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A Review on Bio Methane Production using Kitchen Waste

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***Abstract* – Increasing population has led to increase in energy demand and waste production hence it is of great need to provide alternative to fuelling. This review paper contains the deciding parameters for increasing the efficiency of a biogas plant. In this paper municipal kitchen waste has been used as substrate for biogas production which not only produces more biogas as compared to traditional substrate but also solves the problem of municipal wet waste disposal. The parameters discussed in the paper are temperature, pH, particle size, CN ratio, total solid and volatile matter of the kitchen waste slurry and operating conditions of biogas plant like organic loading waste, retention time, agitation, filtration, and storage of biogas. The methodology proposed processing of the kitchen waste through shredder mechanism via hopper, into bio-digester, storage of biogas and filtration before utilisation.**
Keywords – biogas, kitchen waste, methane, wet waste, carbon neutral, LPG, digester, gas storage tank, shredder, etc.

INTRODUCTION

Today's growing community has led into generation of municipal solid waste on a large scale and has led to an ever-increasing demand of energy. Waste generation has led to various problems of pollution and is a cause of nuisance. Even after applying the concept of four R's which stands for Reduce, Reuse, Recycle, and Renewable energy, no proper solution for disposal of municipal solid waste is achieved. Dry and solid waste is processable using various methods to recycle it. But wet waste including kitchen and garden waste is the area of major concern. Wet waste cause land pollution, leaching of leachate into ground water, scarcity of land due to generation of landfills, breeding of rodents and insects causing diseases and air pollution. Increased population has led to increase in demand for cooking gas which led to inflation of prices. LPG on burning releases ample amount of carbon dioxide as compared to methane. It possesses numerous hazards while working with as being heavier tends to sink. Biogas being renewable source of energy generated from wet waste provides sustainable development and clean fuel which is eco-friendly. Biogas is the way possible to solve this being carbon neutral i.e., it doesn't add up carbon in atmosphere but recycles it.

Biogas is a mixture of primarily methane (CH_4) 55 – 60 % and carbon dioxide (CO_2) 30 – 40 % and traceable gases [1]. Anaerobic digestion is a microbial process used for production of biogas; whereby organic matter is broken down by microbiological activity in absence of oxygen. Biomethane is one of the main constituents of biogas which is used as fuel. Biomethane being odourless, blue burning flame is used for cooking and heating purposes. 28 m^3 of biogas is equivalent to one domestic LPG cylinder. Organic waste of 200 kgs can contribute one LPG cylinder daily [2].

Traditional biogas plants were prone to various problems like no portability, low quality biomethane production, less efficient, high cost, no filtration equipment and robust design. Hence compact design and more efficient biogas plant is need of future.

Anaerobic Digestion –

It is a simple process in which micro-organism break down complex organic matter into simple by-products in absence of oxygen. It is further subdivided into 4 steps as follows:-

1. Hydrolysis : being the prime step of anaerobic digestion involves breaking of macromolecules into micro molecules. It involves conversion of organic polymers into monomers using enzymes and bacteria. The macromolecules include polysaccharides, proteins and complex fatty acids which are converted into soluble sugars, amino acids, and simpler fatty acids respectively. Carbohydrates are converted into sugars within few hours whereas proteins and lipids require few days to beak down [3].
2. Acidogenesis : it involves formation of volatile fatty acids from substrate obtained from hydrolysis. It involves conversion of sugars, amino acids, fatty acids into short chain organic acids, alcohols, hydrogen. etc [3].
3. Acetogenesis : it is fermentation process that involves conversion of volatile fatty acids into acetic acid, carbon dioxide and hydrogen with help of specific group of fermenting bacteria called as acetogenic bacteria.
4. Methanogenesis : this is the last stage of anaerobic digestion where the main by-product methane is obtained. In this process microbes known as methanogens are responsible for production of biomethane in suitable conditions. The end products of acetogenesis are converted into methane, carbon dioxide and hydrogen. pH level between 5.5 – 8.5 and temperature between 30 – 60 oC must be maintained for higher rate of digestion [3]. At the end of methanogenesis reduction between carbon dioxide and hydrogen takes place resulting in formation of one-third of total biomethane produced [4, 5].

