Utilization of Kitchen Waste for Generation of Fuel

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Abstract

About 80% of homes in rural India meet their energy needs through solid biomass such as firewood, crop residue and cow dung. In urban areas, Liquefied Petroleum Gas (LPG) supplied in portable cylinders is used in over 59% of homes. However, India being an oil scarce country and increased reliance of our country on costly imports, alternative measures of energy need to be pursued.

The Bhavans' college campus in Andheri West suburb of Mumbai has an area of 64 acres, consists of three colleges and three schools. There are around four canteens and three dining halls that utilize several LPG cylinders and generate high amount of kitchen waste every day. Kitchen waste can have as high calorific value (HCV) of around 17000 kJ/kg. Survey was conducted of all campus kitchens and tests were performed on their food wastes to determine the feasibility of extracting energy from them. The samples collected had high calorific value and organic content. The moisture content of these samples was moderate high; therefore anaerobic digestion was considered preferred waste to energy plan. The following study consists of characterisation of waste and designing an anaerobic digester that would produce cost effective, high quality methane gas from this food waste, which can be used to supplement the fuel requirements of the campus kitchen.

Keywords: fuel; biogas; energy; calorific value

1.0 Introduction

Municipal Solid Waste (MSW) is defined as any waste generated by household, commercial and/or institutional activities and is not hazardous [1]. With rapid urbanization, the quantities of municipal solid waste, an important by-product of an urban lifestyle, is increasing at a rate faster than urbanization itself. In India, ten years ago, there were 2.9 billion urban residents, each generating 0.64 kg/capita/day of MSW. Today, there are about 3 billion residents generating 1.2 kg/capita/day. It is estimated that by 2025, these numbers will increase to 4.3 billion urban residents with 1.42 kg/capita/day of MSW [2]. Waste generation is directly related to the economy of a country. There can be variations in the generation rates within a country, and even within the same city. Industrial countries account for a large portion of the world's MSW relative to their share of world population, while developing countries give a large portion of MSW relative to their share of world income. Classification of the regions of the world based on their affluence provides a more organized outlook to waste generation rates and waste management practices. The World Bank has classified the 188 World Bank member countries based on the Gross National Income per capita (GNI) [3]. Solid Waste Management (SWM) is an organized process of storage, collection, transportation, processing and disposal of solid refuse residuals in an engineered sanitary landfill. It is an integrated process comprising several collection methods, varied transportation equipment, storage, recovery mechanisms for recyclable material, reduction of waste volume and quantity by methods such as composting, waste-to-power and disposal in a designated engineered sanitary landfill[3]. A major part of MSW is generated from urban areas i.e. cities and bigger towns. India is primarily a country with a huge rural population. However, it is estimated that about 40% of the Indian population will move towards urban areas by 2026. Currently, an estimated 48 million tonnes of solid waste and 4,400 million cubic meters of liquid waste are generated every year in the urban areas of the country. As per the study of "National Master Plan for Development of Waste to Energy in India", 17 (6%) cities have generation rate in excess of 1000 TPD, 80 (26%) cities generate between 150-1000 TPD and balance 202 (68%) cities generate less than 150 TPD. The MSW ranges from 250 gm to 700 gm per day per person with an average of 490 gm per day per person [4].

Table 1: Waste generation rates

Income Level	Waste generation (kg/capita/day)
High	0.7-14
Upper Middle	0.11-5.5
Lower Middle	0.16-5.3
Lower	0.09-4.3

It's evident that the high income countries produce more waste per capita as compared to the low income countries. There is a country-wise classification of economies into the upper, middle and lower incomes.

However, in a single country itself, the affluence varies among the population. For eg, in India and China, there is disproportionately high urban waste generation per capita relative to overall economic status. This is because they have very high poor rural populations that dilute their economic status [4].

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A study conducted by the Central Pollution Control Board (CPCB) on MSW management in India shows that waste generation is estimated to increase rapidly at present from 490 gm per person per day to 945 gm per person per day which would result in 300 million tonnes per year from 48 million tonnes per year by the year 2047.

