Design, Construction and Performance Analysis Of Biogas Digester for Sharda University India

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Abstract

Sharda University is developing and the demand for cooking gas is increasing, the university still relies on gas from the Indraprastha Gas limited to meet its cooking requirements. It spends much for buying cooking gas, while the use of fuels such as gasoline and diesels in our generators contributes to the increase in the greenhouse gases; the demand for biogas digester arises as a result of huge amount of food waste produced per day and its potential. It was recorded that biogas digesters that uses kitchen waste are 800 times efficient than conventional biogas systems, therefore a 4.8 m^3 capacity of biogas digester that would digest 86 kg of daily food waste to 25.8 $m^3$of biogas was successfully designed, constructed, tested and analysed to reduce overdependence on CNG for cooking in the three

Mandela hostel messes of the University. After testing the digester for 40 days, its performance was found low; this could be due to the leakages from the gas storage chamber resulting from the use of bricks instead of stones in its fabrication during construction process. High amount of carbohydrate waste (85 %) instead of vegetables could hinder the digester performance. The biogas produced is considered as an ideal gas, and the ideal gas equation was therefore used to find the volume of biogas produced. 7.5108 L was the maximum volume produced on 27th day at 35^oC. The maximum temperature recorded during the process was 42^oC.The amount of food waste produced and the corresponding gas consumption by each mess of the university are discussed.

Keyword: *Biogas digester, design, construction*

I. INTRODUCTION

By definition, biogas is a method of digestinganaerobically animal waste to produce methane gasused for heat orlight. The history of biogas was dated2, 000 to 3,000 years ago in ancient China. There aresome evidences showing biogas was used for heatingbath water in Assyria during the 10th century BC andin Persia during the 16th century AD. Today manydeveloping countries have begun to build anaerobicdigester units in order to meet new environmentalregulations or to provide small amounts of energy[1]. Many research scholars have studies the use of biogas as a source of energy. Ray et .al [2] studied the rich benefits of using biogas from kitchen waste for cooking purposes. Mittal et. al [3] looked into the principles and possible applications of biogas. According to Tata [4], Biomass alone currently meets 57% of the national energy demand of India. Indeed, statistics shows that in 1995, 63.3% of India's energy production was from its reserves of low-gradecoal, 18.6% from petroleum, while hydroelectricity, natural gas and nuclear accounted for 8.9%, 8.2%,and 1% respectively [5]. India's overall energy production in 1995 was approximately 8.8 quadrillion Btu (quads), while consumption was 10.5 quads. India's energy demand is increasing, and its inability to step up production to meet demand, has increased India's reliance on costly imports, the gap between consumption and production projected to widen into the next century, as demand for energy is projected to grow at an annual rate of 4.6%, one of the highest in the world [5]. In this regard, there is need to install anaerobic digester in the universities where more food waste is produced from the kitchen. Mandela hostel mess was established in 2010 primarily to cater for the student breakfast, dinner and launch, as a result of increasing demand for student accommodation. The mess has one vegetarian and two non-vegetarian parts making three messes altogether in the hostel. Investigation revealed that the vegetarian part produces the average of 50-100kg of food waste per day depending on the type and taste of the food, while non-vegetarian mess produces 80 Kg more. Biogas typically refers to a mixture of different gases produced by the breakdown of organic matter in the absence of oxygen. It can be produced from raw materials such as agricultural waste, manure, municipal waste, plantmaterial, sewage, green waste or food waste. It is a renewable energy source and in many cases exerts a very small carbon footprint. It can be produced by anaerobic digestion with anaerobic bacteria, which digest material inside a closed system, or fermentation of biodegradable material [6]. The fermentation process consists of two final steps in which 70% of the methane could be produced is metabolized from acetate and 30% from carbon dioxide reduction with hydrogen [7]. Methane is also a cleaner energy than traditional fossil fuels since it is compliant with policies of theClean Air and Energy Policy Act representing a fuel source that can reduce SO_X emissions (biomass contains low amounts of sulfur), reduce NO_X emissions (biomass contains less nitrogen than coal), and reduce methane (formed in degradation of unused biomass) released into the atmosphere [8]. Most of the biogas plant designs depend on theavailability of the biomass; other designs are based on the biogas requirement. This project focuses on the design based on the availability of food waste in Mandela Hostel of Sharda University India.