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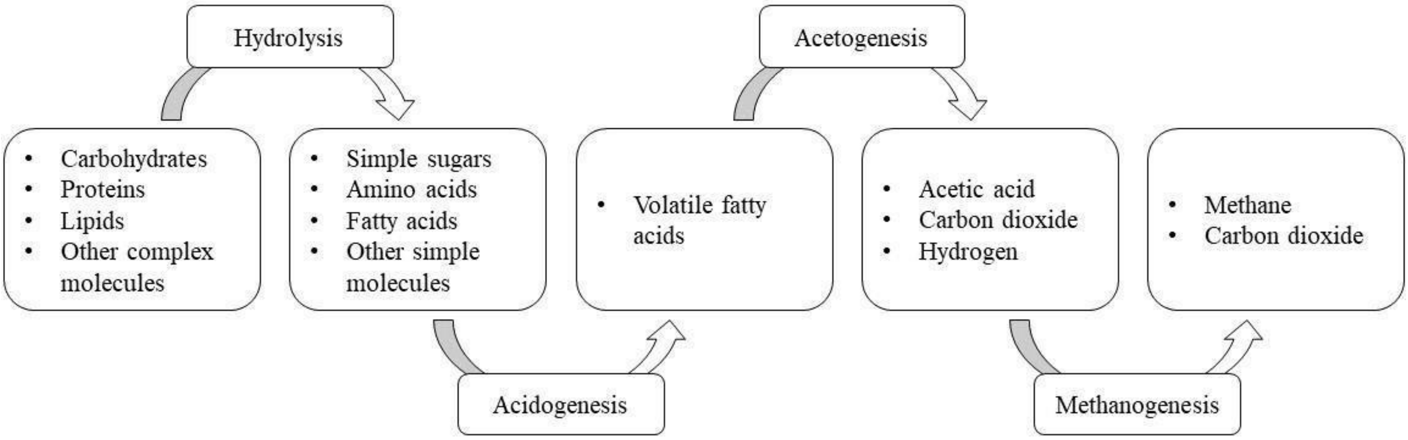

Fig. 1 Anaerobic digestion process Types of Digestors –

Based on design there are various types of digestors available. Type of digestor design to be selected is based on geographical condition, climatic condition and feedstock available.

1. Fixed dome digesters : these type of digestors is also known as Chinese digestors which is most common model used for biogas production. [5, 6]. In this type of digestors there is an inlet and outlet through which feedstock is fed and slurry obtained is removed respectively. The greatest advantage of these type of model is no external agent is required to develop pressure inside the digestor as difference between the slurry level and gas in the storage part creates optimum pressure required. The biogas produced is stored in the digestor in upper part itself. These types of digestors are most feasible. [7] . In India fixed dome digestor are further distinguished into Janta and Deenbandhu models.
    a. Janta biogas plant : These type of digesters were firstly introduced in 1978. The basic structure of this type of plant includes integrated structure of digester and gas holder as a whole brick masonry structure. The plant is provided with inlet and outlet shallow well and are connected to digester with help of chutes [8]. These type of plants do not use any steel components as a part of plant providing with less maintenance cost.

