FEASIBILITY STUDY OF ESTIMATING FOOD WASTE FROM URBAN AREA AND ITS USAGE FOR ENERGY GENERATION

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Abstract: *Everyday more than 15 tones of organic waste is generated in the city of Vadodara. Along through the restaurants excluding agriculture waste, household waste and other dry and wet waste. Around 75-80% of the waste generated by these restaurants is organic waste. This waste is disposed to landfill on outskirts of the city. The closing of landfill as it reaches maximum capacity and more land is needed for waste disposal. This method of disposing waste is rather land polluting hold no economic or environmental benefits and obsolete with contemporary standards. As there is large of waste is organic and also it contains more or less amount of moisture. It can be utilized in biogas production facility. Biogas production from this waste basically enable us to create energy from the wastage which would otherwise pollute the eco system. The aim of this study is to estimate the amount of food waste generated by restaurants on daily basis and its utilization in energy generation. The economic analysis estimates the revenue from the waste collection and can cover the capital investment cost as per study.*

Keywords: **Feasibility, Energy, Waste, Biogas**

1. INTRODUCTION

Biogas is a combustible mixture of gases; it consists mainly of methane and carbon dioxide and is formed from the anaerobic bacterial decomposition of organic compound such that without oxygen. The gases formed are the waste products of the respiration of this decomposer microorganism and the composition of the gases depends on the substance that is being decomposed [1]. Methane is also the main constituents of natural gas almost 77-90%. Chemically methane belongs to the alkenes and is the simplest possible form of these. Pure methane has a calorific value of 39.8 MJ/m^3 which corresponds to 11.06 kWh/m^3. The pioneer of anaerobic digestion in India goes to Shri S V Desai for his first experiments on biogas production in 1939. This led to the development of the first Indian biogas plant in 1951, the Gramalaxi plant of the Khadi and Village Industries Commission (KVIC). KVIC was the first to introduce biogas plants amongst the farmers in rural India. Two other models which became popular are the Janta biogas plant introduced in 1978 and its successor, the Deenbandhu digestor developed by Action for Food Production (AFPRO) in 1984. National Biogas and Manure Management Program (NBMMP) is being implemented in the country since 1981-82 for promotion of biogas plants based on cattle dung and other organic wastes [2]. A number of developing countries use biogas extensively. In India and China alone, there are more than one million small, simple plants, each treating waste (sewage, animal manure etc.) from a single household. The biogas is used in the house for cooking and the digested biomass is used as fertilizer [3]. Biogas produced is green replacement of unprocessed fuels (wood, dung cakes etc). Biogas technology has the potential to meet the energy requirements in rural areas and also counter the effects of reckless burning of biomass resources. Anaerobic digestion thus proves to be more efficient in utilization of crop residues [4]. The social benefits associated with bio methanation along with its capacity to generate income for the rural household make it a viable alternative for conventional method. This study is limited to the treatment of organic waste generated from the vegetable and fruit markets in the city of Vadodara. The biogas produced from the AD process is assumed to be used only for electricity generation and the digestate for composting. The investment cost, operation and maintenance costs including the transport of organic waste from the markets to the biogas plant are included in the analysis. The cost for external distribution of electricity and compost are not taken into consideration in the study. Biogas, biomass, and biofuel are all renewable energy sources existing in different phases of the transformation. Biogas can be made from different biomass like poultry droppings, agricultural crop wastes, and cattle manure by controlled anaerobic degradation. Produced biogas can be processed further and concentrated to produce biomethane which can be injected into natural gas pipelines [5]. Biogas which is a byproduct of microbial metabolism can be used in its raw form for heat and power generation or can be upgraded to biomethane and for production of value-added chemicals for energy and industrial process application. The use of biogas can reduce greenhouse gas emissions as it has huge potential for use as a renewable resource [6]. As an example, 0.29% of total energy consumption in Switzerland for the year 2014 was in the form of biogas and it accounted for close to 8% of the total renewable energy production without accounting for hydropower [7]. Biogas is produced by anaerobic digestion (AD) process whose benefits include production of a renewable energy resource while the process can lead to treatment of feedstock during the treatment and also produce digestate which is a useful organic fertilizer that can substitute chemical fertilizers in sustainable agriculture [8]. Biogas has a significant role to play in the global energy transition because of the need to transform the global electricity systems from fossil fuel-based generation to low carbon and renewable energy-based power generation [9]. With huge biomass to biogas conversion potential and many feasible biogas to electricity conversion technologies, biogas will play an extremely important role in the energy transition as a renewable energy fuel resource and feedstock for industrial production of chemical fuels and renewable products [10]. Microbially controlled generation of biogas is a significant part of the global carbon cycle where we have a natural anaerobic biodegradation estimated to generate 590–800 million tons of methane into the global atmosphere [11]. Biomass with significant energy potential is produced in increasing quantities by the society globally. Various organic feedstocks can be used to produce biogas through anaerobic digestion which can be processed through enrichment to produce natural gas like biomethane [12].