The growth of university population, coupled with the increased demand for accommodation necessitated the construction of the Mandela Hostel for international students. The amount of food waste produced per day and the need to reduce the cost of cooking, demand the installation of biogas digester for the conversion of food waste to cooking gas. To design, construct and test a fixed dome biogas digester based on the amount of daily food waste produced in Mandela Hostel, the following procedurehave been followed:

i. Obtaining the amount of daily food wasteproduced, number of student and daily gasconsumption of all the four hostels in theCampus.
ii. Design the biogas digester
iii. Construction of the digester
iv. Testing for leakages
v. Fabrication of metal dome
vi. Covering the digester
vii. Feeding the plant with 90 kg of kettle dung
viii. Daily feeding of the digester
ix. Adding 5l of 0.5M sodium hydroxide to thedigester
x. Keeping 200g of grass in 250 ml of water for two weeks
xi. Obtaining and keeping the slurry sample in a laboratory
xii. Measuring the pH of the slurry and the grassy water.
xiii. Gas pressure and temperature measurement
xiv. Calculation of number of moles.

II. MATERIALS AND METHODS

A. *Manometer*

It is a gas-pressure analogue type manometer bought from Chawri Bazar market, New Delhi. It is the lowest analogue gas-pressure measuring device available with maximum capacity of 10 Kg/cm^2. Thepressure was read after the gas flow becomes steady.

B. *Methods of Analysis*

To design, construct and test a fixed dome biogasdigester based on the amount of daily food waste produced in Mandela Hostel, the following procedurehave been followed:
Four messes have hitherto been operational in the Sharda University campus- Mandela, Jawahar, Indira and Sarojini, all produce a lot of food waste indifferent proportions as shown in table 1.

Table 1 Number of Students, Food Waste Produced and Fuel Consumed Per Hostel Per Day.

	Mandela	Jawahar	Indira	Sarojini
No. of student	817	750	508	295
Food waste (Kg)	190	205	50-500	95
Fuel consumption (M^3)	425	236	N/A	228

C. *Daily Gas Consumption*

A gas meter that measures the amount of gas (in cubic meter) used by all the three Mandela messes has long been installed in a strategic location of the hostel by Indraprastha gas Limited. The readings for 7 days were directly taken from gas meter at 11p.m daily- the time at which all the cooking activities stop and the gas stops flowing.

III. DESIGN OF BIOGAS DIGESTER

A. *Gas Production Rate*

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 86kg/day was found to be:
$G = W X 0.3 = 86 X 0.3 = 25.8m^3/day$.

B. *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. A typical slurry is shown in fig 2.The food waste from the Mandela hostel contains great amount of water, therefore 1:0.4 ratio food waste to water was used. Active slurry is therefore given by:

$$V_s = (1.4 \times W \times HRT)/1000, \quad HRT = 40 \text{ days}$$
$$= (1.4 \times 86 \times 40)/1000$$
$$= 4.816 \, m^3$$

Fig 1. Mandela Hostel Mess Gas Meter

C. Daily Feed

Amount of slurry to be fed into the digester per day, Daily feed = Vs/HRT

= 4.816/40

= $0.1204 m^3$ = 120 l

Fig. 2 Slurry

D. Calculation Of Height (H) And Diameter (D) Ofthe Digester

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

$Vs = (D^2H)/4$

$4 \times 4.8 = D^2H$, but D = 2H, [9].

Then H=1.15 m and D = 2(1.15) = 2.30 m

E. Dome Radius R

R = 0.725D (LGED, 2011)

= 0.725 x 2.3 = 1.67 M

IV. CONSTRUCTION OF DIGESTER

The success or failure of any biogas plant primarily depends upon the quality of construction work [10]. The biogas has successfully been constructed in four month time at a distance 5 m behind the Mandela Hostel; the following have been taken into consideration during the construction.

A. Selection of Construction Materials

A successful biogas plant should not leak, in order to avoid the leakage, qualitative construction material was used. According Rura [10], qualitative fixed dome biogas plant should be constructed with round stones, the dome with reinforced concrete, only inlet and outlet tanks should be built with bricks as shown in fig.3.

Fig 3 Laying Foundation of the Digester

The cement should also be high quality Portland cement which should not be laid on the ground or wall to avoid moisture absorption. The cement used for this project was high quality Portland cement obtained Lakshimi cement industry, Haryana. River sand with specific modulus of 2.6 and fines modulusof 2.42 was used for the construction. Standard redbricks of 230 mm x 110 mm x76 mm were also used.

