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Effect of Temperature and other factors on Anaerobic Digestion Process, responsible for Bio Gas Production

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Abstract

The efficiency of plant is maximum at ideal temperature and it falls with increase and decrease in temperature. The two factors of utmost significance, which have effect on biogas production, are the sublayer temperature and the process temperature of anaerobic digester. These temperatures decide the inhibition/stimulation of a particular microorganism kind (for instance, an optimal temperature for the survival of thermophilic and mesophilic bacteria are 55ºC and 35ºC, respectively). This, in turn, renders various organic material biodegradability levels that influence the biogas production amount and quality, attaining the maximum at 55ºC. Excluding temperature, the raw materials' organic matter content that undergoes microbial action is of greater significance in deciding the biogas production quantity and quality. The sublayer pH and C/N ratio allows to determine the organic matter content. Maximum biogas production is possible with the maintenance of ideal values for pH, C/N ratio, pressure and temperature, in accord with the microbial activity.

Keywords: biogas; temperature, anaerobic; digester; organic matter, pH, C/N ratio, pressure.

1. INTRODUCTION

Biogas represents a gaseous mixture, where carbon dioxide and methane serves as the major gaseous constituents [9] [28]. These majorly present gases of biogas are formed through digesting the organic material [3] in an anaerobic environment. The methane constitutes a percentage in-between 55 and 80, in accordance with the changing process states or the fermented organic material kind. The other gases of biogas, which are present in trace amounts, include water steam, nitrogen, oxygen and hydrogen sulphide.

The environments to achieve anaerobic digestion are the digestive tract that belongs to ruminants, wetlands, mashes and pond bottoms.

The methane quantity decides the energetic value [5], which the biogas holds. Table-1 portrays the energetic value associated with biogas, containing methane at different percentage concentration. Additionally, the table depicts the energetic value of biogas at a pressure of 760 mm Hg, at two different temperatures (0°C and 20°C).

Table- 1. Biogas content and Biogas calorific power table

Methane content %	**Calific power kcal/m^3**		**Methane content %**	**Calorific power kcal/m^3**	
	at 0° C and 760 mm Hg	**at 20° C and 760 mm Hg**		**at 0° C and 760 mm Hg**	**at 20° C and 760 mm Hg**
50	4281	3955	66	5650	5261
52	4452	4145	68	5822	5420
54	4623	4304	70	5993	5579
56	4794	4463	72	6164	5739
58	4965	4623	74	6335	5898
60	5137	4782	76	6507	6058
62	5308	4942	78	6678	6217
64	5479	5101	80	6849	6376

The source of biogas is umpteen numbered [23], as it involves waste [1] from farming, forestry municipality [4] and sewage sludge. The liquid manure that has undergone fermentation is also included in it [16]. The applications that the biogas supports are the gas turbines and burners for power generation, combustion engines and power as well as heat co-generation. Biogas enhancement ensures improved gas quality, prior to being distributed in the public gas grid. While performing anaerobic digestion on the organic matter (for instance, organic waste from agriculture [7], municipality [17] and energy crops [13]), biogas gets produced. During anaerobic digestion, numerous bacteria kinds decompose the organic waste in the absence of air to produce the biogas. The fermentation procedure gets altered due to various parameters. Biogas can be renewable. Further, it has no effect on increasing green house gas, irrespective of the CO_2 release during biogas combustion with oxygen.

The reason is that the carbon release of biogas combustion is not additional, but it is already a part of the biosphere circulation. The CO_2 release is same, in case of biological material decay. The methane content of biogas has carbon, which result from the CO_2 intake of plants during photosynthesis. The same procedure allows natural gas production. However, the natural gas has its carbon being stored for several years in the earth's crust and lacks to be CO_2 neutral. So, biogas imparts numerous merits to environment than natural gas. Table 2 deals with the composition of biogas. CO_2 and methane form the chief biogas constituents, irrespective of the substrate. As the processing conditions change, methane and CO_2 contents of biogas also varies as 45%-85% and 15%-45%, respectively. Nitrogen, ammonia and hydrogen sulphide contribute to biogas in smaller traces.