1.1. Objective of Study

(a) Our first and prominent aim is to get an estimated weight of total organic waste created by restaurants in the city of Vadodara. For that a sample survey of 100 restaurants across the city in various area was conducted. The survey indicated the states of waste whether it is dry or wet or plastic. It also evaluated the satisfaction level of Vadodara Municipal Corporation (VMC) waste collection service.

(b) There are several sites that are suitable for the use where biogas plant can be erected. Each of these sites are ranked based on certain parameters on a scale of 1 to 5. Suitable site size, logistics access, easy administrative approval, land cost, suitable amenities are the primary ranking criteria for the selection of site.

(c) In this study it is essential to find specification of the biogas plant in order to build a plant suitable for waste amount generated in Vadodara. In order to obtain various plant specification, the amount of food waste generated in Vadodara is calculated.

(d) Biogas is a combination of methane and cow which has calorific value of 6 kWh/m^3 of biogas. After obtaining the volume of biogas produced from the organic waste the total energy stored in biogas will be calculated.

(e) The main aim of this work is to estimate the economic viability of plant or not.

2. Food Waste Survey

To estimate the total amount of waste generated in restaurant across Vadodara city and contemporary ways of its disposal by restaurants. Vadodara is a metropolitan city with population over 2 million. It is then becoming evident that there will be large number of outlets to serve the large number of people. Hence significant amount of food waste would be generated by all the restaurant collectively. According to city records there are more than 1000 big and small-scale restaurants active in the city. A survey was conducted and restaurants were selected based on number of customers they served and their ratings were 3-star, 4-star and 5-star restaurants. The questionary that was asked to the restaurant's owner are as follows:

(a) Restaurant Rating: (1) 3 star (2) 4 star (3) 5 star (4) Not rated

(b) Type of Food Waste: (1) Wet (2) Dry (3) Plastic

(c) Weight of Food Waste per Day: (1) Wet in kg (2) Dry in kg (3) Plastic in kg

(d) Does the restaurants segregate the waste: (1) Yes (2) No

(e) Where the waste is disposed by the restaurant management: (1) In VMC container (2) On an open field (c) Personal approach

(f) Are the waste disposal services used private or public:

(g) Restaurants managements views on VMC services:

Each outlet was visited by the team conducting survey and was asked mainly about type and weight of waste being generated. Restaurant representative were also asked about their disposal methods. The review of VMC waste collection service were also included. Different types of waste included dry, wet and liquid waste were discussed with them. The name of the restaurants is not mentioned due to their wish not to document their name but here the list of 50 restaurants stating their solid waste, wet waste and plastic waste is listed in Table 1. Wet waste generated in the restaurant are generally lighter than the dry waste. Overall plastic waste generated is minor of the total waste. However plastic waste generated was kept in the same containers with dry and liquid waste. Most of the restaurant relies on VMC services for their organic waste disposal. Several restaurants are giving away their left over to the farmers for cattle food. Except a little minority, most of the outlet were happy with VMC services.

