Biogas Processing by Anaerobic Digestion of Organic Solid Waste

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Abstract

The demand for fossil fuel increases the development of renewable energy, but due to high prices, people are shifting their attention from non-renewable sources to renewable sources to fulfill their energy demands. This research is based on the conversion of biomass into biogas to fulfill the energy demand most cheaply and effectively. Organic solid waste (OSW) had analyzed when the balloon was burst, it was due to the acidification of acids present in the OSW and resulting in the production of a large amount of carbon dioxide. Other experiments show the production of carbon dioxide by the expansion of the balloon, due to the first stage of the process that is hydrolysis. Later anomalous behavior has been observed, as balloons were sucked into the bottles. Hence creating an anaerobic condition in the bottle, during this stage batches were sometimes kept in the sun to raise the temperature of the culture.

Key Words: Aerobic, anaerobic, biogas, methane, organic waste

1. Introduction

The world's fossil fuel demand increases, their prices rise, and interest has rightly initiated the development of renewable energy resources. Throughout the world, awareness has been created on the disadvantage of relying on fossil fuel. Because of the rise in the recent prices of oil-based fuels and their harmful impact on the environment, due to these causes, people are shifting their attention from non-renewable sources to renewable sources to achieve their energy demands. Renewable sources of energy offer tremendous potential energy development and preservation option for the future. Bioenergy is the carbon-based organic material of plants and animals. Biomass consists of stored solar energy and can be transformed into biofuel by physical, chemical, and biological processes [1, 2]. The fermentation of organic material involved in the conversion of biomass into biogas is known as anaerobic digestion or anaerobic fermentation. Biogas is produced in digester by anaerobic fermentation with a retention period of 15 days or more, which is too short for the conversion of methane to other gases [3, 4].

An Italian scientist Alessandro Volta first discovered biogas; he observed that the formation of the gas depends on a fermentation process and that the gas may form an explosive mixture with air. In recent years a scientist, named William Hennery confirmed that this gas is similar to methane gas. More scientific research had started in France whose objective is to decrease or suppress the bad odor caused by the wastewater pools, during their research they investigated several microorganisms which are known to be essential in fermentation processes, amongst them is 'Methanogens'. Herter reported that the acetate found in wastewater pools stoichiometric produce the same amount of methane and carbon dioxide [5, 6]. First attempt to use biogas as energy made by Exeter, England. They obtained biogas from the anaerobic digestion treatment of wastewater while the latter was used to light the street lamps. In Germany, for the first time, biogas was sold to the public in 1923. In 1945 only the Germans started to use agricultural products to produce biogas on a large scale [1, 5]. Table 1 shows some typical values of methane content from different organic waste [7, 8].

Table 1: Typical composition of biogas

Sr. No.	Organic waste	Percentage of CH_4
1	Cattle manure	65%
2	Poultry manure	60%
3	Pig manure	67%
4	Farmyard manure	55%
5	Grass	70%
6	Leaves	58%
7	Kitchen waste	50%
8	Algae	63%
9	Water hyacinths	52%

Table 2: Properties of biogas

Characteristics	Unit	Characteristics of Constituents of Gases				Biogas (60% CH_4 & 40% CO_2)
		CH_4	CO_2	H_2	H_2S	
Volume share	%	55-70	27-44	1	3	100
Calorific value	MJ/m^3	35.80	-	10.8	22.8	21.50
Limit of inflammability in air	Vol.%	5.15	-	4.80	4.45	6.12
Ignition temperature	°C	650.75	-	585	585	650.750
Density (°C,760 mm Hg)	g/cm^3	0.74	1.98	0.98	0.98	1.20
Specific gravity	-	0.55	1.5	0.07	0.07	0.83

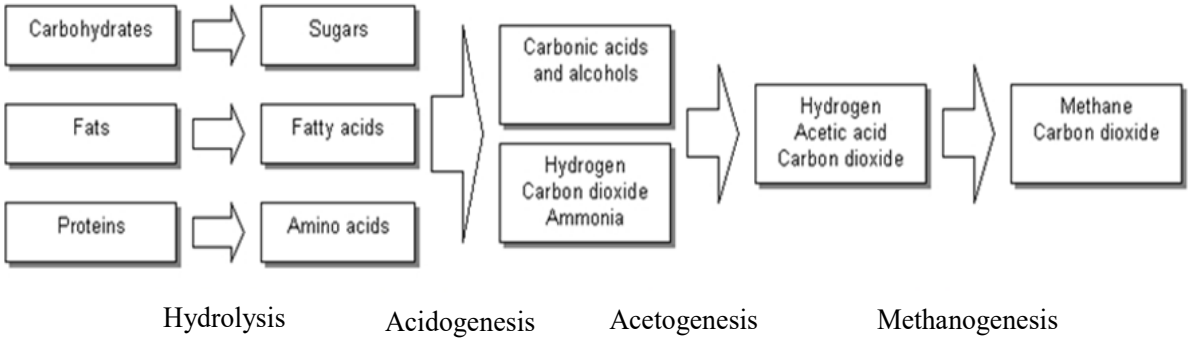

Fig. 1: Key process stages of anaerobic digestion

Production of biogas is a complex process; it involves the decomposition of biomass in the absence of oxygen (anaerobic fermentation). The main products of anaerobic digestion are biogas and digestate. Biogas is a combustible gas whereas digestate can be used as a fertilizer. Table 2 represents the properties of biogas [7, 9]. Production of biogas consists mainly of four stages hydrolysis, acidogenic phase, acetogenic phase, and methanogenic phase [10]. Hydrolysis is the initial phase of biogas production; it involves converting complex polymers (carbohydrates, fats, and proteins) into simpler and soluble monomers (glucose, glycerol, and amino acids).