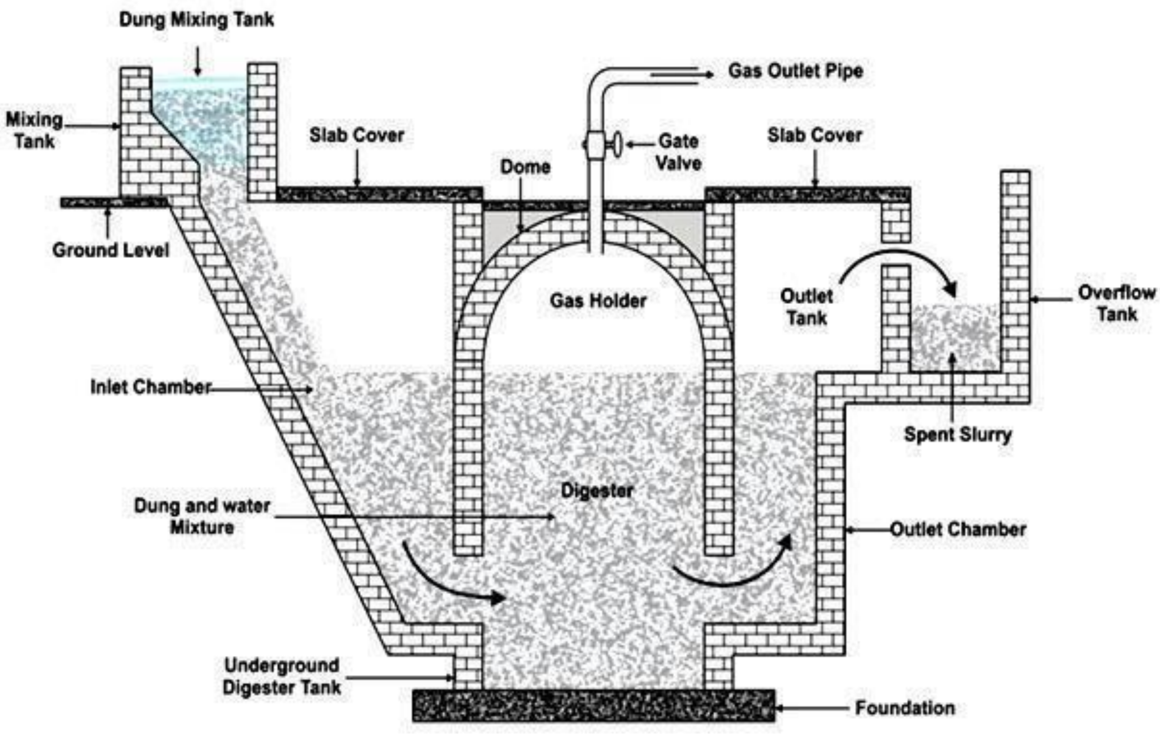

Fig. 2 Janta model biogas plant [8]

    b. Deenbandhu biogas plant : These type of biogas plants was introduced in 1984 in India. As the name suggests these type of biogas plant is the cheapest model introduced among all available models. The main feature of this type is that to reduce installation cost the surface area of plant is minimized without reducing efficiency of plant. The design consists of two spheres of different diameters joined at their bases providing gas chamber as well as digester chamber [8].