Table 1. Restaurants Number stating total waste generated

Sr No	Solid Waste (kg)	Wet Waste (kg)	Plastic Waste (kg)	Total (kg)
1	0	6	0	6
2	0	2	0	2
3	0	25	2	27
4	0	25	3	28
5	1	2	1	4
6	0	3	9	12
7	10	0	1	11
8	7	25	0	32
9	0	20	0	20
10	0	10	0	10
11	4	7	1	12
12	10	20	0	30
13	0	50	0	50
14	35	6	3	44
15	1	10	0	11
16	3	0	0	3
17	15	15	3	33
18	0	15	5	20

19	0	10	3	13
20	0	12	0	12
21	0	7	0	7
22	2	3	0	5
23	20	20	0	40
24	0	5	0	5
25	0	15	0	15
26	10	30	0	40
27	0	4	0	4
28	0	7	1	8
29	0	10	1	11
30	0	10	5	15
31	0	10	0.5	10.5
32	3	15	1	19
33	0	10	0	10
34	0	2	0	2
35	0	5	0	5
36	0	2	0	2
37	0	70	5	75
38	0	30	1	31
39	0	80	0	80
40	0	30	1	31
41	0	15	1	16
42	0.5	10	0.5	11
43	0	15	2	17
44	2	15	1	18
45	0	3	1	4
46	0	1	0	1
47	0	30	0	30
48	0	40	0	40
49	0	3	0	3
50	1.5	10	0	11.5
Total	125	770	52	947

From the given data it is observed that total organic waste from food outlets is estimated to be 15 tons per day. It can be noticed that huge amount of waste is being generated on daily basis only by restaurants. Moreover, large portion of that waste is in wet and organic state. This implies that this waste is suitable for biogas production.

3. PROCESS ANALYIS & TECHNOLOGY

The typical biogas system consists of the following steps (a) Manure collection (b) Anaerobic digestion (c) Effluent storage (d) Gas handling (e) Gas use. Biogas is a renewable form of energy where methanogens are last link in a chain of microorganisms which degrade organic material and returns product of decomposition to the environment. There are two types of digestion process Aerobic digestion and Anaerobic digestion. Agricultural waste, animal manure, municipal solid waste is some of the feedstock suitable for anaerobic digestion and now we can propose the use of waste food as feedstock. Anaerobic digestion a natural process that takes place in absence of oxygen and involves biochemical decomposition of complex organic material by various biochemical processes with release of energy rich biogas and fertilizer as subsidiary product.

Anaerobic digestion technologies have been implementing in different countries in small and large scale. The technologies can also be adopted depending on the volume and characteristics of the feedstock. These technologies provide renewable energy and, in many cases, can be a feasible and efficient way for treating and reducing the amounts of waste. Several small-scale biogas systems are used in domestic cooking and lighting purposes in developing countries. The small-scale biogas technologies commonly include the following components and system (a) Structural component – inlet tank, outlet chamber and digestor; (b) Piping components – gas pipeline and valve; (c) Biogas utilization systems – biogas stove and biogas lamp; (d) Effluent disposal systems – storage of digestate and reuse; (e) Elements related to Anaerobic digestion process – biogas production; (f) Electricity generation component – micro turbine. The anaerobic digestor is the main element of AD process. According to the content fed into the digestor the fermentation process can be classified as wet or dry digestion. The DM content of the feedstock is a relevant factor when selecting AD technologies due to it determines the design of the plant and the type of digestor. Dry digestion is suitable for feedstock with dry matter values greater then 25%. The common systems for dry digestion are batchwise. Dry digestion systems have a small digestor volume in comparison to wet digestors. On other hand wet digestion technologies are suitable for treating feedstock such as slurries and sewage sludge that have dry matter content lower than 15%. Other way to classify the AD technologies is by its feeding mode. The technologies can be continuous or batch wise. The process is continuous when new biomass is added to the digestor and the same amount of digestate leaves the system. In this mode of operation, the waste material is moved through the digestor by mechanical pressure. Continuous digestors are commonly suitable for wet digestion. In the case of batch wise digestors, the feedstock is fed once at a time, the feedstock is fed once at a time. The feedstock is left inside the digestor until the AD process has been completed to then be removed. This technology has a simpler structure in comparison to continuous digester and it is suitable for dry digestion or combined dry wet digestion for stackable feedstock. For an estimated amount of waste generation from the food outlets which is 15 tons different types of small-scale biogas plant types which can be expanded to medium size plants as per the organic waste input. The AD technology that international community uses can be classified in 5 or more basic types. In this paper we include the most appropriate technology relevant to waste amount collected and the geography of Vadodara city. Indian floating dome technology is especially designed for the Indian terrain. Another advantage is that due to the weight of floating drum gas is delivered at constant pressure. Moreover, it has longer life span and construction is quite easier compared to other available technologies.