Table 3: Micro-organism involved in anaerobic digestion

Stage	Bacteria
Stage I	
$n(C_6H_{10}O_5) + nH_2O = n(C_6H_{12}O_6)$	
Stage II	
$C_6H_{12}O_6 + 2H_2O = 2CH_3COOH + 4H_2 + CO_2$	Bacteroides, clostridium
$C_6H_{12}O_6 + 2H_2 = 2CH_3CH_2COOH + 2H_2O$	Butyrivibrie, eubacterium
$C_6H_{12}O_6 = CH_3CH_2CH_2COOH + 2CO_2 + 2H_2$	Bifidobacterium, tactobacillus
$C_6H_{12}O_6 = 2CH_3CHOHCOOH$	
$C_6H_{12}O_6 = 2CH_3CH_2OH + 2CO_2$	
Stage III	
$CH_3CHOHCOOH + H_2O = CH_3COOH + CO_2 + 2H_2$	Desulfovibrio, syntrophobactor
$CH_3CH_2OH + H_2O = CH_3COOH + 2H_2$	Wolinii, syntrophomonas
$CH_3CH_2CH_2COOH + 2H_2O = 2CH_3COOH + 2H_2$	
$CH_3CH_2COOH + 2H_2O = CH_3COOH + CO_2 + 3H_2$	
Stage IV	
$4H_2 + CO_2 = CH_4 + 2H_2O$	Methanobacterium formicicum
$2CH_3CH_2OH + CO_2 = 2CH_3COOH + CH_4$	Methanobacterium bryantii, Methanobrevibacter
$2CH_3(CH_2)_2COOOH + 2H_2O + CO_2 = 4CH_3COOH + CH_4$	Ruminantium, Methanobrevibacter arboriphilus
$CH_3COOH = CH_4 + CO_2$	Methanospirilum hungatei, Methanosarcina barkeri

The Acidogenesis phase is the continuation of the hydrolysis process in which simple sugars, amino acids, and fatty acids were converted into acetate, carbon dioxide, hydrogen, volatile fatty acids (VFA), and alcohol. Acetogenesis phase, products produced from the previous phase was utilized in this phase. The Methanogenesis phase is the most important in the production of methane; in this stage methanogenic bacteria convert acetic acid, carbon dioxide, and hydrogen into methane as shown in Table 3 [11]. The temperature has a significant effect on biogas yield. The optimum temperature of biogas may vary depending on the composition of feedstock's and type of digester, but in most anaerobic digestion processes it should be maintained constant to sustain the gas production rate.

The carbon/nitrogen ratio plays a vital role in the high production of biogas. For optimal growth and activity of bacteria, nutrients must be available in the correct chemical form and concentration. Nitrogen is a building element for cell structure, while nitrogen supplies energy. The substrate with low carbon to nitrogen ratio supports the formation of ammonia and inhibits methane formation. The C/N ratio varies according to feed composition. C/N ratio in the ratio 15:1 to 25:1 was found optimum in the case of cattle dung. A too high C/N ratio means a lack of nitrogen, from which negative consequences for protein formation and thus the energy and structural material metabolism of the microorganisms result [12].

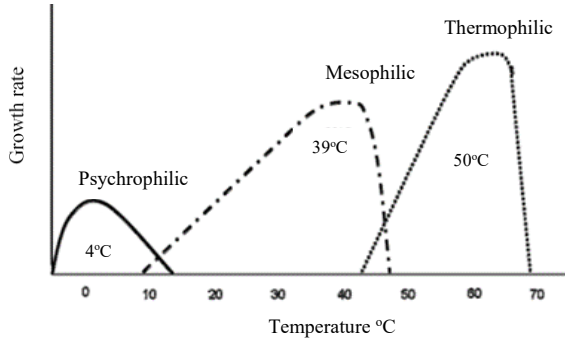

Fig. 2: Curves of different types of fermentation

Figure 2 shows the curves of different types of fermentation. The more varied composition in the digester the more chances are that new microorganisms will grow as more components are available for growth, but this variation should be too high that it inhibits the growth or cause the rate of death to increase [13, 14]. In a typical biogas plant factors like the toxicity of gases, explosive limits, and ranges, biological hazards must be taken into account before carrying out the process [15, 16].

1.2 Methane Fermentation Kinetics

A model was developed for a continuous stirred tank reactor without solid re-circulation. Material balance equations were developed for micro-organisms and digestible substrate [17, 18]. The rate of accumulation of material= rate of material inflow positive rate of appearance or disappearance of the material positive rate of material outflow.

$$\frac{\mathrm{D[X]}}{dtV} = \mathrm{F[Xo]} + \mathrm{rV} - \mathrm{F[X]} \quad (1)$$

V = Volume of the slurry in m^3, F= flow rate of micro-organisms (m^3/s), r= net rate of cell growth ($kg/m^3.s$), X_o= influent concentration of micro-organisms (kg/m^3) and X =effluent concentration of micro-organisms (kg/m^3). Since the concentration of micro-organisms in influent is negligible ($X_o << X$), hence neglecting X_o.

$$\frac{\mathrm{d[X]}}{dtV} = \mathrm{rV} - \mathrm{F[X]} \quad (2)$$

If hydraulic retention (HRT) was defined by θ_h (days).

$$\theta_h = VF \quad (3)$$

Substituting Eq. (3) into (2) hence,

$$\frac{d[X]}{dt}V = rV - \frac{V}{\theta_h}[X] \quad (4)$$

The net rate of the generation of micro-organisms is given by.

$$r = \mu X \quad (5)$$

After substituting Eq. (5) into (4) and dividing by 'V' gives.

$$\frac{d[X]}{dt} = \mu X - \frac{X}{\theta_h} \quad (6)$$

Neglecting dilution rate and death rate of cells. The rate of accumulation of substrate = Rate of substrate inflow – the rate of substrate outflow – the rate of consumption of substrate.

