The International Journal Of Engineering And Science (IJES)
||Volume||2 ||Issue|| 11||Pages|| 70-76||2013||
ISSN(e): 2319 – 1813 ISSN(p): 2319 – 1805

Conversion of Kitchen Waste into Biogas

Ogur, E. O.[1] and Mbatia, S.[2]

[1,] *Department Of Mechanical And Mechatronic Engineering, Technical University Of Kenya, P.O. Box 52428 – 00200, Nairobi*

[2] *Department Of Mechanical Engineering, Kabete Technical Training Institute, P.O. Box 29010-00625, Nairobi*

---ABSTRACT---

Facing energy crisis and climate change, the world is in need of a green, efficient, carbon- neutral energy source to replace fossil fuels. The search for energy alternatives involving locally available and renewable resource is one of the main concern of governments, scientists, and business people worldwide. Biogas, formed by anaerobic digestion of organic materials, makes sustainable, reliable and renewable energy possible. There is potential for biogas production from kitchen waste, and at the same time the waste themselves can be treated to minimize the environmental impact and provide nutrient rich organic fertilizer. The study's main objective was to design an anaerobic digester which utilizes food waste to generate biogas for use in Kabete Technical Training Institute's (KTTI) kitchen. The institute's main source of energy was mainly wood fuel, supplemented with liquefied petroleum gas (LPG) which is very expensive. The amount of waste generated from the kitchen was found to be of sufficient quantity to generate enough biogas for use in the kitchen hence the level of biogas production would in turn mean that this technology could be a viable investment for the institute to make.

KEYWORDS: *Biogas, organic waste, anaerobic, aerobic, organic fertilizer*

Date of Submission: 30 March 2013 — Date of Acceptance: 20 November 2013

I. INTRODUCTION

Everything, in essence, is about energy. There is no doubt now that energy is fundamental for our development. Energy is vital for the internal and external security of a country and energy issues are at the core of social, environmental and economic security challenges. The world is experiencing an economic downturn and in these dire times, individuals and institutions are more likely to consider options for renewable energy or other measures that help the environment. As the demand for the world's fossil fuel increases and with their price increase, interest has rightly begun to be given to the development of renewable energy sources. The search for energy alternatives involving locally available renewable resources is one of the main concerns of governments, scientists and business people worldwide [1]. Biogas is defined as a combustible mixture of gases produced by micro-organisms when biological wastes are allowed to ferment in the absence of air in closed container [2]. Biogas is mainly composed of 50 to 70 percent methane (CH4), 30 to 40 percent carbon dioxide (CO2) and low amount of other gases. Biogas is about 20 % lighter than air and has an ignition temperature in the range of 650^0C to 750^0C. It is odourless and colourless gas that burns with clear blue flame similar to that of liquid petroleum (LPG) gas. Its caloric value is 20 Mega Joules (MJ) /$m^3$and burns with 60 %efficiency in a conventional biogas stove. Biogas refers to a gas made from anaerobic digestion of agricultural and animal waste [3]. The gas is useful as a fuel substitute for firewood, dung, agricultural residues, petrol, diesel, and electricity, depending on the nature of the task, and local supply conditions [4].

1.1 Statement of the Problem

The purpose of this study was to find out how the food waste at KTTI could be converted into biogas and to design an anaerobic digester which uses food waste to generate the biogas. The waste generated in kitchen in the form of vegetable refuse, stale cooked and uncooked food, waste milk and milk products could all be processed in this plant. Research has shown that One kg of kitchen waste in 24 hours can produce the same amount of biogas as 40 kg of cow dung in 40 days. That means more than 400 times efficiency can be achieved by using kitchen waste as compared to cow dung. Thus the efficient disposal of kitchen waste can be eco-friendly as well as cost effective.