4. SPECIFICATION EVALUATION

To examine and analyze various standard sources and materials in order to determine the basic specifications of various components of plant. For plant selection specification were selected from the best set of data which could apply to design the functional biogas working plant. It is quite certain that these plant specifications will produce the best possible results for local small-scale plant as these specifications are based on standard data and relations. Most specifications are derived through calculations based on standard formula and relations. However, some dimensions were difficult to evaluate as there was no standard basis for size determination of the component. These types of dimensions are obtained on comparative basis with other reputable sources. All these dimensional specification forms a base for design of the biogas plant based on food waste collected from restaurants and other food outlets situated in Vadodara. Size and shape of each component of the system in consideration is specified and derived. The total amount of biogas generated is calculated by considering the biogas yield. The following equation gives the total amount of biogas generated from the biowaste.

M = m * Y

M is amount of biogas per year (cubic meter per year)

m is mass of bio waster per year (kilogram)

Y is biogas yield (cubic meter per kilogram)

As per literature review the value of Y is 0.02 cubic meter per kilogram of biowaste. So, if we multiply the total amount of biowaste generated per year with 0.02 we get the total amount of biogas generated in cubic meter per year. The methane yield and biogas yield are important factors of the biogas, since methane is the main component influencing on the energy content of the biogas and therefore also the biogas yield. They can be calculated theoretically if the exact waste composition is known. Due to the waste contains several organic components, methane and biogas yield can be difficult to estimate theoretically. A biogas yield value of 20 cubic meter per ton biowaste was assumed considering a methane content of 61%. This value is a general estimation found in literature for biowaste. In our study net biowaste generated per day is 15 tons, therefore 300 cubic meter of biogas is yielded from the biowaste mentioned. The total electricity generated from the biogas power plant is depend upon the total amount of bio gas generated, total calorific value of biogas such that total energy contains in the biogas and efficiency of electric generator. The total calorific value of a biogas is 6 kWh per cubic meter and the efficiency of a generator is around 30% then the total amount of electricity generated is calculated as follows

E (kWh per year) = M * energy content in gas * efficiency of generator

Thus, it is observed that we can get around 20 cubic meters of biogas from 1 ton of biowaste, which contains around 61% of methane. And from one cubic meter of biogas, we can generate around 2 kWh of energy with considering the efficiency of electric generator. Therefore, we get around 40 kWh energy from the one ton of biowaste. Calculating the biogas volume for 15 tons of waste we can obtain 600 kWh of electricity per day. The type of digestor selected is cylindrical type and the floating drum which is the gas collector part and floats at the top part of the digestor has almost flat conical shape above it. For calculation the top surface is considered flat and calculation is carried out. As per the standards volume of the digestor drum should be 2.5 times the volume of biogas generated per day. For 300 cubic meter of biogas yield the volume of digester can be calculated as it's 2.5 times. So, the volume of digestor is worked out to be 750 cubic meters. Furthermore, the height to diameter ratio for the Indian floating drum digestor is known to be 1.3. So, the diameter and height of the drum with the given data is

H = 1.3 * D

Thus, in aid with this equation of volume of cylindrical drum will be useful in determination of height and diameter of the digestor. With reference of 750 cubic meter of volume of biogas we can calculate radius and height of digestor as follows

$\text{Volume} = \pi * R^2 * H$

$750 = 3.14 * R^2 * 2.6R$

R = 4.512 meter

H = 11.73 meter

D = 9.024 meter

These values can be rounded off to D = 9 meters and H = 12 meters. Gas holder or floating drum is the uppermost part of the anaerobic digester. Its size should be such that it can freely float on the slurry of waste without having friction with aligning walls of the digestor. For the metal drum to float freely, it is quite clear that its diameter should be less than that of digestor. As per standard design procedure the diameter of floating drum should be at least 15 cm less than the digestor diameter.

D (Floating Drum) = 9.0 – 0.15 = 8.85 meter

Furthermore, total volume of the floating drum should be 60 percent of the volume of biogas generated per day.