$$\frac{d[S]}{dtV} = FS_o - RV - FS \quad (7)$$

where; S_o= Influent Substrate (volatile solids) concentration (kg/m^3), S=effluent substrate (volatile solids) concentration (kg/m^3), R= rate of substrate utilization ($kg/m^3/day$). Dividing equation by V (volume of slurry in m^3) and using Eq. (3) gives.

$$\frac{d[S]}{dtV} = \frac{S_o - S}{\theta_h} - R \quad (8)$$

The growth rate of micro-organisms is the dependent amount of substrate utilization hence substrate utilization can be written using growth yield constant ($Y_{X/S}$) for micro-organisms.

$$Y_{X/S} = \frac{mass\ of\ cells}{mass\ of\ substrate} \quad (9)$$

$$\frac{d[S]}{dt} = \frac{d[S]}{dX} \times \frac{dX}{dt} \quad (10)$$

$$\frac{dS}{dt} = \frac{1}{Y_{X/s}}, \frac{d[S]}{dX} \times \frac{dX}{dt} = \mu X \quad (11)$$

Substituting in the Eq. (11) gives.

$$-\frac{d[S]}{dt} = \frac{\mu}{Y_{X/s}} \quad (12)$$

Integrating equation (12).

$$-Y \int_{S_o}^{S} dS = \int_{X_o}^{X} dX \quad (13)$$

Gives.

$$Y(S_o - S) = X - X_o$$

Since the concentration of micro-organisms in influent is negligible ($Xo<<X$), hence

$$X = Y(S_o - S) \quad (14)$$

Since the operation is taking place at steady-state conditions hence the Eq. (6) and (8) yield the following equations.

$$\mu = \frac{1}{\theta_h}, (\frac{dX}{dt} = 0) \quad (15)$$

If $\mu \rightarrow \mu_m$ as $\theta_h \rightarrow \theta_{hm}$

$$R = (S_o - S)/\theta_h (\frac{dS}{dt} = 0) \quad (16)$$

To develop the volumetric methane production Contois equation is used as a model equation for cell growth [19].

$$\mu = \frac{\mu_m S}{BX + S} \quad (17)$$

μ_m = maximum specific growth rate of micro-organisms (day-1), B= Coefficient of the Contois equation. Substituting Eq. (14) into (17) forming.

$$\frac{\mu}{\mu_m} = \frac{S}{BY(S_o - S) + S} \quad (18)$$

Taking $BY=K$, where K is a dimensionless kinetic parameter. Hence forming,

$$\frac{\mu}{\mu_m} = \frac{S}{K(S_o - S) + S} \quad (19)$$

Re-arranging Eq. (19),

$$\frac{\mu}{\mu_m} = \frac{S/S_o}{K + (1-K)(S/S_o)} \quad (20)$$

Taking the inverse of Eq. (20),

$$\frac{\mu_m}{\mu} = K + \frac{(1-K)S/S_o}{S/S_o}$$

$$\frac{1}{\mu} = \frac{1}{\mu_m} + \frac{K(S_o - S)}{\mu_m S} \quad (21)$$

Using Eq. (15) and (21) the following Eq. (22) is formed.

$$\theta_h = \theta_{hm} + K\theta_{hm}(\frac{S_o}{S} - 1) \quad (22)$$

where θ_{hm} is the minimum hydraulic retention time. Re-arranging the above equation yields.

$$\frac{S_o}{S} = \frac{K}{(\theta_h/\theta_{hm}) - 1 + K} \quad (23)$$

From the above equation, it can be seen that effluent substrate concentration is dependent on influent substrate concentration. If $B=m^3$ of methane at STP produced per kg of chemical oxygen demand [COD], $B_o=m^3$ of methane at STP produced per kg of chemical oxygen demand [COD] as $\theta_h \rightarrow \infty$ (Ultimate methane Yield). Since it is difficult to measure the amount of COD consumed as compared to the amount of methane produce so S/S_o is replaced be $\frac{B_o - B}{B_o}$

$$\frac{B_o - B}{B_o} = \frac{K}{(\theta_h/\theta_{hm}) - 1 + K} \quad (24)$$

Re-arranging the above equation yields.

$$B = B_o(1 - \frac{K}{(\theta_h/\theta_{hm}) - 1 + K}) \quad (25)$$

The (COD/VS) is generally constant for a given residue and VS are readily determined than COD for the concentrated complex substrate, it more convenient to use quantities expressed regarding VS. Hence B can be expressed as m^3 of CH_4 at STP/kg of VS added and B_o as m^3 of CH_4 at STP of VS added as $\theta \rightarrow \infty$ and these can be substituted in the values of B and B_o. Now to calculate volumetric methane production V_{CH4}.

$$V_{CH_4} = \frac{BS_o}{\theta}\left(1 - \frac{K}{\frac{(\theta_h}{\theta}_{hm}) - 1 + K}\right) \quad (26)$$

$$V_{CH_4} = \frac{BS_o}{\theta}(1 - \frac{K}{(\mu_m \times HRT) - 1 + K}) \quad (27)$$

V_{CH4}= methane production [m^3 of CH_4/m^3 of digester volume/day], S_o= influent volatile solids concentration, kg/m^3. K values are inhibitory, Hashimoto relates the K values to S_o.

For cattle manure;

$$K = 0.8 + 0.001e^{0.6S_o} \quad (28)$$

K is relatively insensitive to temperature but increases as influent concentration increases above, 80kg VS/m^3. K values indicate overloading with S_o, heavy metals, salts will inhibit the reaction.

$$\mu_m = 0.013(T) - 0.129 \quad (29)$$

where, μ_m = Maximum specific growth of micro-organisms, T= Temperature in ºC (20<T<60).