1.2 Objectives of the study

The main objective of this study is to design a biogas digester utilizing kitchen waste for KTTI. To achieve this, the following specific research objectives would have to be met:

[1] To analyze the systems and methods used in the institute to dispose kitchen waste.
[2] To establish how kitchen waste could be converted to biogas.
[3] To analyze the extent to which biogas generation will impact the KTTI's operations.
[4] To determine the benefits of kitchen wastes biogas plant over conventional biogas plant.
[5] To determine how improper kitchen waste disposal affects the environment.

1.3 Significance of the Study

The study was to provide information to help KTTI adapt the use of an anaerobic biogas system to replace the expensive LPG and wood fuel sources. The study was also to provide the institute with a basic explanation of the mechanics of a small, continuous flow anaerobic digester which the management could adopt for use. This would assist the KTTI adopt strategies that would reduce waste disposal and fuel costs by converting food waste into feedstock for the biodigester which would be used for cooking.

II. MATERIALS AND METHODS

2.1 Materials

A biogas production system consists of the following features:

a) **Substrate inlet**
This consists of a receptacle for the raw fresh organic waste and pipe of at least 10 cm diameter leading to the digester. The connection between the inlet pipe and the digester must be air tight.
b) **Digester**
This is the reservoir of organic wastes in which the substrate is acted on by anaerobic micro organisms to produce biogas.
c) **Gas Storage /Reservoir**
Depending on the proposed design, this may be simply an empty but enclosed space above the slurry in the digester, an inverted floating drum whose diameter is just slightly smaller than that of the cylindrical digester or an air tight polythene tube with an inlet –outlet outfit.
d) **Gas Burner**
This may be a special lighting lamp or a modified burner for cooking.
e) **Exhaust outlet**
This consists of a pipe of similar size to the inlet pipe connected to the digester at a slightly lower level than the inlet pipe to facilitate outflow of exhausted slurry as shown in Figure 1.

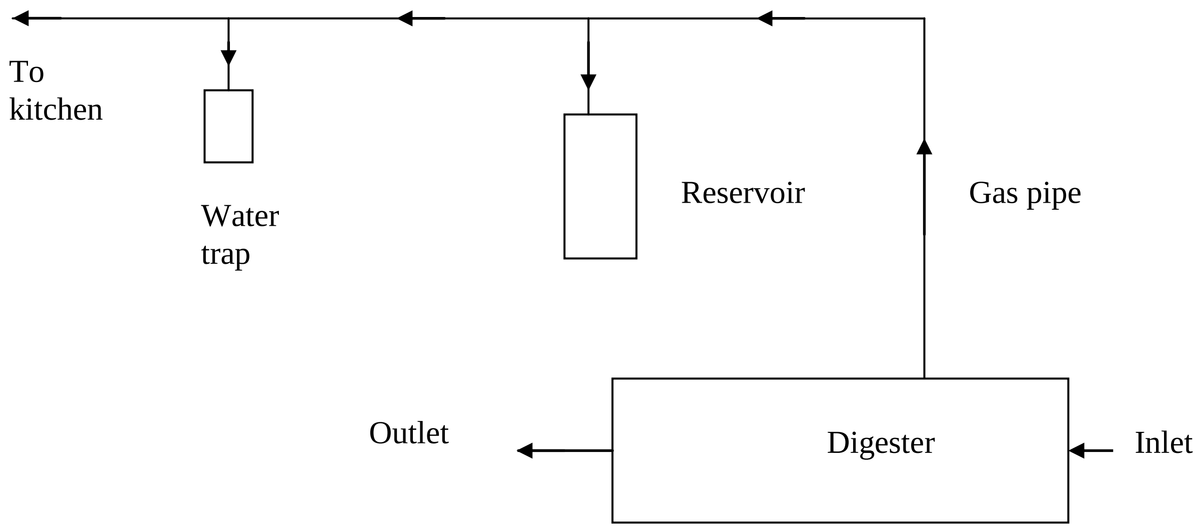

Fig.1: Biogas Production System

2.2 Methods

Biogas can be obtained from any organic material after anaerobic fermentation by three main phases. The fermentation of organic wastes under anaerobic conditions to produce biogas occurs in the following three stages as illustrated in Figures 2 and 3:

1. **First Stage**

Complex organic compounds are attacked by hydrolytic and fermentative bacteria, which secrete enzymes and ferment hydrolyzed compounds into acetate and hydrogen .A small amount of the carbon converted will end up as volatile fatty acids, primarily propionic and butyric acids.