V (Floating Drum) = 0.6 x biogas yield = 0.6 x 300 = 180 cubic meters

Height of the floating drum can be obtained by equation of volume.

V (Floating Drum) = π x R x R x H

180 = 3.14 x R x R x H

H = 2.9276 meter

Hence D (Floating Drum) = 8.85 meters and H (Floating Drum) = 3 meters. Waster receiver tank is the initial part of the biogas plant. All the trucks loaded with waste is emptied in this container. This container is designed according to the daily waste reception amount. It is possible to include 2 or more waste receiver tank in the plant of various size according to different amount of waste coming in. It is considered that the volume of the receiver tank should be less than 25 percent of digestor volume. Hence volume of receiver tank such that V (Receiver) = 160 cubic meters. Water mixing chamber dimension is the system component which mixes the water with the waste coming from waste receiver tank. In order to make good slurry which will generate biogas efficiently and rapidly it is essential that waste is mixed with water. Water boosts the anerobic digestion process when mixed with partially dry waste. As per design procedure the mixing chamber volume is 1/600 to 1/800 times the digestor volume.

V (Mixing Chamber) = (1/166) x V (Digestor) = 1.125 cubic meters

The power of the motor required is 15 HP. The digestate collection tank which is connected with digestor and its function is to collect the digestate coming out of digester. Once the anaerobic digestion is completed and biogas is extracted through floating drum the leftover is collected in this tank. Volume of this tank is perceived to be same or little bigger than the digestor volume so V (Collector Tank) = V (Digestor) = 750 cubic meters. Gas engine is the last part of the biogas plant where electricity is generated by combustion of biogas. For the biogas yield of our analysis, a small-scale gas engine is required which can be incorporated with the plant. The gas is sent from the gas collection chamber through metal tubes to the gas engine inlet. Combustion of biogas takes place here which moves the piston and in turn generates electricity. There are various types and capacity of gas engines. The selection is based on daily electricity generation potential of plant which is 600 kWh. For a large pool of varieties there are 4 potential gas engine of 55 kW, 65 kW, 98 kW and 100 kW capacity. The designed plant has a capacity of 300 cubic meter per day, from which we can calculate the net working hours for the gas engine. For each engine the net working hours calculated is to be 8, 9.49, 6.55 and 6.26 hours respectively. This gives the total electricity generated in kWh to be 522.78, 522.15, 641.92 and 626.3 for each engine. It is observed that 98 kW capacity engine gives the maximum electricity thus the biogas plant will be using 98 kW gas engine as its best alternative.

4.1. Process Parameters

Several parameters influence on the performance of methane production. Different microorganisms are involved in the process of anaerobic digestion and they require certain conditions to growth. The main parameters in the AD process are (a) Temperature The bio methanation process can occur at different temperature ranges between 25°C to 42°C known as the mesophilic range, between 43°C to 55°C thermophilic range and at temperature below 20°C psychrophilic range. At mesophilic temperature the anaerobic digestion process is more stable than at thermophilic and psychrophilic conditions due to at this temperature range the anaerobic bacteria are more tolerant to changes in the environment. At low temperature the methane production takes longer than at high temperature. The methane rate production decreases under temperature below 35°C because of the slow degradation of organic matter. (b) pH the acidity or alkalinity of solutions is measure by pH. This parameter influences on the growth of methanogenic bacteria and thus on the methane production. The optimum pH value for the anaerobic digestion process is the range of 6.5-7.5. The pH is a determining parameter for AD because at low pH values the methane formation is inhibited. (c) Pressure is the mixing power which influences the gas recirculation especially for technologies lacking mixing systems. An increment in pressure during the AD process leads to high carbon dioxide concentrations in liquid phase. Carbon dioxide has a high solubility in comparison to methane. For this reason, an increase of pressure can result in high concentration of carbon dioxide in the substrate stimulating the methane production. The partial pressure of hydrogen should be low enough to offer a balanced environment for methanogenic and acetogenic bacteria. Methanogenic bacteria consume hydrogen in order to produce methane so it is important to have availability of hydrogen during the AD process. On the other hand, acetogenic bacteria produce hydrogen thus the hydrogens partial pressure should be low enough to give space to the hydrogen molecules produced by the acetogenic concentration.