Moreover, biogas consists of traces of ammonia and its derivatives and hydrogen sulfide. Therefore the construction material of the biodigester should be resistant to these chemicals and should maintain this resistance over a long period of time. A large scale biodigester should have a pressure relief valve in case of a fixed dome type reactor to prevent explosion and leakage hazards. In a typical biogas plant factors like the toxicity of gases, explosive limits, and ranges, biological hazards must be taken into account before carrying out the process [15, 16]. The level of the digester is filled 75% with the slurry; this biowaste potential is enough to produce a sufficient amount of biogas to lift the dome to its maximum height. A dome lock must be installed in the digester to prevent it from jumping outside due to overpressure and a safety valve to cut the pressure. Mechanical sealing in the agitator shaft and proper lubrication in the bearings is mandatory to avoid the inside material to escape into the atmosphere while providing smooth rotations with less wear and tear. Sometimes, the digester needs to be shifted from one place to another, while transporting it via men or vehicles there are chances for it to be tipped causing damage to the material. Therefore the *L/D* ratio must be according to the standards set by OHSAS 18000 [16, 20].

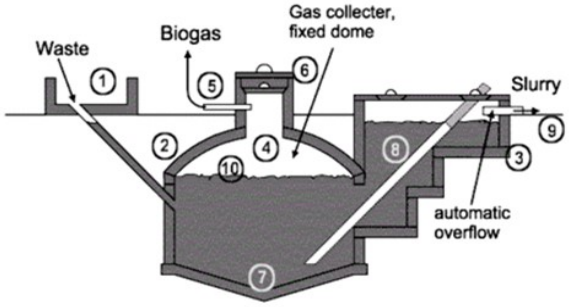

Fig. 3: A typically fixed dome digester

By feedstock input and output operation, biogas digester is divided into two types; batch type digester and continuous type digester. The batch plant was wholly filled with a portion of feedstock, which was emptied after a fixed time. Commonly batch type digesters are employed for dry digestion. In continuous type, plant feedstock is continuously fed normally daily. Unlike batch-type digesters, continuous digesters produce biogas without interruption for loading new feedstock and unloading the digested effluent. Biogas production is constant and predictable. Three types of continuous digester tank systems are horizontal, vertical, and multiple. By the gas collection system, biogas digester can be distinguished as fixed dome digester, floating dome digester, and balloon digester. Figure 3 shows the fixed dome digester, which consists of a fixed and non-moveable dome at the top of the digester. This type of reactor has mainly two parts, the reaction chamber, and the compensation tank. When the gas was produced inside the digester, the difference between the height of the slurry level in the reaction chamber and the compensation tank begins to increase; this is due to the pressure exerted by the produced gas in the constant volume area at the slurry surface [21, 22].

Floating dome digester consists of a torospherical or spherical or cylindrical dome-shaped top used for the collection as well as transport of gas from the inside of the vessel to the short distant appliance as shown in Figure 4. When the pressure is built up inside the reactor, the dome begins to move upwards to keep the pressure constant and comes down by the time gas is consumed.

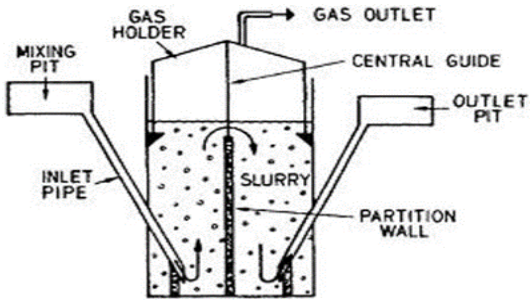

Fig. 4: A typical Floating Dome Digester

Figure 5 represents balloon-type digesters, are used in the areas where there are high digester temperatures in warm climates and high groundwater table this type of digester is preferred whose reaction chamber and gas holder both are accumulated in a bag made up of materials like RMP (Red Mud Plastic), PVC, trevira and butyl [22].

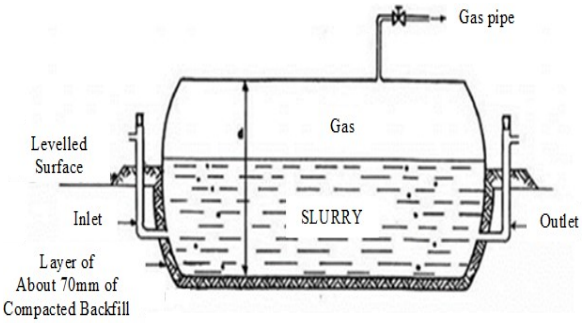

Fig. 5: Balloon type digester

The production of biogas via anaerobic digestion depends upon many factors like pH, temperature, and HRT. Anaerobic digestion is a

slow process that consumes a large amount of Hydraulic Retention Time (HRT) of 30-50 days in conventional biogas plants. Some experiments were performed with different feed/water ratios, digester sizes and different collection methods of gas produced [22].

2. Materials and Methods

The first experiment was performed with various wastes which include kitchen waste, fruit waste, and cow dung. The main aim of this experiment was to check whether the raw materials using produce the gas or not and to get an estimate of the retention time or study period. This experiment was performed in plastic bottles of cold drinks of size 2.25 L and 1.5 L. To make this process anaerobic and to collect the gas the opening of the bottle was close with balloons. After collecting several types of waste from our houses, waste was classified according to vegetable and fruit wastes. Batches were prepared with waste and water added in the ratio 1.1, this was because fruit and vegetable waste already has a tremendous amount of water content.

Batches were prepared with waste and water added in the ratio 1.1, this was because fruit and vegetable waste already has a large amount of water content. The batches were prepared to contain orange peelings, peas waste, peanut waste, banana peelings, and apple remaining's. Another batch was also prepared to contain onion waste (OSW), garlic waste, and cow dung. All these batches were left for fifteen days. After two days when the bottle containing cow dung, OSW was analyzed the balloon was burst. It was due to the acidification of acids present in the OSW and resulting in the production of a large amount of carbon dioxide, hence causing the balloon to blow. When other bottles were analyzed balloon did show the production of carbon dioxide by the expansion of the balloon, the production of carbon dioxide was due to the first stage of the process that is hydrolysis.