B. Selection of Construction Site

The drawing of the Mandela hostel was studied to ensure safe construction site. The site of the construction was selected to reduce the cost of transporting both the food waste and water, and that of piping. Besides, increasing the risk of biogasleakage, the cost of piping from the digester to themess is also a factor. It was located 5m behind the hostel and some 7m away from the well. The site is an even surface and no tree or any plant whose root could disturb the digester. Being the digester closer to the 12 story building (Mandela Hostel) would reducethe temperature effect by over shadowing the digester, lower temperature produces discouraging result. The water logging from the mess is also closed to the digester this could lead to water leakages into to the digester.

C. Plant layout

The setting out of the plant house was carried out as per design and shown in fig 4.

Fig 4 Plant lay-out work

D. Excavation (Digging of pit)

After lay-out work, the excavation commenced, thedepth of the excavation was 1.35m, the pit bottomand thevertical walls were labeled.

E. Construction of Digester Main Chamber

The digester foundation was overlaid with gravel and embedded with concrete composites. The foundation was 15cm thick. At the center of the pit, a straight rod was positioned in an exact vertical direction. The vertical pipe was later used to ensure symmetry of the biogas plant; at ground level, a rigid pipe was placed horizontally across the diameter of the pit; the vertical pipe waschecked to ensure it was still in the vertical position;the outlet tank was constructed before the inletchamber. Water proof chemical with fiber mesh wasused for preparing the inside plaster.

F. Outlet Chamber (Tank) Construction

The manhole of 60 cm x 40 cm was first built and excavation was done just behind the manhole. The manhole shares a common foundation with thedigester vessel. It is worth noting that the dimension of the outlet tank was not exactly in compliance withthe designed dimensions, this could reduce the gas pressure. The depth of the excavation was designed to be inner depth of outlet plus the thickness of plaster plus the thickness of flooring from the ground level. The earth in the base of the outlet, behind the manhole, was well compacted to avoid cracks in the outlet floor later on. After the excavation was completed, the floor was compacted and broken bricks were placed on the floor as hard core and covered with mortar of 1:4 ratio. At least 2 cm for plastering (in each side) was allowed when dimensioning the tank. The first layer of mortar of1:3 ratio was laid and wall construction was started.
The outside of the tank was plastered to avoid leakage. Outside of the walls was supported with sufficient compacted earth and later on bricks and plaster.

G. Construction of Inlet Tank

A pipe of 200mm was installed at the inlet chamber to allow the passage of the slurry, manual grinding and mixing of the waste. This is more economical than installing a metal or automatic mixer. The ground of the inlet chamber was made slope, so the slurry moves into the position of the inlet pipe in the active volume easily, the position of inlet pipe in the floor was made such that a pole or rod could be entered through it without obstructions if any de-blocking is needed as shown in fig 5.

Fig. 5 Inlet Tank With Pipe Passage

The construction of the inlet tank was made on a well compacted, hard and labeled surface. Both inside and outside of the tank were plastered with cement mortar of the same ratio, and the bottom of the tank was made14cm above the overflow level in the outlet wall.

H. Testing of Leakages

Prior to the dome installation, the open digester was filled up with water to a certain level, and left for six days. The water level didn't decrease, no leakage from the wall of active volume was observed. After the water was evacuated, the digester was dried up and water proof chemical with fiber mess were used, some leakages of water from the mess water clogging into the digester were then noticed, to correct this water leakage a plaster was made from outside wall of the digester.

I. Dome Construction

When the construction works of round wall was completed, the spherical, dome-shaped gas holder with a pipe extension as gas outlet was fabricated as in fig 6. A metal hemisphere of 1.6m radius was made by manual arc welding process; it was placed on the digester thereby forming the dome, bricks were arranged on the metal dome, cemented and plastered.

Fig 6. Experimental Set-up

J. Gas Piping

The set-up for gas collection and reading taking was shown on fig 6. A thread length was first mounted on the extension pipe extruded from the metal dome before the installation of first T-joint, a 50 mm long, 12mm diameter metal pipe was mounted on the T-joint and ½ bushing was installed to grip the first valve and a thermometer was mounted on the left valve.

K. pH Measurement

No pressure was produced during the first 11 days; therefore a sample of the 11-day slurry was collected and kept in the laboratory and its pH was recorded after every 5 days as shown in fig 7. Its first pH value was 3.58 and subsequent results were recorded.