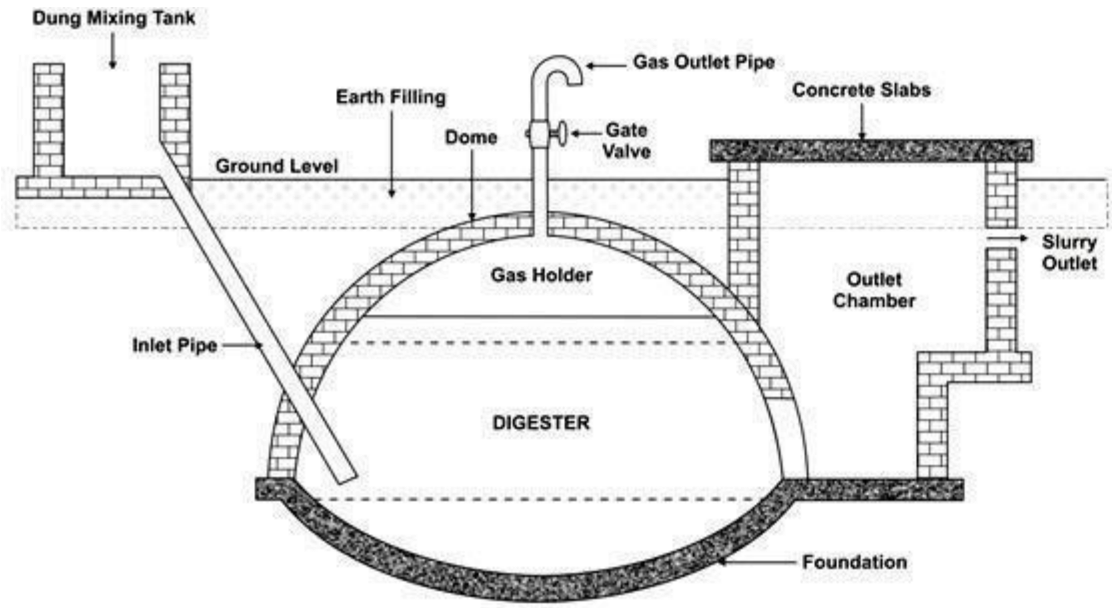

Fig. 3 Deenbandhu biogas plant [9]

2. Floating drum digester : these models was primarily developed in India. In this type of design there is a moveable inverted drum placed on bottom digestor that acts as storage tank and provides required pressure into biogas plant. This drum moves up and down based on amount of biogas accumulated into it and weight of the drum provides necessary constant pressure for the gas flow through pipeline for use. The drum helps to indicate the level of biogas stored into it. [8]

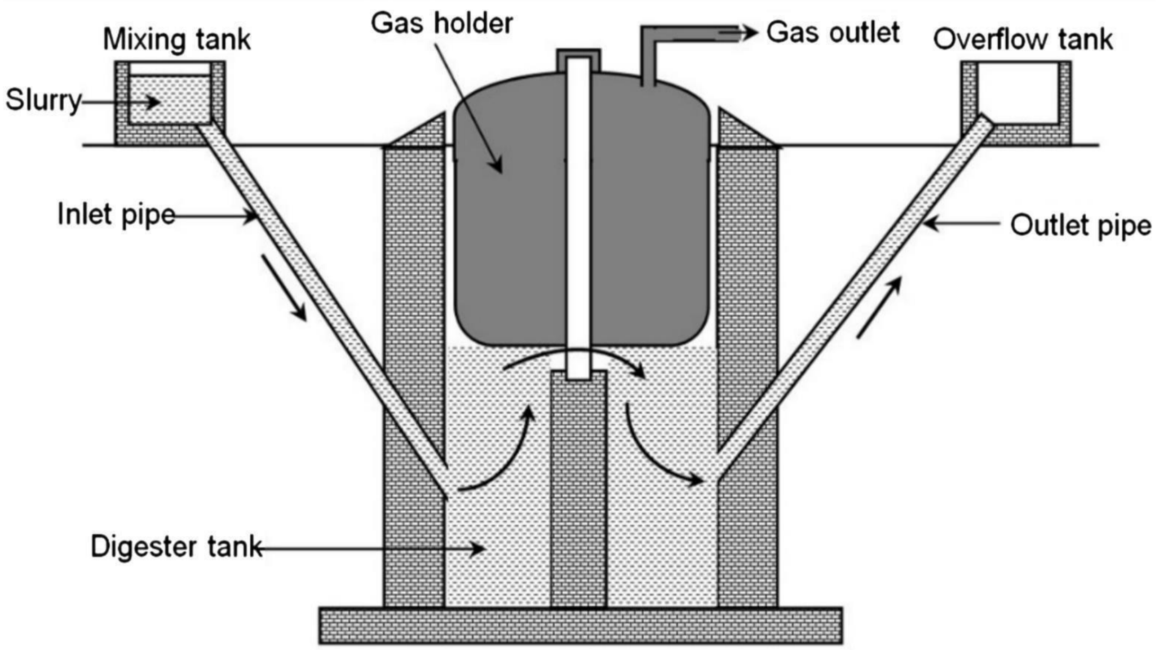

Fig. 4 Floating drum biogas plant [11, 12]