Table 2. Biogas composition

Component	Symbol	Concentration
Sulfide	H_2S	20-20,000 ppm
Hydrogen	H_2	< 1 Vol.-%
Ammonia	NH_3	< 1 Vol.-%
Nitrogen	N_2	< 2 Vol.-%
Oxygen	O_2	< 2 Vol.-%
Water vapor	H_2O	2-7 Vol.-%
Carbon dioxide	CO_2	25-45 Vol.-%
Methane	$\mathrm{CH_4}$	50-75 Vol.-%

We have different sources of energy like dry wood, lignite, Coal Dust briquettes , Tar, Fuel radiator, Diesel fuel, Natural gas, Liquefied petroleum gases ect. Now, we discuss the amount of energy when we compare the energy with bio gas 60% at O^{o} C and 760 mm Hg. Now we compare 1 m^3 of gas and other energy sources as 1Kg and we compare calorific power Kcal/U.M. and equivalent of U.M for 1 m^3 of biogas , the results are in the table no.3.

Table-3. Comparison between thermal energy sources and biogas

Fuel kind	U.M.	Calorific power Kcal/U.M.	Equivalent in U.M. for 1 m3 of biogas
Liquefied petroleum gases	kg	22000	0.23
Natural gas	kg	8500	0.60
Diesel fuel	kg	10000 - 11000	0.51 – 0.47
Fuel radiator	kg	9500 - 9700	0.54 – 0.53
Tar	kg	9400 - 9500	0.55 – 0.54

Coal dust briquettes	kg	4000 - 6800	1.28 – 0.76
Lignite	kg	1800 - 3800	2.85 – 1.35
Dry wood	kg	1800 - 2200	2.85 – 2.34
Biogas 60% methane, at $0^{\circ}C$ and 760 mm Hg	m^3	5137	1

2. DISCUSSION

2.1 Sources and natural procedure of biogas

The merits of using organic remains for producing biogas are numerous, since it satisfies the following requirements [24].

- During each year, there is a drastic growth in worldwide population. Hence, organic wastes are produced in abundance. Biogas production from organic remains allows waste disposal
- Provides some means of managing the waste (for instance, the livestock manure [11], waste from house as well as food industry and agricultural products [18] of secondary importance) in an eco-friendly and pollution-independent manner
- Fails to produce smell, which occurs during the decay of manure in the presence of air.
- Renders fertilizer of excellent quality to aid in agricultural purposes
- Cuts down the effect of global warming and associated green house gas release
- Offers energy, independent of time, and decreases the need for fossil fuels
- Renders job to people of local regions, thus improving the socio-economy of a nation.

Biogas production takes place at different places depending on different types of climates and other factors and the type and size of biogas production depends according to the situation.

For good process of biogas production, the bacterial action is desired to produce intermediate compounds from the organic materials of biodegradable nature. It is only then the methanogenic bacteria can indulge into action. The conditions of the reacting medium should be set in a way to support the development of all bacteria in a simultaneous fashion. The reacting capability and the growing nature of anaerobic bacteria are not too rapid. Hence, the reaction medium has to possess optimum conditions to support the anaerobic bacterial growth.

2.2 Different types of Bio reactions

The non-complex organic compounds serve the purpose of sublayer for the acidogenic bacteria to act upon. The acidogenic bacteria (OPHA) differs from the hydrolytic bacteria by producing organic acid chains of small size, which then acts as the sublayer for the other sets of bacteria kinds. Various bacteria kinds, which aid in the production of biogas are as follows [8]:

- The Homoacetogene bacteria: It is an acetate-synthesizing bacteria, which makes use of hydrogen as well as carbonic anhydride to form the acetate
- The Metanogene bacteria: It has two main categories and they are as follows:
  a) Acetoclastice, which is capable of utilizing acetic acid to yield CO_2 as well as methane
  b) Hydrogenotrofe, which utilizes hydrogen as the starting material for yielding carbon anhydride as well as methane

The differing bacteria species have strong interaction among them such that an element yielded by one species serves as the growth feature or the sublayer for one or more same/different bacteria species.