Biogas is treated as ideal gas because of the following;

1. It has an appropriate calorific value
2. It is easy to store, handle and transport
3. It is easy to be processed from waste
4. It has an appropriate ignition temperature
5. It burns smoothly and does not leave behind much residue; in fact it contains negligible non-volatile material.

Since it is ideal gas, it obeys the ideal gas equation of PV = nRT

From table 5a, gas Pressure and temperature on 25th day were measured to be 0.3 kg/cm2 and 39^oC (312K) respectively.

$0.3\ kg/cm^2 x10^4 = 3000\ kg/m^2$It has an appropriate calorific value

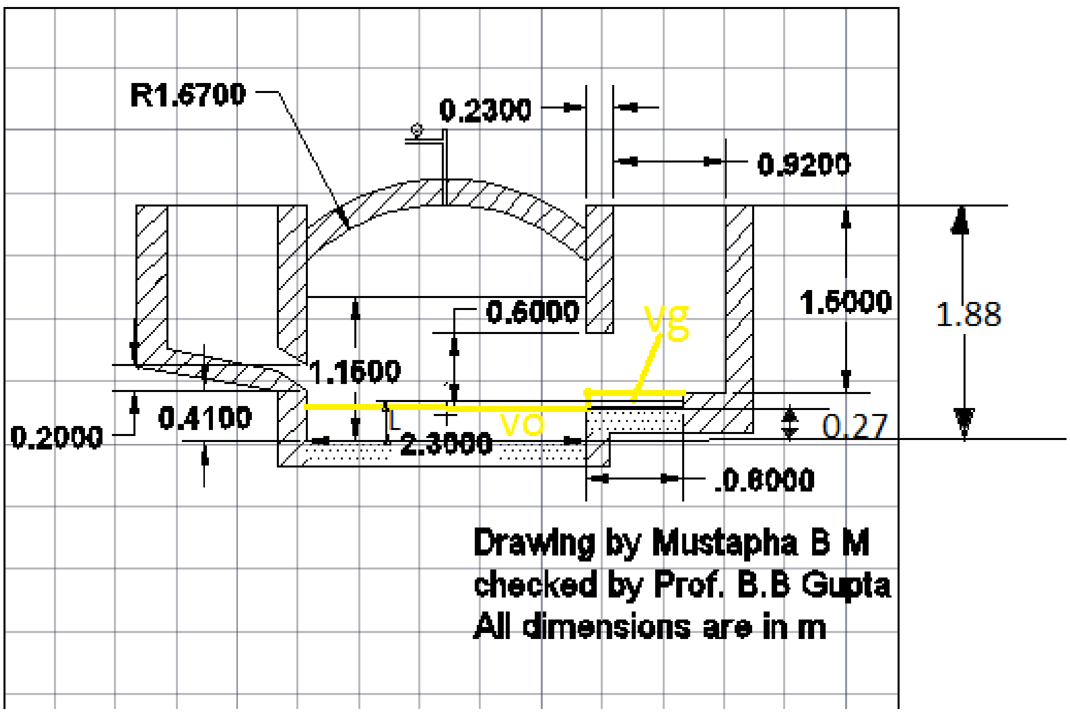

Fig. 8 Digester

From figure 8, $volume\ v_o,\ v_o = 0.27 \times \pi r^2 = 1.15^2 \times 3.142 \times 0.27 = 1.122\ m^3$

After 20 days, 2.408 M3volume would be filled, which is more than 1.1222 m^3

At 20th day, $2.4o8 = \pi r^2 L + 0.4\ \times 0.8(l - 0.27)$

Froth the above equation, L = 0.5572 M. this is above the heights of V_o and V_g combined (0.27 and 0.11 M respectively, = 0.38 M). Hence the new equation will be;

$V_n = \pi r^2 L_n + 0.4 \times 0.8 \times 0.11 + 0.4 \times 0.35 \times (L_n - 0.38)$

From which $L_n = \frac{V_n + 0.0864}{4.4764}$

$L_{20} = V_{20} + 0.0864)/4.4764$

Volume of the slurry at 20th day = daily feed X 20 = 0.1204 M^3 X 20 = 2.408 M^3

$L_{20} = (2.408 + 0.0864)/4.4764 = 0.5572$ M

The slurry would occupy $\pi r^2 L_{20}$ active volume = 4.156429 X 0.5572 = 2.3161 m^3

From section 3.2, the active slurry volume is 4.816 M^3. The gas storage volume at 20^{th} day is active slurry volume.