To tackle the yearly 5% increase of waste in urban India, urban local bodies are investing around 35-50% of its available funds yearly, spending about Rs. 500-1500 per ton on solid waste management. In view of growing challenge, Central Government has incorporated solid waste management as one of the components in Jawaharlal Nehru National Urban Renewal Mission (JNNURM) for extending financial resources. Approximately, 62 cities are covered under this mission with total investment of US$20 billion in 7 years [7]. MSW contains compostable organic matter (fruit and vegetable peels, food waste), recyclables (paper, plastic, glass, metals, etc.), toxic substances (paints, pesticides, used batteries, medicines), and soiled waste (blood stained cotton, sanitary napkins, disposable syringes).

Table 2: Waste Generation rates in India

Population	Waste Generation Rate kg/capita/day
Cities with a population < 0.1 million (8 cities)	0.17-0.54
Cities with a population of 0.1–0.5 million (11 cities)	0.22-0.59
Cities with a population of 1–2 million (16 cities)	0.19-0.53
Cities with a population > 2 million (13 cities)	0.22-0.62

MSW composition at generation sources and collection points, determined on a wet weight basis, consists mainly of a large organic fraction (40–60%), ash and fine earth (30–40%), paper (3–6%) and plastic, glass and metals (each less than 1%). The C/N ratio ranges between 20 and 30, and the lower calorific value ranges between 800 and 1000 kcal/kg [8]. The disposal methods may include open dumping, incineration, composting, landfilling and using it as refused derived fuel.

The major goal of this study was to characterize the solid waste and find its potential to be recovered in the form of energy from the large amount of food waste generated. For this purpose a survey of campus kitchens was conducted by circulating a questionnaire will to collect the data of the daily food waste and the frequency of substituting the liquefied petroleum gas (LPG) cylinders. The characterization of the kitchen waste would consists of finding the basic parameters like moisture content, volatile matter and calorific value to check it's feasibility to be used for production of biogas in various climatic conditions. The design of bio-digester along with the rate analysis of the same was conducted.

2.0 Methodology

The survey for the Bhavan's Campus kitchens and the waste produced by the same was divided into two main parts:

a) A consideration of all the available canteens and kitchens, followed by a basic survey, which led to the selection of kitchens

b) Use of questionnaires to understand the actual amount of waste generated and the feasibility of utilizing all the canteen kitchens for the project.

Bhavan's campus encompasses the following colleges and hence, their canteens namely Bhavan's college of arts, commerce and science, Sardar Patel College of Engineering and Sardar Patel Institute of Technology, SP Jain Institute of Management and Research, Hansraj Morarji School and Raj Hans School.

A questionnaire was designed for collecting information about waste generation in all the canteens. The questions included, were so as to get a basic idea about the two important qualities of the waste generated viz. quantity and disposal as given in Appendix I. The questionnaire gave the basic idea about the amount of waste generated and characterization of waste based on moisture content, organic matter and calorific value. Sampling was carried on during peak hours of solid waste collection from the kitchens during rainy season. An average sample of 1.5 kg of solid waste generated was collected and characterized to find the quality. The characterization of solid waste was done to by finding total moisture content (Standard Methods, APHA), organic matter (volatile matter, Standard methods, APHA) and calorific value (Parr oxygen bomb calorimeter) of solid waste. Digester design was carried out according to the “System Design Flowchart” given by Curry and Pillay. An approximate area of 100 m^2 was proposed to be allotted for the biogas plant. Accordingly, a suitable location was scouted inside the campus so as to maintain proximity to the canteens and not hinder any student or campus activity. Approximate gas piping distances were measured from the proposed location to each canteen. The distances were measured using the Sports Tracker application which made use of a Global Positioning System (GPS) to map distances, and a rough sketch was prepared thereafter. A detailed quantitative survey and estimation gave the cost of the digester. A breakeven analysis was also carried out for the entire project.