Parameters for digesters operation –

1. Feedstock : Kitchen waste provides with more biogas production as it contains carbohydrates, proteins and fats. 1 Kg of kitchen waste produces around 0.3 m^3 of gas [13]. At same HRT 1 kg of kitchen produces same amount of biogas which 40 kg of cow dung could produce. Hence 400 times more efficiency can be achieved. The total solid concentration of kitchen waste ranges between 14 – 25% best suited for biogas production. Hopper could be used is the inlet of the biogas plant which is used to collect the feedstock. Based on the feeding rate of the feedstock hopper capacity could be designed. Experimental feedstock of kitchen waste includes cooked rice, vegetable leftover of tomatoes, carrots, onions, banana peels, etc. were brought from canteen and poured into digestor. The temperature of digester was constant between 38 – 45 ºC during the day and 35 – 40 ºC during the night. [14].
2. Particle size: Particle size highly affects the biogas production. Smaller the particle size more the biogas production and lesser the HRT required. Hence smaller particle size would lead into better optimization of plant design. Particle size less than 5 mm gives more biogas production [15]. In order to achieve smaller particle size shredder mechanism

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could be incorporated. HRT is largely influenced by particle size of the feed. Smaller the size of feed, lesser the HRT. Hence, it is essential to use some mechanism such as grinder or shredder to convert waste into smaller particle to improve overall efficiency of plant. Size and material optimization are done [13]. Five particles were taken as sample of following sizes 0.088, 0.40, 1.0, 6.0 and 30.0 mm. Maximum biogas was produced from 0.088 and 0.40 mm sized particle. The physical pre-treatment like grinding also leads to increased biogas production. It was concluded that the smaller the particle size more degradation of feed and more biogas production. [16].

3. Feeding rate: Organic loading rate highly depends on availability of feedstock and amount of biogas to be produced. For household and small canteen purpose 3 – 25 kg/day feeding rate is observed. In order to provide liquified inflow to the feed 20 % water of total feedings is added to make kitchen waste slurry [17]. For example, considering college canteen if 10 kg/day of kitchen waste is fed then 2 litres (approx.) of water is needed to provide required liquified inflow. 1 kg of kitchen waste when digested properly yields 0.3 m3 of biogas. The gas produced by kitchen waste feeding of 80 kg/day gives 24 m3/day of biogas. HRT is selected as 30 days. Sufficient biogas of 2.4 m3 can be obtained by loading rate of 10 kg/day [18].
4. C/N ratio: C/N ratio is ratio of carbon to nitrogen in any substrate. C/N ratio of feedstock for biogas plant ranges from 10:1 to 30:1. For kitchen waste the range lies from 15:1 to 25:1 [18]. C/N ratio from 15 to 25 is best suited for different physical and chemical pretreatment like fungi activation. Increased temperature makes it more effective and provides with rapid digestion with lower retention time. To maintain higher temperature of digester tank, energy consumption for heater arrangement increases and also inhibition of ammonia formation is large [19].
5. Temperature: Optimum temperature for mesophilic bacteria culture to develop is between 35 – 45 ºC [5]. In the mesophilic range, the activity and growth rate of bacteria decrease by 50% for each 10 ºC drop. Fall in biogas production starts, when temperatures decrease to 20 ºC and the production even stops at 10 ºC. Heating system based on solar water tubes increases the digester chamber temperature. It is seen that 35 ºC is optimum temperature required for faster digestion and particle size was taken 0.05 mm. It was noted that biogas yield and degradation efficiency were substantially higher for the substrate of pH 7 compared to other pH values. Heating element could be provided in order to maintain the temperature of digester for all weather conditions. Solar based water tubing arrangement which is non-direct method of heating could be replaced by direct heater arrangement [20].
6. Retention time: Hydraulic Retention Time (detention period) ranges between 15 days to 100 days [5]. HRT is highly affected by temperature of the digester. Low temperature requires higher HRT and larger digester size whereas high temperature requires lower HRT and lower digester size. Very low HRT leads to wash out of reactor which means all the microorganism escape out of reactor. It is highly recommended to consider minimum 30 – 40 days as HRT, best suited for most of areas of India for operating temp of 35 – 40 ºC. Use of kitchen waste improves production of biogas as kitchen waste has more nutrients compared to cow dung [21].
7. pH: Mesophilic bacteria are more efficient to work with neutral pH. Hence considering pH of 7.5 – 8.5 as operational pH of the digester in order to achieve more biogas production [22].
8. Agitation: Since HRT of a biogas plant could be long which leads to scum and crust formation on top layer leading to stop further biodegradation and stoppage of biogas production thus hampering the efficiency of the plant. Therefore, agitation i.e., mixing of whole slurry could be incorporated. Using automated mechanism will greatly enhance efficiency of the plant.
9. Filtration: Along with production of CH_4 other gases like CO_2, H_2S, water vapours and other trace elements are produced which reduces the efficiency of biogas plant. In order to increase efficiency these impurities must be removed. For these purposes filtration system has to be used. 10 % NaOH in water or else 40 % KOH solution could be used for CO_2 filtration i.e., when biogas passed through the solution CO_2 is removed [23]. H_2S could be highly dangerous to inhale and corrosive in nature so must be removed. When biogas passed through iron wool reacts with it to remove it, if considered rusted would give better results. Filtration of biogas could provide with up to 99 % pure bio-methane that could be used for cooking purpose, [23, 24]. CO_2 has no heat value i.e.; they don't take part in combustion hence must be removed. Raw Methane i.e., methane with other impurities has heat value of 7.2 kWh/m^3 and after filtration we gets 9.94 kWh/m^3 hence efficiency increases by 27.5 % [23].
10. Material: Traditional biogas plants were made of bricks and cement provide with a good self-life but having the greatest disadvantage of leakage of biogas and robust design made is less suitable in use. Organic acids produced during anaerobic reaction may corrode the digester body if made of steel of any metal making its self-life shorter although it provides with no leakage of gas. FRP material developed offers with more tensile strength and is thermally and chemically resistant, hence provide with longer life span than steel. If FRP material is used for biogas plant, it offers most economical body of plant having longer lifespan along.