Slurry volume = 4.816 – 2.316 = 2.5 M^3

Hence, the performance of digester is tabulated in table 2 while gas meter reading in table 3

Table 2 Performance Result For The Digester From 25th September To 5th November 2015

Days	Volume of slurry at nth day (M^3)	L_n (M)	Active volume (M^3)	Gas Storage Volume (M^3)	Gas pressure (Kg/ M^2)	Gas Temp. (K)	No. of moles (moles)	Biogas vol. (L)
20	2.408	0.5572	2.3161	2.4999	0	311	0	0
21	2.5284	0.5841	2.4279	2.3881	0	311	0	0
22	2.6488	0.6110	2.5396	2.2763	2000	311	1.7606	3.9438
23	2.7692	0.6379	2.6514	2.1645	3000	310	2.5193	5.6433
24	2.8896	0.6648	2.7632	2.0527	3000	310	2.3892	5.3518
25	3.01	0.6917	2.8750	1.9409	3000	312	2.2446	5.0279
26	3.1304	0.7186	2.9868	1.8291	4000	311	2.8295	6.3381
27	3.2508	0.7455	3.0986	1.7173	5000	308	3.353	7.5108
28	3.3712	0.7724	3.2104	1.6055	5000	307	3.145	7.0448
29	3.4916	0.7993	3.3222	1.4937	4000	306	2.3484	5.2605
30	3.612	0.8262	3.4340	1.3819	4000	305	2.1798	4.8828
31	3.7324	0.8531	3.5458	1.2701	3000	309	1.4832	3.3223
32	3.8528	0.8799	3.6576	1.1583	3000	310	1.3483	3.0201
33	3.9732	0.9068	3.7694	1.0465	3000	310	1.2181	2.7286
34	4.0936	0.9337	3.8812	0.9347	2000	302	0.7446	1.6678
35	4.214	0.9606	3.9930	0.8229	2000	304	0.6512	1.4587
36	4.3344	0.9875	4.1048	0.7112	2000	306	0.5591	1.2523
37	4.4548	1.0144	4.2166	0.5994	2000	302	0.4774	1.0694
38	4.5752	1.0413	4.3283	0.4876	1000	302	0.1942	0.435
39	4.6956	1.0682	4.4401	0.3758	1000	303	0.1492	0.3342
40	4.816	1.0951	4.5519	0.2640	1000	304	0.1045	0.234

Table 3 Gas Meter Reading

Gas meter reading (m^3)						
Date	6/11/2015	7/11/2015	8/11/2015	9/11/2015	10/11/2015	11/11/2015
Mandela	0315296	0315781	0316272	0316780	0317205	0317511
Jawahar	5395200	5395593	5395869	5396153	5396389	5396569
sarojini	0303457	0303820	0304082	0304311	0304539	304735

Gas consumption by Mandela Hostel mess on 7_{th} November = 0315781- 0315296=485 m^3
Similarly, the average gas consumption per day for different hostels is stated in table 4 and fig. 9. The result shows that the average gas consumption per day is more in Mandela hostel than other hostels. This may be as a result of more number of students residing there contributing to increased quantity of food consumed.

Table 4. Gas Consumption/ day (m^3)

	Gas Consumption/ day (m^3)		
	Mandela	Jawahar	Sarojini
7/11/2015	485	393	363
8/11/2015	491	276	262
9/11/2015	508	284	229
10/11/2015	425	236	228
11/11/2015	306	180	196
Average	443	273.8	255.6