Later anomalous behavior was observed, as balloons were sucked into the bottles. These phenomena can be explained by the second and third stages of the process as acidic micro-organisms are utilizing the air containing oxygen. Hence creating a partial vacuum (anaerobic condition) in the bottle, during this stage batches were sometimes kept in the sun to raise the temperature of the culture, but this had an adverse effect on reducing the elasticity of the balloon and hence tearing the balloon destroying the anaerobic environment. A bottle containing peanut waste did not show any of the results as its waste contain a large amount of lignin which is difficult to decompose.

After the failure in the first experiment but having confirmation of the gas being produced, we decided to make a batch in a water dispenser can. Reasons for selecting the dispenser can are; the can is dome shape at the top that is good for a collection of gas and it is in accordance with the design available of bio-digesters, strong and anaerobic conditions can be easily created and maintained, 19 L can be used for this experiment. The materials used in construction include 19 L water dispenser can, one 0.75" ball valve, two 0.75" elbow (90^{o}), 35 psi pressure gauge, 0.75" PVC pipe, and polymeric solution. This experiment was performed to check the flammability of the gas produced, so the raw material that was selected was only cow dung. Dispenser inlet was used as a feed inlet, through which the slurry of cow dung was entered that was prepared in the ratio of 1.2 (cow dung. water). In this experiment, only half of the can was filled so that there is enough air in the can for the decomposition of feed. Piping was done along with the bends to condense water vapors to prevent water vapors in the gas. The batch was left for 20 days. The temperature of the surrounding varies between 10˚C to 25˚C.

After lag days of 20 days when gas was analyzed by producing a flame in front of the exit valve but unfortunately the gas was not burned and the water droplet was flown at the bottom. Reasons for failure consist of; the temperature was not optimum for the production of biogas, cow dung/water ratio was not optimum and there were sufficient chances for the leakage of gas from the vessel.

The method applies to the determination of total solids fixed and volatile fractions in such solids and semi-solids samples as soil, sediments, biosolids (municipal sewage sludge, cow dung), sludge separated from water and wastewater treatment processes, and sludge cakes from vacuum filtration, centrifugation or other sludge dewatering processes. Use glass or plastic bottles to collect a sample for solid analysis, provided that the material in suspension solid does not adhere to container walls. Begin analysis as soon as possible after collection because of the impractically of preserving the sample. Preferably do not hold the sample for more than 24 hours because microbiological decomposition starts. Bring a sample to room temperature before analysis.

Fluid/slurry samples, if the samples contain enough moisture to flow readily, stir to homogenize, place 5-6 gm sample aliquot on a

prepared evaporating dish. Weighed the sample along with the dish and covered the sample so that no evaporation took place. Dishes containing samples were heated at 103ºC to 105ºC for 1 hour in an oven. After that cool the sample and weight it. Repeat the procedure with all the 3 dishes and weighed. The mass of total solids is present in the sample. Subtract that mass with the mass of the initial sample to get the moisture content of the sample [23].

$$\%\, total\ solid\ = \frac{W(total)-W(dish)}{W(sample)-W(diash)} \times 100 \quad (30)$$

where, *W* (total) = weight of dried residue and dish (mg), *W* (sample) = weight of wet sample and dish (mg), *W* (dish) = weight of dish (mg), *W(total)* = 25.45 gm, *W(dish)* = 24 gm, *W(sample)*= 29.07 gm. Using Eq. (1), % total solids = 28.6%.

Now the moisture removed sample is then to be treated further for the evaluation of fixed solids and volatile solids. For the evaluation of volatile solid clean the evaporating dish and ignite in the muffle furnace for 1 hour at the temperature of 550ºC. After 1 hour bring out the sample and weighed it. To evaluate the volatile component of the sample subtract the mass of the sample before furnace to the mass of residue. Mass of the sample (residue) is the fixed solids of the sample [20].

$$\%\, fixed\ solids\ = \frac{W(volatile)-W(dish)}{W(total)-W(dish)} \times 100 \quad (31)$$

$$\%\, volatile\ solids\ = \frac{W(total)-W(volatile)}{W(total)-W(dish)} \times 100 \quad (32)$$

where, *W* (volatile) = weight of residue and dish after ignition (mg)= 16.34 gm, *W* total = 17.75 gm, *W* dish = 16.30 gm. The % fixed solids is 2.75 % and volatile solids = 97.24%.

3. Results & Discussion

Fresh cow dung was used in combination with soaked paper waste and sludge water for slurry formation. Table 4 shows the amount of constituents used.

Table 4: Mass of feed used in the digester

Sr. No.	Feed	Mass/Volume
1	Cow Dung	7 kg
2	Paper Waste	0.3 kg
3	Sludge Water	8 liters

The properties of the mixed feed were shown in Table 5. The water dispenser can was used as a batch digester, for feedstock inlet and outlet operation PVC pipes ease used. The Inlet pipe should not touch the bottom of the digester. The drainage of feedstock was done by the ball valve at the bottom of the digester. Rubber pipe was used for a gas outlet. Table 6 represents the reactor specification.

Table 5: Properties of mixture

Properties	Requirement
Mixing ratio	1.1
Specific gravity	1.1
Density of mixture	1100 Kg/m^3
Retention period	26-30 days
Ambient temperature	28 - 35ºC

Table 6: Reactor specification

Equipment	Specification
Total digester capacity	20 liters (approx.)
Digester height	40 cm
Slurry height	13 cm
Inlet pipe diameter	¾”
Outlet pipe diameter	¾”
Nozzle	¼”
Valve	¾"
Elbow	90º
Gas outlet valve	¼”

After 10 days of lag phase, gas production starts. Initially, gas was collected through water displacement method, but due to lack of apparatus and improper arrangement of the system, gas was also lost correct measurement was difficult as there was not sufficient pressure build-up of gas to displace water. The water displacement method was replaced by a tire tube. At the end of the 24th day, the tube was filled with gas.