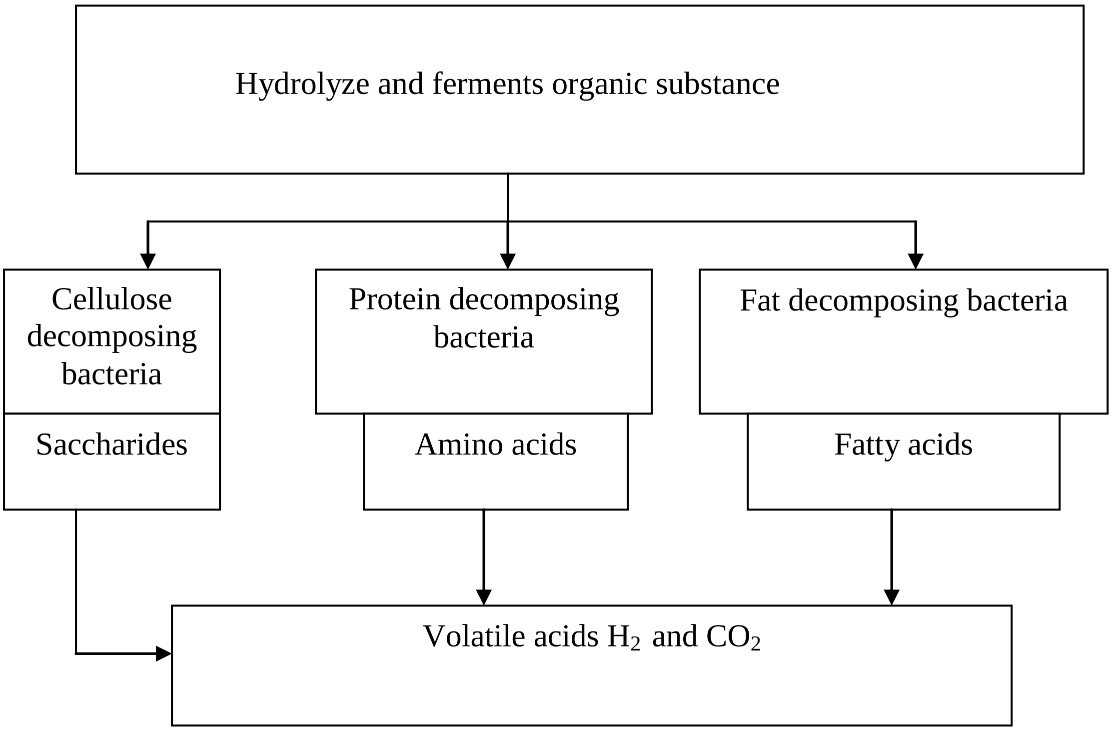

Fig. 2: Fermentative Bacteria

2. **Second Stage**

The hydrogen- producing acetogenic bacteria continue decomposing by converting the volatile fatty acids into acetate and hydrogen producing acetogenic bacteria.

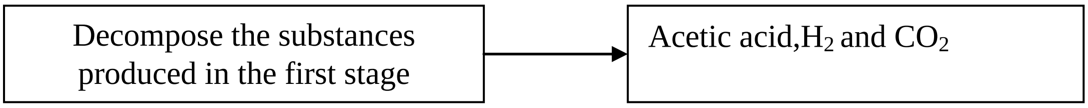

Fig.3: Decomposition of Fatty Acids

3**. Third Stage**

Methane –producing bacteria convert the hydrogen and acetate into methane .There is a certain amount of specialization in that different bacteria act on different substrates .In order for these bacteria to work properly and achieve the desired end products, the following conditions have to be well balanced .