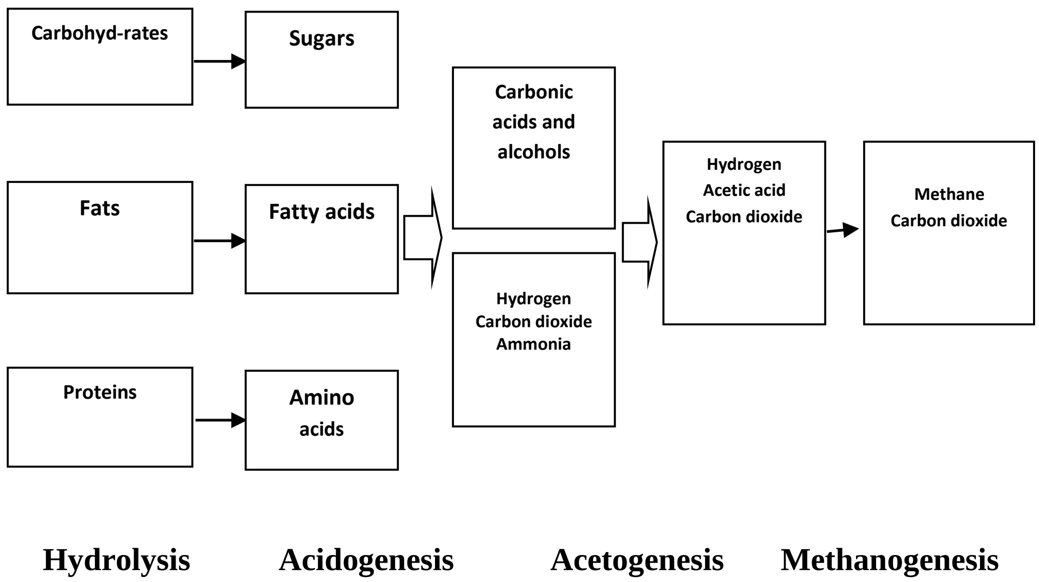

Fig. 1: Simplified process of anaerobic digestion.

Main factors in the production of biogas [29]:

1. Volatile Fatty Acids (VFA).
2. Fermentation medium pH
3. The digester's working pressure
4. Retention time
5. The digester's inner temperature
6. The composition of the sublayer

2.3 The composition of the sublayer

During the anaerobic process of fermentation to yield biogas, the feedstock should never hinder the development of microorganisms nor disallow its ability of performing optimal metabolism [14].

The medium, which facilitates the fermenting procedure to take place, must meet the following conditions

- Should lack materials that inhibit microorganism growth (for instance, antiseptics, antibiotics and detergents)
- C/N ratio has to vary from 15 to 25
- The pH should take values between 6.8 and 7.3
- Should own organic matter with biodegradable nature

The frequently deployed sublayers include organic solid [19] as well as liquid wastes from food industry (based on flora or fauna), agricultural by-products, remains of energetic crops (Miscanthus, sorghum, rye, corn) animals or plants, manure, food wastes, zootechnic wastewater, organic solid wastes from municipality and sludge formed by treating wastewater.

Table-4 Biogas production level and methane content of different sublayers

Sublayer	Average dry matter(DM) Content S.U.%	Biogas potential l/kg S.U.	Methane content %
Pig manure	13,5	480	60,0
Sheep dung	25	320	65,0
Horse dung	27,5	200 - 300	66
Cattle manure	14	260 - 280	50 - 60
Poultry wastes	27,5	520	68,0
Beet leaves	13,5	501	84,8
Dried leaves	12,5	260	58,0
Corn stalks	86	309	-
Corn silage	34	108	52
Grass	16	557	84,0
Lucerne	22,5	445	77,7
Barley straws	84	380	77
Wheat straws	86,5	367	78,5

Anaerobic digestion is termed as the dry digestion process, in accordance with the sublayer’s dry matter content. The sublayers usually have DM in the range between 25% and 45%. Now we compare the different processing modes of dry and wet digestion and we get different types of results for both dry and wet digestion. This is shown in table-5.