Table 7: pH data of constituents and slurries at different times

Constituents	pH
Fresh cow dung	6.4
Paper waste	5.7
Sludge water	5.1
Slurry	5.8
7th day	6.4
14th day	6.9
18th day	6.2
21st day	7.1
Digested slurry	6.9

To check the flammability test, first separated the tube from the digester and showed a lighted match at the tube outlet pipe. Initially, the gas burned with bluish yellow flame but after 4-5 seconds the flame vanished. The gas might contain a high amount of carbon dioxide and the mixing of biogas with air was not achieved to carry out an efficient flammability test.

The pH of cow dung, paper waste, sludge water, and the mixed slurry was determined using a digital pH meter, then after a mentioned interval of time mentioned in Table 7 sample of the slurry was taken out from the digester, and pH was determined. Figure 6 represents the pH comparison between paper waste, cow dung, and sludge water.

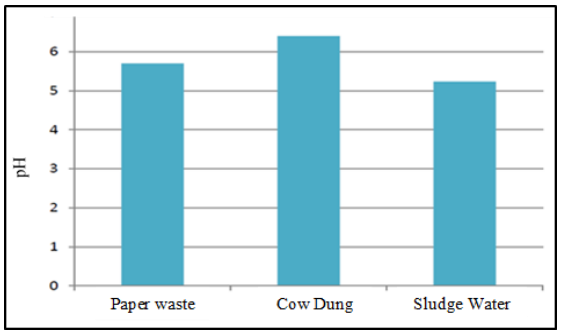

Fig. 6: pH comparison chart

3.1 Reactor Design

Figures 7, 8, and 9 represent the orthographic of the biogas digester reactor. A biogas digester is a chemical reactor that was connected to the inflow and outflow channel. Biogas yield is not depending only on the biodegradability of material or microorganism growth but also on the dispersion of solid within the digester. For scaling of biogas considered the parameter that is; specific gas production per day, retention time, and amount of fermented slurry. Digester volume is a sum of active volume (*Vs*) and gas storage space. *Vs* represent the slurry volume in the digester [17, 24].

Volume of slurry = Vs (m^3) = Retention time (days) x Amount of fermented slurry (m^3/day) (33)

Slurry volume is depending upon the dilution ratio. Normally for a mixture of cow dung and water dilution ratio is 1.1 considered. For operational ease biogas digester fed on a semi-continuous basis. The mixing of slurry increased the yield of biogas [25].

Power number (N_p) of an agitator from the above agitator generic curve are evaluated, the value of power number is approx. 5.1 Now substitute all the respective value in the equation (6) to evaluate the required power for the agitator. The basic calculation for the power of agitation based on the size of the vessel, the diameter of the agitator, rotation of the agitator, the density of the slurry, and the dynamic viscosity of the slurry. The formula for the calculation of the power of agitator can be given as [21].

$$Power\ (P) = N_p.\rho.N^3.D^5 \quad (34)$$

where; N_p = Power number of agitator, ρ = Density of slurry (1100 kg/m^3), N = Rotation per min of agitator (5 rpm) and D = Diameter of agitator (0.7366 m). The power number (N_p) of the agitator can be calculated using the generic agitator curve through the value of the Reynolds number. The calculation of the Reynolds number was based on the $Re = D^2N\rho/\mu$. (where μ is the viscosity of the slurry). Calculation for Reynolds number is [17, 21, 23].

$$Reynolds\ No.\ (Re) = (D^2N\rho)/\mu = 62376.25 \quad (35)$$

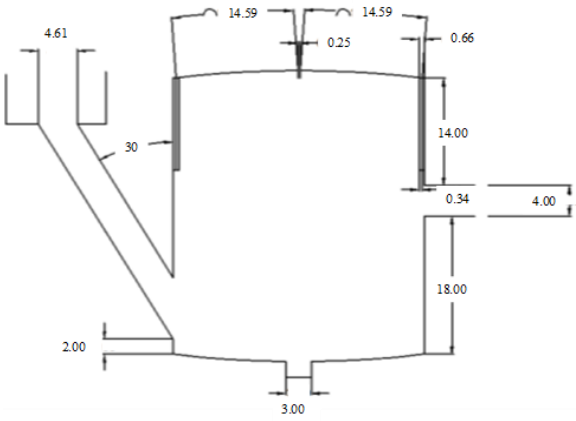

Fig. 7: Orthographic diagram (Front view)

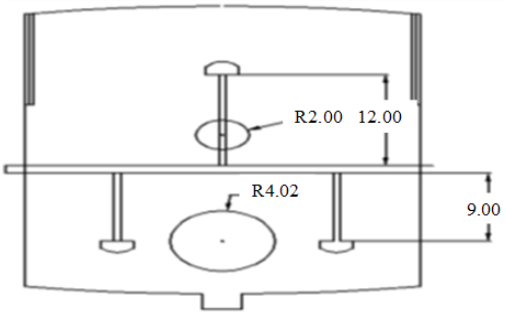

Fig. 8: Orthographic diagram (Side view)

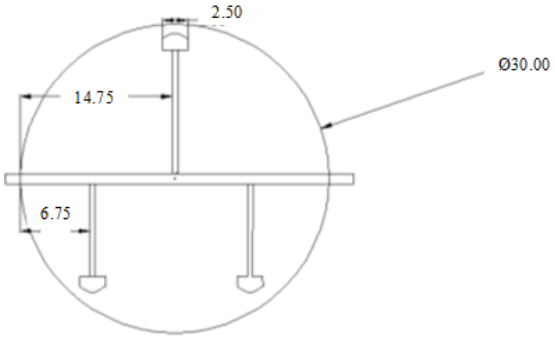

Fig. 9: Orthographic diagram (Top view)

The generic agitator curve, find the value of the agitator power number. The corresponding Reynolds number is given in Figure 10.