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Property	Material Type				
	CFRP	GFRP	AFRP	BFRP	Steel
Density (gm/cm^3)	1.50–2.10	1.25–2.50	1.25–1.45	1.90–2.10	7.85
Tensile Strength (MPa)	600–3920	483–4580	1720–3620	600–1500	483–690
Young's Modulus (GPa)	37–784	35–86	41–175	50–65	200
Elongation (%)	0.5–1.8	1.2–5.0	1.4–4.4	1.2–2.6	6.0–12.0
Coefficient of Linear Expansion (10^{-6}/°C)	–9.0–0.0	6.0–10.0	–6.0–2.0	9.0–12.0	11.7

Table 1. Comparison of mechanical properties of FRP and steel [25]

Proposed Design –
The proposed design of biogas plant is fixed dome model comprising with agitator mechanism.

1. Digester volume: Digester volume can be calculated based on feeding rate and HRT. For feeding rate of 3 kg (kitchen waste), 0.6 litres of water (20% of total waste) is required to provide inflow for the waste [16]. Considering HRT = 30 days recommended for weather conditions of Maharashtra.
   Inflow = 3 kg waste + 0.6 L water = 3.6 litres/day (considering kg = litre).
   Volume of digester = daily inflow x HRT = 3.6 x 30 = 108 L + 10% (due to formation of bubbles) = 120 L (approx.).
2. Gas storage volume: Gas produced is stored in the upper part of digester and is used as per requirement. COD of kitchen waste = 242 g/L [24].
   Total COD of feed = COD x waste inflow = 242 x 3 = 726 g.
   4 g COD = 1.4 L CH_4 [16]. Therefore, CH_4 produced = (726 x 1.4) / 4 = 254.1 L/day. Total biogas produced = 254.1 / 0.65 = 390 L/day (approx.)
3. Total volume:
   Total volume of plant = 120 + 390 + agitator volume + tolerances = 550 L (approx.)
4. Dimensions of plant:
   Cylindrical biogas plant having radius = 0.4 m, height = 1.1 m provides with the required volume i.e., 550 L.