Table -5 The dry digestion and the wet digestion, a comparison

Mode of processing	**Dry**	**Wet**
Variety waste components	Low	High
Solid liquid separation	Simple	Expensive
Short circuit flow	Low risk	High risk
Foam generation	Low risk	High risk
Stirring	Difficult	Easy
Transport engineering	Expensive	Simple
Reactor volume	Minimized	Increased
Total solids content	High 25-45%	Low 2-15%

When we compare pretreatment methods (Biological pretreatments, Chemical as well as physic-chemical pretreatments and Physical pretreatments) the different processing's like Milling, Irradiation, hydrothermal ect. (Physical treatments) Explosion, Alkali, Acid, Gas, Oxidizing agents (Chemical and physic-chemical pretreatments) Fungi and actinomycetes (Biological pretreatment) . Different possible changes take place in case of the biomass and we have different observations which are marked by notable remarks in the *table no. 6.*

Table -6 Pretreatment methodologies for the lignocellulosic materials [12]

Nrcrt	**Pretreatment methodology**	**Processes**	**Feasible biomass changes**	**Prominent interpretations**
1	**Physical pretreatments**	**Milling** (*vibro energy milling, colloid milling, hammer milling,two-roll milling, ball milling*) **Irradiation** (*microwave irradiation , electron-beam irradiation, gamma-ray irradiation)* **Other methods** *(pyrolysis, extrusion, expansion, high pressure steaming, hydrothermal)*	• Enlarged accessible pore size as well as surface area • Reduced polymerization levels • Reduced cellulose crystallinity	• The methodologies, for the most part, necessitate high energy • Lignin eradication is not possible with all methods • Denied usage in industrial applications • Working of the methods is devoid of chemical usage

2	**Chemical and physic-chemical pretreatments**	**Explosion (** SO_2 *explosion,* CO_2 *explosion, ammonia fiber explosion (AFEX), steam explosion*) **Alkali (***ammonium sulfite, Ammonia, sodium hydroxide)* **Acid** (*phosphoric acid, hydrochloric acid , sulfuric acid*) **Gas (***sulfur dioxide, nitrogen dioxide , chlorine dioxide*) **Oxidizing agents (***ozone, wet oxidation, hydrogen peroxide)*	• Enlarged accessible surface area; • Delignification is nearly complete or partial • Reduced cellulose crystallinity • Reduced polymerization levels • Hemicelluloses are hydrolyzed either partially or completely.	• Methods of increased efficacy, best suited for industrial applications • Rate of treatment is more too fast • Harsh conditions are necessitated • Chemical requirements are more in number
3	**Biological pretreatments**	**Fungi and actinomycetes**	• Reduced polymerization levels, in case of cellulose • Delignification • Hemicelluloses are hydrolyzed partially	• Does not support commercial application • Rate of treatment is small • Serene environmental conditions • Energy need is less • Chemicals are not necessitated

The sublayers involved in the anaerobic digestion process is set up with the raw material, whose kind and measure rely on the protein content, fat content, sugar content and the sublayers' DM content.

The sublayer's ability of producing high methane quantity aids in evaluating the sublayers, taking part in anaerobic digestion. Methane production is provided by several organic sub layers.

Table-7: Raw materials (Self + mixtures)have following Metanogenic ability

Feedstock type	Mixing ratio in %	Biogas l/kg S.O.	To increase of calculation %
Sewage sludge + grasses	50 - 50	387	+ 42
Birds manure + grasses	50 - 50	513	+ 13,5
Birds manure + sewage sludge	50 - 50	495	+ 12,3
Cow manure + pigs + birds	25 – 50 - 25	585	+ 9,6
Pigs manure + birds	50 - 50	634	+ 7
Cow manure + grasses	50 - 50	363	+ 5
Cow manure + sewage sludge	50 - 50	407	+ 26
Cow manure + birds	50 - 50	528	+ 6
Cow manure + pigs	50 - 50	510	+ 7,5
Grasses	100	277	-
Sewage sludge	100	265	-
Poultry manure	100	617	-
Pigs manure	100	569	-
Cow manure	100	380	-