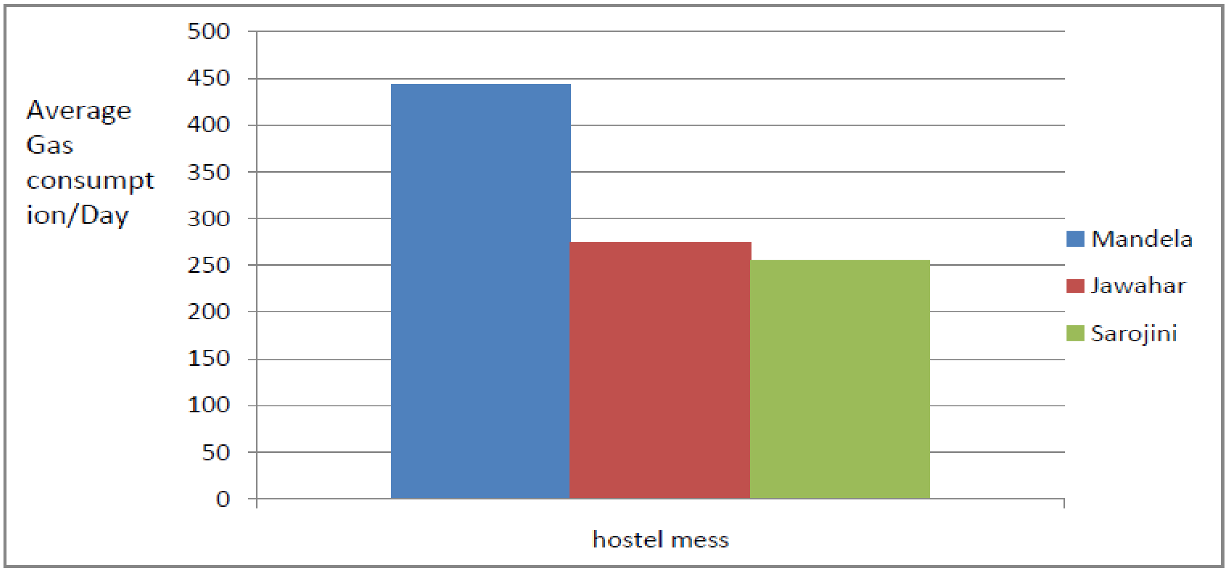

Fig 9 Average Gas Consumption/Day (M^3)