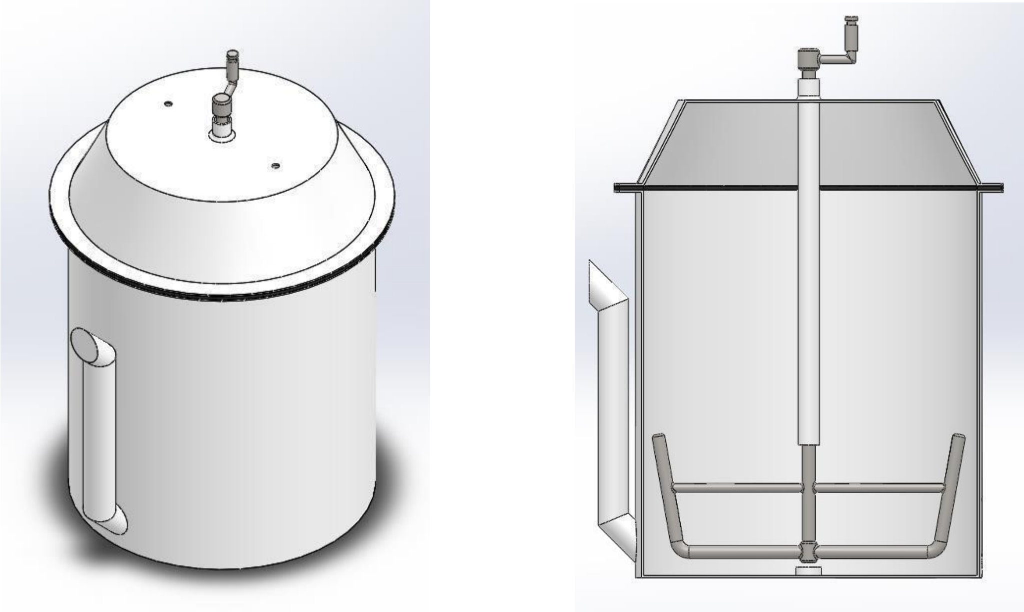

Fig. 5 Prospective and section view of proposed model

METHODOLOGY

Based on the trends observed the following steps could be followed in order to achieve better biogas production along with applying parameters suggested in to this review paper. This would surely lead in more production of biogas having higher biomethane compositions.