- The dilution of the substrate i.e. amount of water to dilute the animal waste.
- The optimum temperature which should be 35^0C
- Type of substrate (due to their suitable carbon to Nitrogen (C: N) ratio and total solid content cattle, pig and poultry manures are recommended).
- Rate of feeding the digester (overfeeding can lead to accumulation of volatile fatty acids).

The study aimed to evaluate the viability of designing a biodigester for biogas generation at KTTI kitchen utilizing food waste generated. Table 1 shows the type of fuel used and cost, whereas Table 2 presents data collected on type of waste and amount generated daily.

Table 1: The type and cost of fuel used at KTTI kitchen on monthly basis

Fuel used	Amount (Kg)	Cost (Ksh)
Wood fuel	4000	20,000
Liquid petroleum gas (LPG)	200	40,000

Table 2: Type and amount of kitchen waste generated from the KTTI kitchen

Type of waste	Amount (Kg / day)
Food leftovers	40
Vegetable peelings	60
Others	20

III. RESULTS AND DISCUSSION

3.1 Design based on end-use-substitution of biogas for cooking

The wood consumption of KTTI is 4000 kg/month which has a Biogas equivalent of $0.18m^3$/kg of wood. A comparable biogas volume would then be (0.18 x 4000) = $720m^3 = 0.5m^3$/kg. Therefore the required daily biogas volume = 720/30 = $24m^3$. The proposed biogas plant is of fixed dome type of digester constructed in cylindrical shape. The relevant dimensions for the flat bottom digester are shown in Figure 3.

