable rate. Usage of a chopping machine to chop the food waste in to small pieces could be helpful to accelerate the biogas production and to optimize the yield of biogas.

The temperature within the digester has to be sustained in a range between 30^0 – 35 ^{0}C by incorporating a proper insulation in order to avoid overheating during dry periods and overcooling during rainy periods so that the mesophilic digestion can be made optimal. Removal of Hydrogen Sulfide (H_2S) and water vapour to be done in order to have a cleaner biogas yield.

V. CONCLUSION

Biogas is considered as a cleaner energy source that can be produced by using biodegradable food waste. Production of biogas is more preferable in order to reduce the dependency on fossil fuels.

Kitchen of the Officer Cadets' mess at the General Sir John Kotelawala Defence University generates 351.9 kg of food waste per day. The waste can be pre-treated and used as bio-manure in the biogas digester in order to produce biogas by anaerobic digestion in controlled conditions, to be used for cooking purposes. Potential biogas yield is 33,518.13 litres per day which can replace 16.84 kg of LPG on a daily basis. The total monetary saving potential of the plant is estimated to be Rs 1,223,881.90 per annum.

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