3.0 Results and Discussion

The results obtained weekly sampling are depicted in table 3. The bucket sampling method was adopted for first sampling which is quite different from the truck load method [9]. As described in materials and methods characterization of waste collected from canteen was performed and the results are as depicted in table 4. The quantities of waste generated from various canteens and mess was different due to several reasons. Mess caters around 200 students living in a hostel twice a day amounting for per capital generation as (total waste/no of students). Whereas the Bhavan’s and SP canteen caters for snacks for total no of students of 2000 amounting for waste generation as 0.1325 kg per capita per day. It was observed that no proper disposal method is followed resulting into smell and fly nuisance in and around campus. The collection bins are open with spillage around the area. The total consumption of LPG gas for the campus is 8.5 cylinders amounting to 120.7 kg and the total monthly requirement as 3621 kg. The characterization was conducted in two different seasons and the results are as given in table 4

Table 3: Questionnaire Results

Canteen name	Bhavan’s Canteen	Sardar Patel Canteen	Sardar Patel Mess	SP Jain Mess
Source/ Type of Waste	Mostly Organic with some plastic and glass	Food and Plastic Mostly organic.	Food and peelings (organic)	Food+ Plastic
Name of owner	Santosh	Anna	Santosh	Santosh
Hours of operation	8 am to 6 pm	7 am to 7:30 pm	7 am to 2:30 pm and 5 pm to 9:30 pm	8 am to 2:30 pm and 8 pm to 11pm
Approximate quantity	100 kg	3 large cans= approx 75 kg	2 large cans= approx 50 kg	1.5 cans= approx 40 kg
Method of disposal	Municipality Van picks from outside campus bin			
Location of disposal	Outside Campus			
Time of disposal	7 pm daily			
Current Recovery from waste	Not applicable			
Type of fuel	LPG	LPG	LPG	LPG
Daily fuel requirement	2.5 commercial cylinders	1.5 commercial cylinders	2.5 cylinders	2 cylinders

The total consumption of LPG gas for the campus is 8.5 cylinders amounting to 120.7 kg and the total monthly requirement as 3621 kg. The characterization was conducted in two different seasons and the results are as given in table 4.

Table 4: Characterization of Waste

	Moisture Content (%)		Ash (%)		Volatile Matter (%)	
	Autumn	Spring	Autumn	Spring	Autumn	Spring
Bhavan's	66.8	81.51	8.43	5.44	91.6	94.56
SPCE Mess	76.4	73.98	23.3	15.48	76.7	84.52
SPCE Canteen	81.6	75.4	10.9	36.26	89.2	63.74
SP Jain Mess	76.6	75.23	19	9.45	81	90.55

3.1 Moisture content

As observed in table 4 the moisture content of the waste varied from 65 to 80% as expected from the kitchen waste. It is comparable to the moisture content obtained by Hafid et al., 2011. This can be a potential problem if we derive energy in the form of steam as a huge amount of fuel would be wasted in drying the waste. Biogas is a better option as there is a requirement of moisture in 50%.

3.2 Ash Content

Ash content of solid waste from the kitchens varied between 8-23 % which is in the range of ash content expected in municipal solid waste (3 -28%) [10]

3.3 Volatile Matter

It was observed that the volatile matter varied from 80% to 92%. This is comparable to the 92% of volatile matter content obtained from the kitchen waste from Burford [11]. Wastes with high volatile matter content produce more biogas if digested properly, as it is the organic matter that produces biogas.

3.4 Calorific Value

Following table indicates different values of calorific value obtained by experimental method as well as by analysis using the equations [10]:

CV=356.248 VM - 6998.497(kJ/kg) Eqn. 1

CV= 356.047 VM-118.035FC -5 600.613 (kJ/kg) Eqn. 2

Benton: CV=4.2*(44.75 VM-5.85 W + 21.2) Eqn. 3

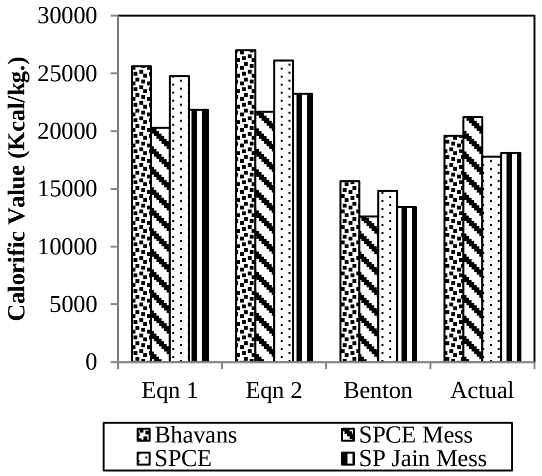
Where,

CV- calorific value in kJ/kg

VM- Volatile Matter in percentage

FC- Fixed Carbon content

W- Moisture Content



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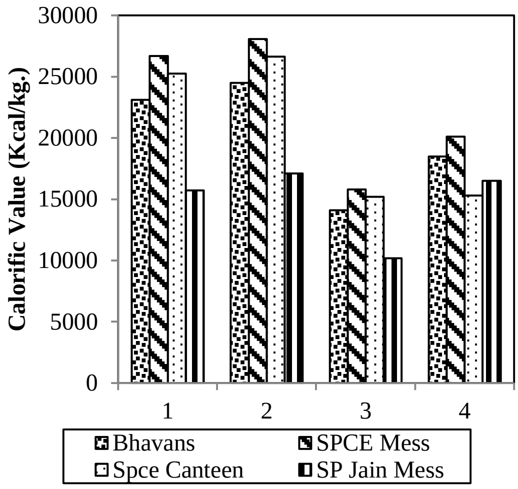

B

Fig. 1. Calorific value for various wastes in different kitchens in Bhavan's campus in (a) Autumn (B) Spring

On the basis of the experimental values and the values obtained using the above mentioned equations, as well considering the factors such as diurnal variation of food constituents, humidity and temperature, it was inferred that the calorific value was 15000-25000 kJ/kg. The above results were compared with those obtained in the research paper by Kalantaifard and Yang (Malaysia, 2011). They obtained a calorific value of 23000 kJ/kg. On the basis of the above results, volume of gas generated was computed, and the discharge of waste sludge, anaerobic digester will be designed to fulfill the purpose of this entire project. Currently, LPG commercial cylinders are used at a rate of 8.5/day (2650 kJ/kg approx.), combining all the 4 locations. Therefore, as a result of the above project, the conventional fuel sources will be replaced by the biogas fuel source; thereby improving the efficiency of the fuel as well as the management of waste will be carried out in an effective manner.

4.0 Design of Digester

Quantity of Waste

Average daily quantity of kitchen waste generated in Bhavan's Campus:
Bhavan's Canteen: 100 kg
SPCE Canteen: 75 kg
SPCE Mess: 50 kg
SPJIMR Mess: 40 kg
The Bhavan's Canteen and SPCE Canteen generate a considerable amount of plastic waste as well. Hence subtraction of plastic weight was carried out.

Table 5 Approximation of plastic waste contained in campus kitchen waste

Particulars	Bhavan's Canteen	SPCE Canteen
Number of Cans	1	1
Radius of Can (m)	0.16	0.19
Height of Can (m)	0.6	0.5
Volume of Can (m^3)	7.238×10^{-3}	8.51×10^{-3}
Density of Plastic (kg/m^3)	0.925×10^3	0.92×10^3
Weight of Plastic (kg)	6.69	7.86

A compaction factor of 0.6 is assumed.
Gross weight of plastic waste = 6.69 + 7.86 = 14.55 kg
Quantity of waste to be considered for the design of the digester = 265 – 14.55 ~ 250 kg
Assume FOS of 1.5
Tonnage of waste per day = 1.5 x 250 = 375 kg

Flow Rate

Let b = 0.15 i.e. dryness
D = 1000 kg/m^3
1000 kg of dry waste corresponds to 1 m3
∴ 375 kg of dry waste corresponds to 0.375 m3

Volume of Digester

Flow rate Q = 0.375 m3/d
Assume HRT = 20 days
∴ Volume of digester = 0.375 m3/d x 20 d = 7.5 m3
Provide 2.2 m diameter and 2 m height
∴ Volume of digester provided= 7.6 m3

Volatile Solids (VS) Concentration

Winter values:
VS Concentration = (190.6+104.48+316.48+125.9)/(1411+597.5+86.55+803)
= 0.2 g/kg
= 200 kg/m3
Monsoon values:
VS Concentration = (358.95+189.33=151.5+288.04)/(1182+1133+925+1573)
= 0.207 g/kg
= 207.3 kg/m3