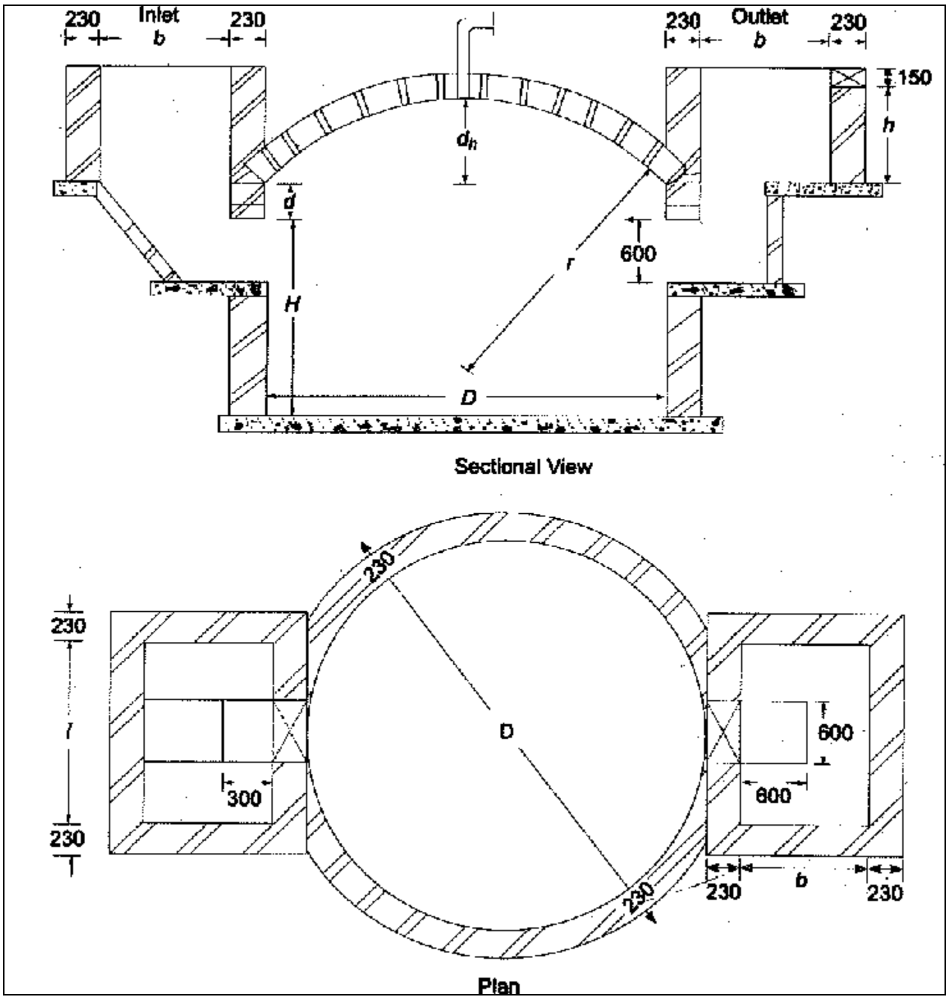

Fig. 3: Diagrammatic sketch of digester with flat bottom (Source: Niangua, 2006)

The related parameters are defined as:
W = Weight of kitchen waste available per day (kg/day)
G = Gas production rate (m^3/day)
V_S = Active slurry volume in the digester (m^3)
S_D = Slurry displacement volume (m^3)
H = height of the cylindrical portion of the digester up to the top edge of the inlet/outlet opening (m)
D = Diameter of the digester (m)
h = slurry displacement in the inlet and outlet tanks (m)
l ,b = length and breadth of the inlet and outlet tank (m)

3.2 Gas production rate, (G)

One kilogram of kitchen waste, if well digested, yields $0.3m^3$ of biogas according to Dublin, 2008. The gas production rate (G) for the available kitchen waste, working with 80kg/day was found to be given by: G = W X 0.3 = 80 X 0.3 = $24m^3$/day.

3.3 Active slurry volume, (V)

The active slurry volume in the digester is directly related to the hydraulic retention time (HRT). This is the theoretical time that a particle or volume of liquid waste added to a digester would remain in the digester . It is calculated as the volume of the digester divided by the volume of slurry added per day and is expressed as days (Niangua, 2006).

Active slurry is therefore given by: Vs = $HRT \times 2\frac{W}{1000}$, for the kitchen waste, HRT = 30 days,

$$Vs = 4.8m^3$$

3.4 Calculation of height (H) and diameter (D) of the digester

The relative values of height and diameter were calculated from the volume of the digester,

$$V_S = \frac{\pi}{4}D^2H$$

In practice the ratio of D/H is taken as 2 (Niangua, 2006). Since the active slurry volume is $4.8m^3$, then, 4.8 = $\pi/4xD^2xH$, but D = 2H, hence $4.8 = \pi/4. 4.H^3$ $H=(4.8/\pi)^{1/3}$ H = 1.15m, and D = 2 x 1.15 = 2.30m

3.5 Slurry displacement inside the digester, (d)

The selection of a suitable value of d depends upon gas usage pattern. Since cooking at KTTI is usually done three times a day, 50% of the gas to be produced in a day will be made available for one cooking span. But since there is a continuous production of gas from the digester, the gas generated during cooking time should also be considered .The total cooking time is about 4 hours, the variable gas storage volume (SD) is obtained from the equation: 4/24G + SD = 50/1 00G. By simplification, SD = 50/1 00G – 4/24G, SD = 0.333G= 0.333 x 24 = $7.992m^3$ = $8m^3$. Then d is obtained from the equation, SD = π/4.D.d, 8 = π/4 x 2.3 x d = 1.93m.

3.6 Slurry displacement height (h) in the inlet and outlet tanks.

The maximum pressure attained by the gas is equal to the pressure of the water (slurry) column above the lowest slurry level in the inlet and out tanks as shown in Figure 1. This pressure is usually selected to be 0.85m water gauge as a safe limit for brick/concrete dome type of digester as the proposed design. Therefore, h + d = 0.85m, and h = 0.85 – 1.93= -1.08m (negative sign means the height is below the tank level).