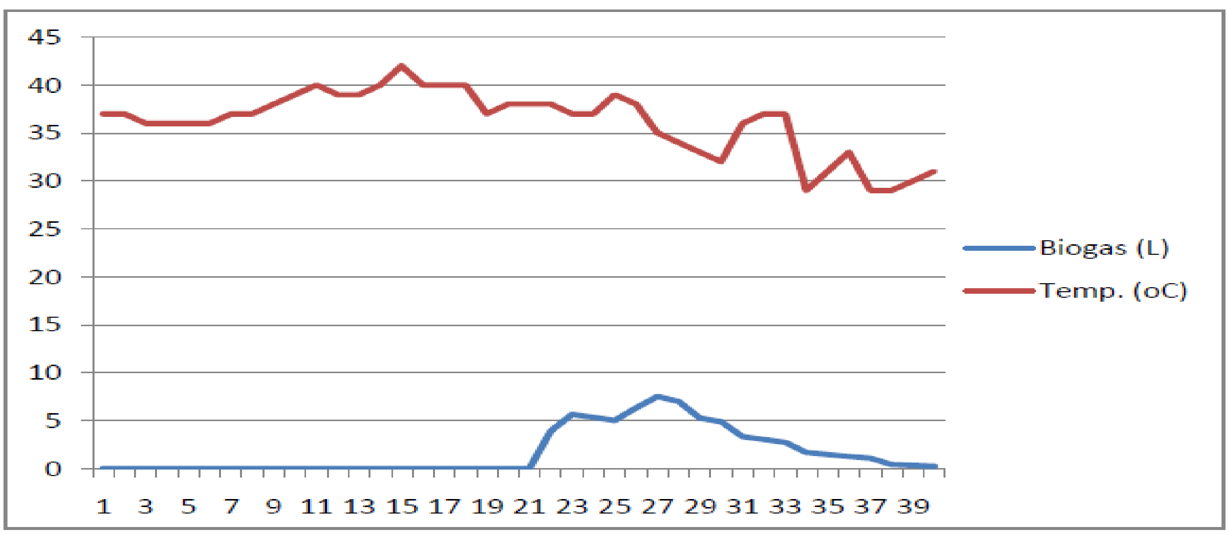

Fig 10 Temperature, Volume Vs Days

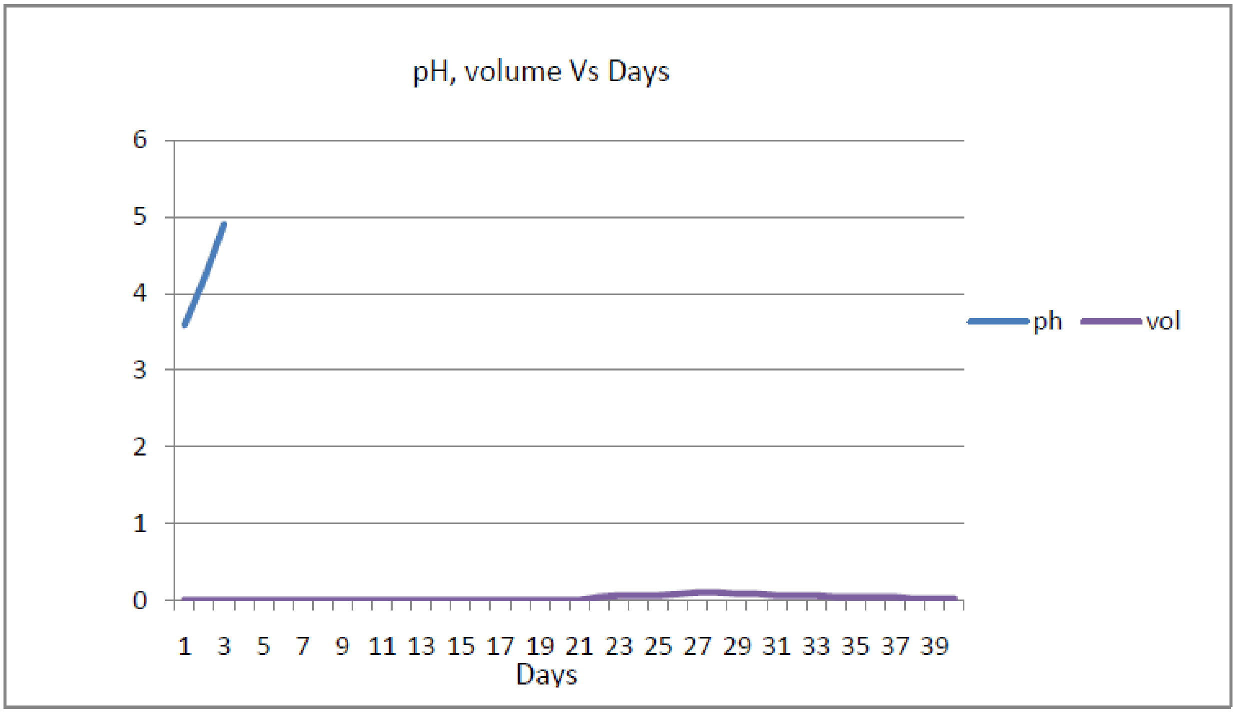

Fig 11 Graph Of Ph And Volume Vs. Days

A 4.8 m^3 capacity of biogas digester was successfully designed, constructed, tested and analysed for forty days to reduce over dependence on CNG for cooking in the three Mandela hostel messes of Sharda University. The leakages from the gas storage chamber and High amount of carbohydrate waste (85 %) present in the food waste could hinder its performance. The biogas produced is considered as an ideal gas, and the ideal gas equation was used to find the maximum volume of biogas produced as 7.5108 L on 27^{th}day. The amount of food waste produced and the corresponding gas consumption by each mess of the university have been shown on table 1. In comparison with An ARTI digester, the organization was able to convert 1 kg of food waste to 500 g of Methane in a day. With the limit of experimental error, the effects of temperature and pH on the biogas production are shown in figs. 10 and 11 respectively. As the pH approaches neutrality the biogas production begins and the manometer began detecting the gas pressure. The gas pressure was detected after 21 days and the maximum pressure of 0.5 $Kg/cm^2$was recorded on 27_{th} day, this was because of the activity of bacteria is largely favored by neutral state of the slurry; too acidic or basic slurry is harmful to the activity of anaerobic bacteria and drastically reduces the gas production.

V. CONCLUSION

The following conclusions can be drawn fromthis paper;

1. A 4.8 cubic meter capacity digester was designed, constructed and tested at the Sharda University Campus, Greater Noida India. Performance analysis of the digester revealed that gas is being produced as the pH of the slurry approaches neutral condition.
2. The maximum pressure and temperature of the gas recorded during the project were 0.3 $kg/cm^2$and 43 ^{0}C respectively.
3. The daily food waste produced by Mandela, Jawahar, Indira and Sarojini messes were found to be 190 kg, 205 kg, 200 kg and 95 Kg respectively. Their average gas consumption per day as read from the gas meter were 443m^3, 273.8m_3 and 255.6 m_3 for Mandela, Jawahar and Sarojini messes respectively.

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