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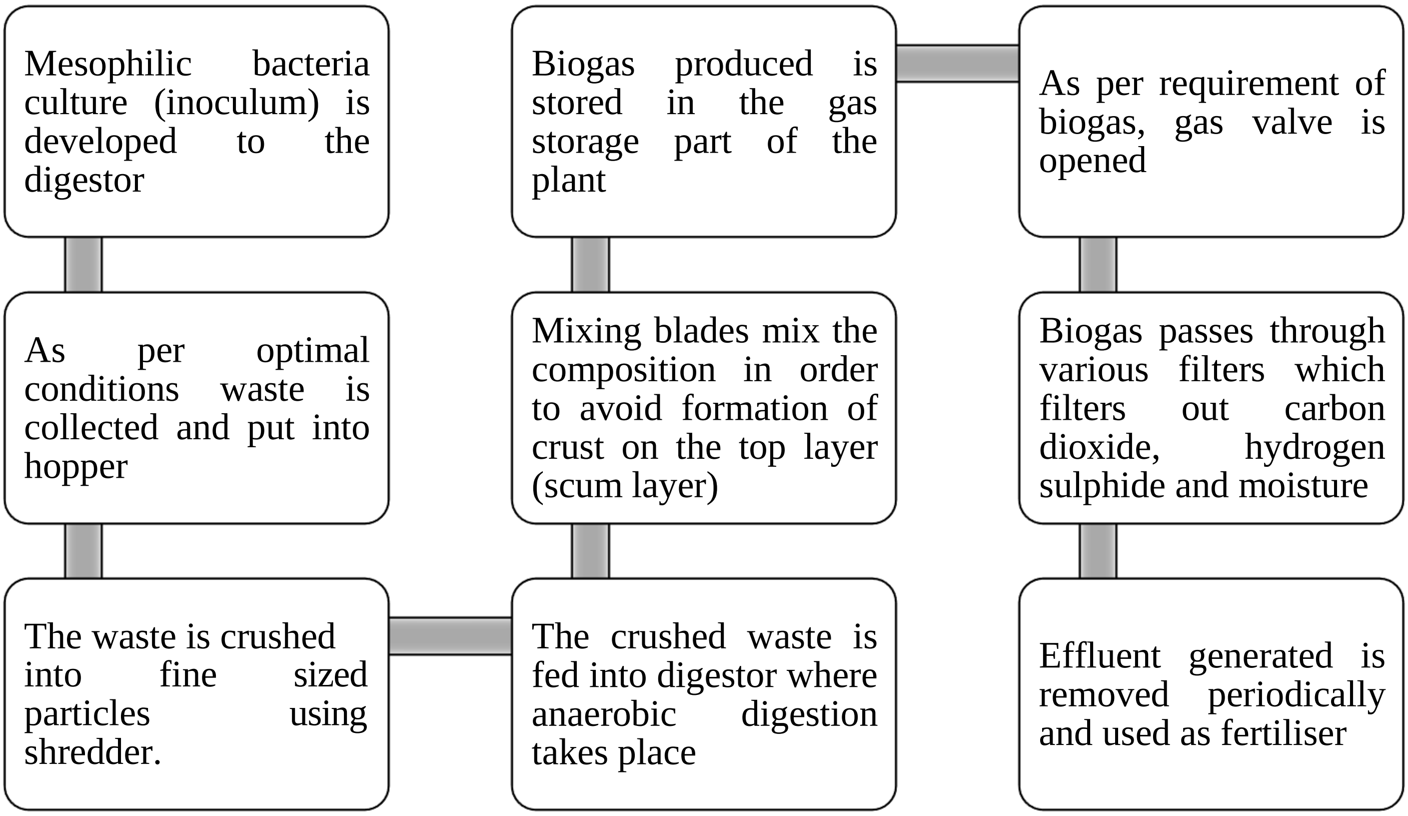

Fig. 6 Flow chart of methodology

APPLICATIONS

1. Cooking and heating: Biogas produced is mainly used for cooking purposes [26, 27]. The value of biogas needed for cooking purpose for family of four varies from 30 to 45 m3 per month which is equivalent to 1 LPG cylinder per month. The calorific value of biogas and LPG are 5000 kcal per m^3 and 10800 kcal per kg respectively which when compared on monthly scale is equivalent.
2. Fertiliser: the left over slurry is rich in nitrogen, phosphorus and potassium which can be used as fertilizer. This slurry increased potato cultivation by 27.5% compared to no fertilizer. [28, 29]. Biogas slurry could be helpful in growing algae and fish food. The fertilizer obtained is organic in nature and no chemicals are involved which is rich in biomass.
3. Other applications: they include electricity and power generation; livestock bedding and helps maintaining nutrient of soil along with wet waste reduction.

CONCLUSION

Biogas could be alternative source for fuelling option. This ensures proper handling and disposal of wet waste in cities. Digestate obtained is highly rich in N:P:K ratio which increases the growth of plant by greater percentage as compared to chemical fertilizer. Kitchen waste has the best suited C/N ratio of 25:1 for biogas production. As per study by incorporating the proposed parameters and substrate parameters would produce more biogas having higher biomethane composition, this also increases efficiency of biogas plant. Biogas also helps to maintain carbon neutrality. By applying all studied parameters biogas containing 75 – 85 % biomethane could be obtained. Biogas is a promising technology which provides sustainable fuelling option along with economic benefits. Further study on efficiency and cost of biogas plant would surely make it most affordable and easy to use technology leading towards greener environment.

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