3.7 Length (l) and breadth (b) of the inlet and outlet tanks.

A rectangular shape of the cross section of the inlet and outlet tanks is taken and usually. L= 1.5b is selected. The cross section areas are selected as identical hence: SD = 2 x l x b x h
where h = 1.08, SD = $8m^3$ 8 = 2 x $1.5b^2$ x 1.08, from which b = (8/2 x 1.5 x 1.08)1/2 = 1 .57m and l = 1.5 x 1.57 = 2.36m.

3.8 Material selection for the proposed fixed dome digester

The methods of estimation of basic raw materials like cement, sand, brick and steel was made for items like concreting, brickwork and plastering. Concreting is required at the digester bottom and at the base of inlet and outlets tanks. The foundations are taken as 0.1m thick. For the construction of the biodigester the quantity of material vary according to the type and size of the unit. Table 3 shows information on material estimate of various sizes of biogas digester obtained from Kenya National Domestic Biogas Programme [5]. From the information on data in the table, an estimate and cost of a 4.8m^3 digester was selected. In Table 4, an outline of the actual cost estimate for the biodigester is presented.

Table 3: Average actual biogas digester table of quotation (Source: [5])

Item	**Quantity per given sizes**					
	4m^3	**6m^3**	**8m^3**	**10m^3**	**12m^3**	**Cost/Unit**
Cement 50kg bags	14	17	20	24	27	700
Sand in ton	3	5	6	7	7	2000
Gravel in ton	1	2	3	4	4	1300
Machined cut stones 6x9	180	200	250	300	420	30
Fired bricks pieces	150	200	300	350	400	5
Round bars 3/8" (R8)	2	3	3	3	3	450
Round bars 1/4" (R6)	2	3	4	4	4	250
PVC pipe 4 inches	1	1	1	1	1	650
PVC elbow 4 inches 45^0	1	1	1	1	1	400
Nails 3 inches in Kgs	1	1	1	1	1	150
Nails 4 inches in Kgs	1	1	1	1	1	180
Binding wire in Kgs	1	2	2	2	2	120
Excavation	2000	4000	5000	5000	5000	-
Plywood	1	2	2	2	2	500
Water proof additive	3	5	5	7	10	200
1" Galvanized pipe	1	1	1	1	1	1200
Manual labour	3000	6000	6000	6000	8000	300
Plumbing	4000	4000	4000	4000	4000	
Technical fee (Ksh)	18,000	20,000	25,000	30,000	35,000	
Total Cost (Ksh)	**56,400**	**68,610**	**75,800**	**101,070**	**110,660**	

Table 4: Cost estimate of the proposed 4.8m^3 biodigester

Item	**Quantity of 4.8m^3 size**	**Cost /Unit**
Cement 50kg bags	5	700
Sand in ton	4	2000
Gravel in ton	1.5	1300
Machine cut stones 6x9	200	50
Fire bricks	180	10
Round bars 3/8" (R8)	3	500
Round bars 1/4 " (R 6)	3	300
PVC pipe 4 inches	1	650
PVC elbow inches 45^0	1	400
Nails 3 inches in Kgs	1	150
Nails 4 inches in Kgs	1	180
Binding wire in Kgs	2	120
Excavation	2,400	-
Plywood	2	500

Water proof additive	4	200
1" Galvanized pipe	1	1200
Manual labour	3,600	300
Plumbing	4,000	-
Technical fee (Ksh)	19,000	-
Total Cost (Ksh)	**59,470**	**-**

V. CONCLUSIONS

Based on the findings of this study, the following conclusion can be drawn:

- The biogas digester is simple but effective option to save cost on power.
- It was established that there was enough waste (100kg per day) for production of sufficient biogas of about 24m^3 per day to substitute the use of wood fuel and liquid petroleum gas.
- Any excess gas generated should be sold to the neighbourhood.
- Organic fertilizers can be made from the slurry generated after the biogas production process. This can also be sold to generate income for KTTI.

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