Thus, VS concentration is taken as 207.3 kg/m3

Organic Loading Rate (OLR)

OLR = (VS Conc (kg/m^3) ×Flow Rate (m^3/day))/(Volume of Digester (m^3))
= 10.23 kg/m^3/day

Estimation of Gas Production

375 kg/d of waste corresponds to 77.6 kg/d of volatile solids
Assume 40% efficiency of bacteria to convert volatile solids into gas
∴ VS = 40% of 77.6 kg

= 31.04 kg
Assume that VS matter in sludge is reduced by 65% due to digestion.
∴ VS reduced = 65% of 31.04 kg
= 20.17 kg
Assume that 0.9 m3 of gas is produced per kg of VS reduced
Amount of gas produced = 0.9 kg/m3 x 20.17 kg
= 18.16 m3
Amount of waste that will be sent to the sludge drying beds = 375-77.6 = 297.4 kg

LPG and Biogas
Weight of LPG in 1 No. commercial cylinder: 19 kg
Weight of LPG in 1 No. domestic cylinder: 14.2 kg

LPG usage
Bhavan's Canteen: 2.5 commercial cylinders
SPCE Canteen: 1.5 commercial cylinders
SPCE Mess: 2.5 domestic cylinders
SPJIMR Mess: 2 domestic cylinders
LPG requirement per day = (4 x 19) + (4.5 x 14.2)
= 139.9 kg/d ~ 140 kg/d= LPG density= 553 kg/m3
∴ 140 kg of LPG is equivalent to 0.253 m^3

Design of Sludge Digester and Gas Chamber
Total volume of digester cum gas chamber = 7.5+18.2 = 25.7 m^3 ~ 30 m^3
We provide 2 sludge digesters of 15 m^3 each
Diameter = 3.5 m
Height = 1.5 m
Volume provided = 14.43 m^3
Volume provided for digested sludge = 6.09 m^3
Step 9: Design of sludge drying bed
Waste that will go to the sludge drying bed: 297.4 kg/d
Density of waste in sludge drying bed: 1000 kg/ m^3
Volume of waste in sludge drying bed = 0.2974 m^3/d
∴In 20 days, volume of waste = 5.948 m^3
Thickness of gravel layer = 35 cm
Thickness of sand layer = 15 cm
Assume thickness of sludge as 30 cm
∴ Surface area of sludge = 19.83 m3
Provide two 2.5 m x 5 m sludge drying beds.

Components of biogas plant
The proposed anaerobic digester will have a capacity to generate close to 30 m^3 of biogas on a daily basis. The components of the proposed biogas plant have been enlisted below:
1. Collection Pit – For dumping raw kitchen waste
2. Hydra-Pulper/Crusher – For crushing the waste before feeding into digester
3. Pump – To pump waste into digester
4. Anaerobic Digester – 2 separate digesters proposed
5. Drying Beds – For waste sludge
6. Collection Bag – For storage of surplus biogas

A layout of the biogas plant with all of its components in a process flow-sheet is shown below:

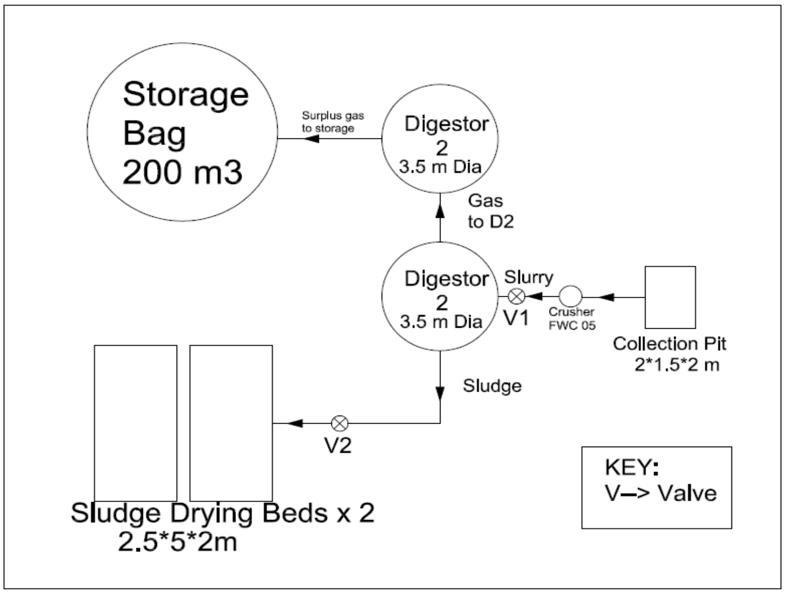

Fig. 2 Layout of biogas plant

Estimation of cost

Total cost to install biogas plant =	Rs. 7, 77, 385.35
	+ Rs. 18,000.00
	+ Rs. 3, 92,134.00
	Rs. 11, 87,519.00
Accounting 3% of total as contingencies,	Rs. 35,625.58
Hence, total cost is:	Rs. 12, 23,144.58
Assuming operation and maintenance cost as 15% of total cost:	Rs. 1, 83,471.69
Hence, Actual Total Cost:	**Rs. 14, 06,616.27**

4.1 Break – Even and Cost Recovery

The cost recovery of the project was calculated and compared with the potential savings in LPG expenditure, which would be brought about due to the proposed substitution of biogas as cooking fuel. For the calculations, the cost of the average domestic LPG cylinder (14.2 kg) was considered as Rs. 450/- and that of a commercial cylinder (19 kg) was taken as Rs. 1600/- .The college campus, and hence the canteens, were considered to be operational for 300 days a year. Using the average annual maintenance cost as well as the one-time installation cost calculated above, a cost vs time graph has been plotted in figure 3. From the figure it is observed that cost recovery occurs after a period of only 4 months after installation. After the first four months, the plant will save an average of close to Rs. 7.5 lakh every 3 months under ideal conditions

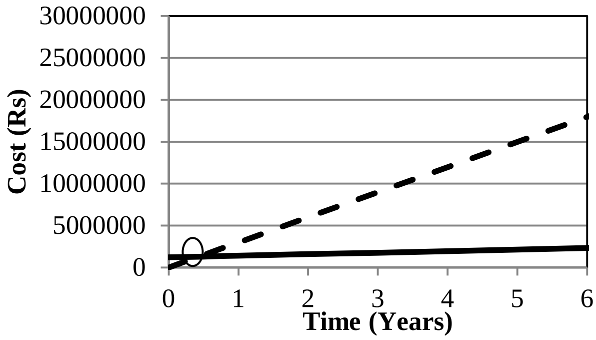

Fig. 3 Break-even time for substitution of biogas as cooking fuel

5.0 Conclusion

From tests conducted on solid waste collected from four canteens in the Bhavan's campus, the average moisture content of the samples was found to be around 75%. High moisture content makes thermal recovery from solid waste uneconomical as considerable fuel is used up by the latent moisture in the solid waste. Anaerobic digestion, which requires high moisture content for the sustenance of the methane bacteria, was the preferred alternative for energy recovery from organic waste in the Bhavan's campus. A higher volatile matter content leads to a better biogas yield. The test samples contained an average of 85% of volatile matter, thus strengthening the case for the adoption of anaerobic digestion in the Bhavan's campus. The calorific values obtained are also comparable to those of LPG, and thus prove that the gas obtained can be used as cooking fuel.

The amount of gas obtained each day was calculated to be 35 m^3. The current usage of cooking fuel in all canteens is about 5 m^3. The surplus gas can be used for electricity production, which can be used for local lighting and for hostel power requirements. This would ensure effective utilization of the gas without wastage. However, even without considering electricity generation from the surplus biogas, the proposed biogas plant is still economically viable. Considering the biogas as a substitute for cooking fuel in the canteens and kitchens, we obtain an encouragingly short break-even time of only four months. This proves that gas generated from kitchen waste has tremendous potential for energy recovery, especially in educational institutes, where large amounts of such waste are generated daily. Kitchen waste can thus be considered as a future source of energy and fuel in large campuses, and potentially even in residential areas.

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