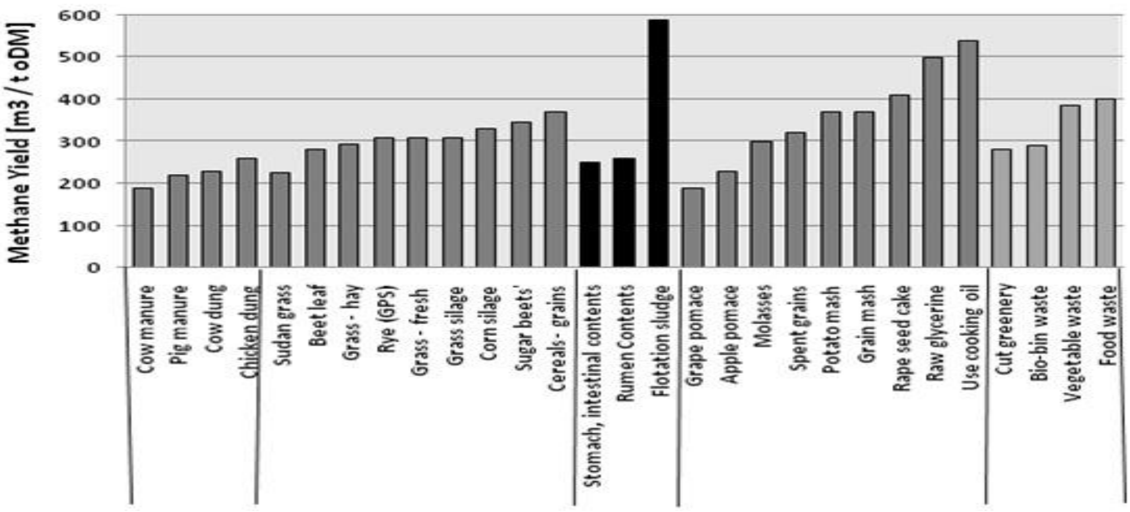

Figure 2: Benchmarks for specific methane yields

During anaerobic digestion, the nutrients are provided by the sublayer as a single source or a multiple source, formed of different adjacent sublayers. Practically, methane production for a single volume of sublayer is high, when it digests manure with the co-sublayers [15]. Positive synergies of biogas yield occur with the utilization of co-sublayer. Additionally, the efficient supply of nutrients occurs with the presence of co-sublayers. The potential of biogas manufacture, which is denoted by l/kg Organic Dry Matter (ODM), is large with co-sublayer fermentation. This increase of potential exceeds the arithmetic mean of the biogas produced by fermenting with only one sublayer.

Naturally, the ammonia content is more in manure. This ammonia content has adverse effects on the methanogenic bacterial growth. In such situations, the biogas yield can be improved with the co-sublayer that is formed of plant material (energy crops, by-products from agriculture). The reason is that the manure is imparted with high buffering ability and nutrients, balancing the C/N ratio to decrease the ammonia defect.

The biogas yield highly relies on the raw materials' ratio of carbon to nitrogen. For an anaerobic digestion process with one stage, the optimal C/N ratio should vary between 15 and 25. In contrast, in case of a two-stage anaerobic digestion process, the optimal C/N ratio varies as 10-45 and 20-30 for stage 1 and stage 2, respectively.

Table-8 The carbon as well as the nitrogen contents and the C/N ratio in several sublayers of biogas yield

Organic substrate	Carbon content %	Nitrogen content %	C/N ratio
Chicken waste	45	3,0	15
Pig manure	7,8	0,65	13
Horse dung	10	0,42	24
Cow manure	7,3	0,29	25
Sheep dung	16	0,55	29
Stalks of soy and bean	41	1,3	32
Potato stalks	40	1,2	22
Tree leaves	41	1,0	41
Lucerne	48	2,6	18
Corn cobs	40	0,75	56
Rice straws	42	0,63	67
Barley straws	42	0,75	56
Wheat straws	46	0,53	87
Different herbs	15	0,6	25

Suitable media for carrying out the fermentation process and highest biogas yield is achievable, if optimal C/N values are chosen separately for the fermentation medium as well as the sublayers of biodegradable nature.

In case of the two-stage fermentation process, the C: N: P: S nutrient ratio is orderly set as 500: 15: 5: 3 and 600: 15: 5: 3, for stage 1 and stage 2.