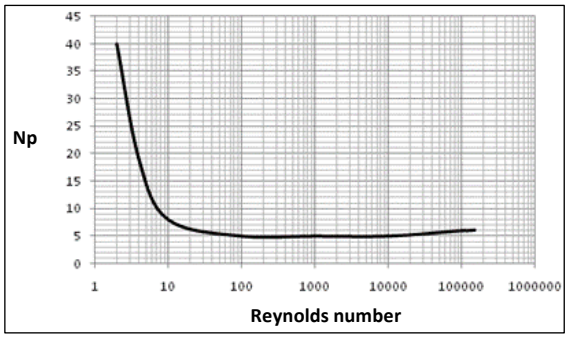

Fig. 10: Power number versus Reynolds number

Power (P) = [(5.1) (1100) (83.4x10^{-3})^3 (0.7366)^5]
= 0.344 kW

3.2 Fabrication of Reactor

Designing of the digester is one of the main objectives of this research and the selection of design requires feasibility regarding urban areas and also regarding the handling of waste easily. Construction of the reactor is carried out in a number of stages. The selection of material, size of material are some criteria and stages of construction. The stages are a selection of material, sizing of the sheet, cutting and grinding of the sheet, welding and joining process, final paint. Mild steel of 18 gauge (1.2 mm thickness) is selected as a building material of our digester. 8x4 Ft sheet of mild steel has been used in the process. The height of the digester 3 ft and a diameter of 2.5 ft have been selected. A moveable dome of 1 ft is constructed to maintain the pressure of the gas throughout. Feed inlet pipe of length 3ft is welded at the angle of 30 degrees so that the desired level of the slurry can be maintained in the reactor. This inlet pipe is welded just at the bottom of the reactor so the hits the bottom and premixing can be done initially. An alternate side valve is designed so can remove the digestive daily. The agitator at about the middle of the reactor has been placed for the mixing of the slurry at regular intervals. The main purpose to place the agitator in it is to avoid the formation of scum, which makes it unable for the gas to move up and gas remain trap in the slurry. A water jacket similar to the size of the dome is constructed at the top of the vessel which is then filled with water so that the dome can freely lift on the application of pressure. A clearance of about 1 inch is created between the jacket and the wall of the reactor. Three guiding rods are also welded on the dome which helps in the lifting process and dome lift straight and pressure remains the same throughout. In last, the bottom of the reactor is made slightly inclined like a hopper and a valve of 0.5 inches diameter is attached, if we want to empty the tank that valve helps us in doing so.

Finally, all the respective parts are perfectly welded and tested that there should be no leakage and seepage left in it. Depoxy has been applied to the critical joints where welding cannot be perfectly done. Last, to avoid rusting black oil paint is applied to the inner and outer wall of the reactor. For the final prototype of the reactor, performed the final experiment by using cow dung as a raw material. It is concluded from the previous experiments described that the cow dung produces more volume of the gas as compared to the combination of either of the mentioned waste potentials. That is why the reactor is run with diluted cow dung slurry with the dilution ratio (DR) of 1 Liter water/kg of dung.

In the initial phase cattle colonies keeping in consideration various factors which include the availability of fresh dung required carbon to nitrogen ratio, distance from the site, transportation cost of dung, labor for dung collection, and low level of sand impurities. Three sacks of capacity 50kg are filled with the cow dung which is closed tightly to avoid any interference and contamination of inside contents. Cow dung of about 70 kg along with sludge water 70 Liters is mixed together under mesophilic conditions. The pH of the sludge water is found to be 7.4 and that of the slurry is 7.2 through the digital pH meter. Inoculum condition is already generated in the reactor. Hydraulic retention time (HRT) of about 10 to 15 days is provided for the methanogens to carry out. After 5 days the flammability test is performed by opening the valve of the outlet of gas. The gas did not burn, but the flame of the match stick vanishes quickly which indicates the presence of carbon dioxide. We concluded that at this stage the reactor is in the acedogenesis stage. The contents of the reactor are mixed daily using an agitator manually with the average speed of 4 rev/min once a day as vigorous mixing can lead to an increased death rate of microorganisms. Again after 10 days flammability test is performed, the gas volume is sufficient to produce flame and it burned with a light blue continuous flame.

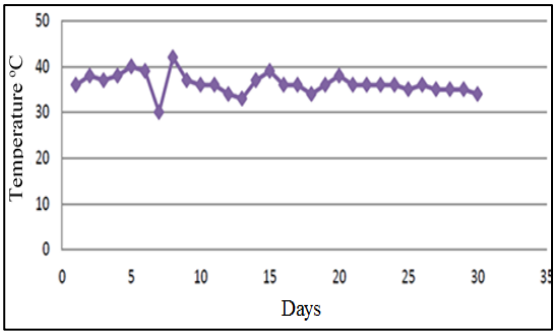

Fig. 11: Effect of temperature in a number of day

Figure 11 shows the effect of temperature in a number of days. On the 15th day when the mesophilic conditions are achieved and maintained, we then add about 80 kg of dung mixed with 80 Liters of sludge water with having the pH the same as before. The dome began to rise to accommodate the entrapped gas in the reactor; the position of the dome concerning height is measured at this point. On the 25th day of the first feed inlet, we observed that the dome raised above the mark to about 4 inches showing the production of gas at that height from which we calculated the amount of gas produced in the meantime. The pressure of the gas is measured using gauge and showed the reading of 1.14 bars which is then manually also be calculated. The total space in the reactor has a height of 8 inches.