5. ECONOMIC ANALYSIS

It is necessary to calculate approximately various costs included in implementation of biogas plant and revenues generated from the produced electricity and bio fertilizer. Any project needs some capital investment and other extra running expenditure. The costs can essentially classify as capital investment costs and plant running cost.

The capital cost includes equipment cost which involves the gas engine of 98 kW. It is the most expensive component of the system and a standard gas engine price is Rs. 11 lakhs. The digestor is made of brick and mortar whose construction costs including material cost and labor cost is estimated to be Rs 2 lakhs. Supplementary equipment like grinder, crusher, mixer and floating dome are collectively expected to cost somewhat around Rs 4 lakhs according to market prices. The cost of waste collector, digestate collector and gas collector is estimated to be Rs 2 lakhs. Thus, total equipment cost is estimated to be Rs 19 lakhs. Another capital cost includes land cost. There is an opportunity of saving complete land acquiring cost by selecting a site which is under control of municipality administration. However, it is essential to calculate the land acquiring cost for which site ranking criteria are 1000 – 2000 square meter of flat accessible land is ideal, easy access to site from major roadways, an existing site with certificate of approval form municipality to locate a waste processing facility or compost plant is ideal and lowest possible purchase price is ideal. The approximate cost of land is coming around Rs 37 lakhs. Thus, the total capital cost involved in establishing the biogas plant is Rs 57 lakhs.

The plant running costs are very nominal compared to capital investment costs. The first is waste transportation cost as the plant needs 15 tons of waste. The municipal corporation uses a van to collect waste across the city which has an average of 20 km per liter of diesel. The average price of diesel can be considered as Rs 67 and a distance of 30 km per day to collect the waste. One van collects 1 tons of waste thus we need 15 vans to collect 15 tons of waste from the city. The approximate cost of waste collection from the city is coming out to be Rs 50,000/-. The small-scale plant which can be easily handle by two personnel with basic engineering skills such at Rs 30,000 per month per person. This amounts to be Rs 60,000/- per two person per month. We need 5 labor to carry out the activity which is 5 person for 30 days for Rs 200 per day which comes out to be Rs 30,000. This cost are approximately Rs 1 lakh. The maintenance cost is merely a small amount of Rs 20000 per month. Thus, the total running cost involved in running the biogas plant is less than Rs 2 lakhs per month.

There are two main sources of earning revenue in biogas plant such that from electricity and fertilizer. This plant has electricity generation of 600 kWh per day and if we consider Rs 3 per unit of electricity generation. Hence, we can have Rs 1800 from electricity per day which will comes out to be Rs 54000 per month. After anaerobic digestion is completed roughly 12 tons of digested waste comes out in digestate recovery tank. One hectare of farmland can contain 3 tons of bio fertilizer. Thus 4-hectare land can be served with fertilizer in one day. Fertilizer for one hectare land is valued at Rs 3000. Hence Rs 12000 can be earned daily form fertilizer which turns out to be Rs 3.6 lakhs per month. Thus, the total revenue obtained from running such biogas plant is coming out to be Rs 4 lakhs per month.

6. CONCLUSION

Based on analysis carried out the total running cost of the biogas plants comes out to be Rs 2 lakhs per month. The revenue generated from the plant is Rs 4 lakhs per month. This indicates that the margin of profit per month comes out to be Rs 2 lakh per month. This ensures the recovery of capital cost in next 3 years and as per life of plant of 15 years one can earn fair amount of profit for remaining period which ensures for economical safe to start biogas plant. In addition, it generates renewable energy credits preventing emission of methane into atmosphere. Another benefit works out to be elimination of landfills due to waste, reducing transportation cost of waste and recycling of energy and nutrient content in organic waste. Biogas facilities based on urban waste streams are located near large energy demand areas this enables to reduce the expenditure on setting up transmission lines. For every 1 kWh of electricity energy generated from the combustion of biogas there is 1.1 kWh of thermal energy created, recovered and available for local use. The direct benefits involved in such plants are construction jobs per facility and plant operations jobs per facility. The indirect benefits in such plants are cleantech finance, carbon credit market development, digestate business development, education and training.

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