3.3 Testing

The final feed is tested for the VOCs and moisture content, two samples of dung were drawn and tests were performed on both samples. Finally, the arithmetic mean of the readings was taken to achieve results as shown in Tables 8 and 9. The exhaust gas analyzer measured the amount of carbon dioxide present in the biogas which was found to be 40%. A known volume of plastic toy ball is used to measure the flow rate, the gas is allowed to fill up the ball till it occupied almost all of the space inside the ball, the time required to fill the ball is measured and then simply dividing the known volume by the measured time will give us the flow rate of the gas leaving the reactor. The pH of different samples is shown in Table 10.

Table 8: Volatile solids results using Muffle furnace (Sample 1)

Sample # 1	**Weight** 'grams'
Mass of dish + sample	24.77
Mass of dish	23.17
Mass of cow dung	1.60
After keeping the sample for half an hour, the following results were obtained at 105°C	
Mass of dish + sample	23.60
Mass of moisture evaporated	0.43
Percentage of moisture	26.9%
Percentage of total solids	73.1%
Mass of crucible + sample	23.08
Mass of crucible	22.52
Mass of sample	0.56
After keeping the sample in the furnace for 2 hours at 500 °C	
Mass of crucible + sample	22.65
Mass of volatile solids evaporated	0.43
Percentage of volatile solids	76.8%
Percentage of fixed solids	23.2%

Table 9: Volatile solids result using Muffle furnace (Sample 2)

Sample # 2	**Weight 'gram'**
Moisture content in cow dung	
Mass of dish + cow dung	17.53
Mass of dish	15.60
Mass of cow dung	1.93
After keeping the sample for half an hour, the following results were obtained at 105°C	
Mass of dish + sample	16.20
Mass of moisture evaporated	0.60
Percentage of moisture	31.1%
Percentage of total solids	68.9%
Mass of crucible + sample	17.4
Mass of crucible	17.04
Mass of sample	0.36
After keeping the sample in the furnace for 2 hours at 500°C	
Mass of crucible + sample	17.17
Mass of volatile solids evaporated	0.23
Percentage of volatile solids	63.9%
Percentage of fixed solids	36.1%

Table 10: pH of different samples

Samples	pH
Tap water	8.02
Sludge water	7.35
Sludge water + cow dung	7.18

Table 11: Comparison of different samples result

Feed	Sample 1	Sample 2	Average
% Moisture	31.1	26.8	28.9
% Total	68.9	73.2	71.1
% Volatile solids	76.7	63.9	70.3
% Fixed solids	23.3	36.1	29.7

Table 12: Testing results of samples

Testing	Results
Composition	60% CH_4, 40% CO_2
Flammability	Yes, burned with light blue flame
pH	6.8
Gas flow rate	3.2 L/min

Tables 11 and 12 comparisons and testing of different samples. Plant effluent also helps to improve environmental hygiene, certain microorganisms continue to exist in effluent which is injurious to health but effluent does not cause any harmful effect. In anaerobic digestion, the mainly biodegradable substance is decomposed during fermentation. Hence, the content of volatile solids of the digestate is reduced as compared to the source material and the fraction of non-biodegradable such as lignin and cellulose is relatively increased. Table 13 shows the effect on the content of the feed after digestion.

Table 13: General changes of digested material concerning the source material

Testing	Result
Dry matter content	↓
Volatile solids	↓
Nutrients (N, P, K), heavy metals	=
The proportion of NH_4-N of total N	↑
pH	↑
C/N ratio	↓
Heavy metals per kg	↑
Odorous substances	↓
Viscosity	↓

Fermentation of straw and grass produces solid sludge which is rich in phosphorous and liquid slurry which is rich in nitrogen and potassium hence the mixture of these two yields the best result. Fermented slurry with a low C/N ratio has better fertilizing characteristics and yields increase 5-15% as compared to fresh manure. Table 14 represents the fertilizer value of biogas manure [26].

Table 14: Fertilizer value of biogas manure

N, P, K is 1000 kg (dry) biogas manure	Equivalent chemical fertilizer
17 kg N_2	37 kg Urea
15 kg P_2O_5	94 kg Superphosphate
10 kg K_2O	17 kg Muriate of potash

The digested slurry can be applied to the field directly without any treatment; it can also be applied after enriching with liquid ammonia and phosphorous, or it can be applied after composting with ammonia and silt, whichever method of application is used it results in a higher yield as compared to direct application of animal manure [27-29].

The risk of creating odor and insect breeding is very less when the digested slurry is spread as compared to untreated waste. Animal manures and many organic wastes contain volatile organic compounds (iso-butanoic acid, butanoic acid, iso-valeric acid, and valeric acid along with at least 80 other compounds) that can produce unpleasant odors. Digestion significantly reduces concentrations of many of these compounds such that their potential for giving rise to offensive and lingering odors during storage and spreading is significantly reduced. The sludge from the biogas plant consists of 90% moisture and it can be dried by absorbing it into materials like dry leaves, sawdust, or charcoal dust and then spread out to dry, through this method of soaking and drying the manure received is twice the quantity of sludge left to dry alone.

4. Conclusion

In this research, experiments were performed at the mesophilic condition for the enhancement of methane content. Designing of the digester is accomplished. Biogas is produced in digester by anaerobic fermentation. For the final prototype of the reactor, the final experiment performed by using cow dung as raw material, it was concluded that among all the experiments described, the cow dung produces more volume of the gas as compared to the combination of either of the mentioned waste potentials. That is why the reactor is run with diluted cow dung slurry. Reactor having conditions of both mesophilic and thermophilic connected in

series can be operated to check the efficiency. Biogas plant not only provides clean fuel but also provides high-quality fertilizer in more quantity.

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