2.5 Biogas plant -The schematic representation

Fig. 4 portrays the schematic diagram, which is associated with the biogas plant. At first, the receptor tank is fed with the household bio-waste and biomass, manure or both from energy crops. The fed ingredients of waste undergo a series of pretreatment procedures like, mixing, macerating, sterilization/ hygenization and concentrating. This mixture, in its fluid state, is transferred to a reactor through a pump. In order to retain a lesser transportation charge, the resultant feedstock is placed nearer to the plants. Heating of the insulated reactor to about 35°C/55°C creates perfect temperature for the bacterial survival, thereby inducing methane production. This temperature in the fermenter is evenly distributed to all bacteria through hydraulic/mechanic stirring equipment, so that all bacteria kinds receive nutrients evenly. The fermenters can be complete stirring reactor, plug flow reactor [25] [26], massive fermenter containing central stirring equipment and fermenter containing foil. The choice of the digester has to be made, in accordance with the fermentation material's dry mass content. The fermenter is built of beton, stainless steel and sheet as well as black steel. The biogas that is formed is then transferred to a storage tank, where the condensate separator filters enable water condensation and particle filteration. The produced biogas can also be transformed to natural gas with appropriate chemical treatment, which is then transferred to a gas net. Direct firing within a co-generating entity is also an application of biogas. A generator, in combination with the gas engine, generates heat as well as electricity in this case. The resulting heat allows fermenter heating or aids heating of household devices. A storage tank facilitates manure storage. The sludge is initially processed to free off the gas. Subsequently, the solid matter from the fluid of sludge is isolated by passing the sludge to a decanter.

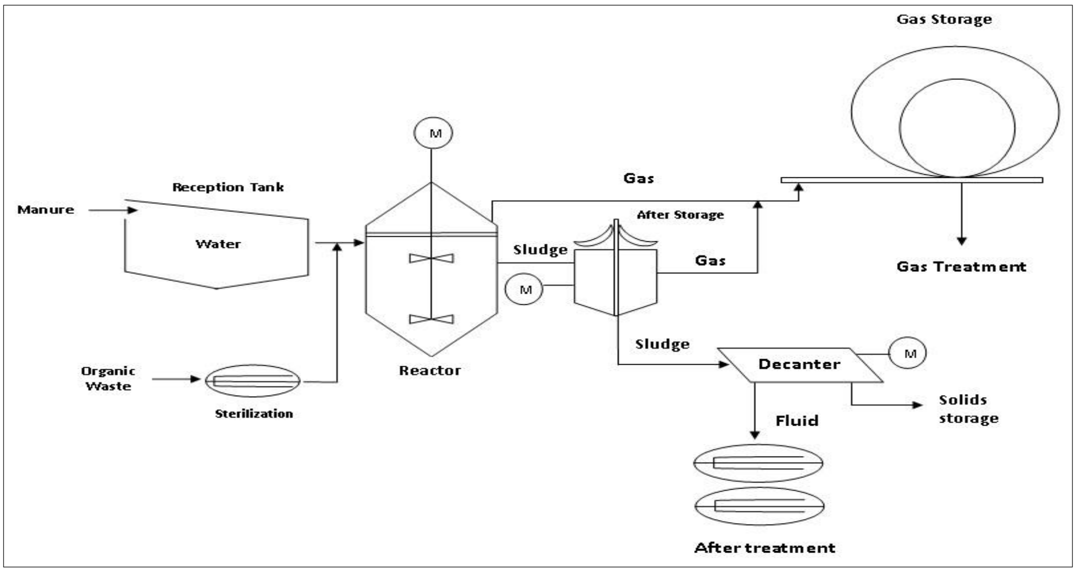

Figure- 3: Biogas plant-A schematic representation

Fig. 3 reveals the schematic of the dom biogas plant in the nations undergoing development. These system types are non-complex with inexpensive installation charges. Biogas technology has been installed and operated for about a century in most countries, which are already developed and undergoing development. Animal manure, waste matters and organic remains are usually the source of biogas in most agricultural households. In most biogas plants that are under operation, the fermenter has 10 m^3 as its nominal volume to render an approximate biogas of 1.5 m^3 to 4 m^3, daily.

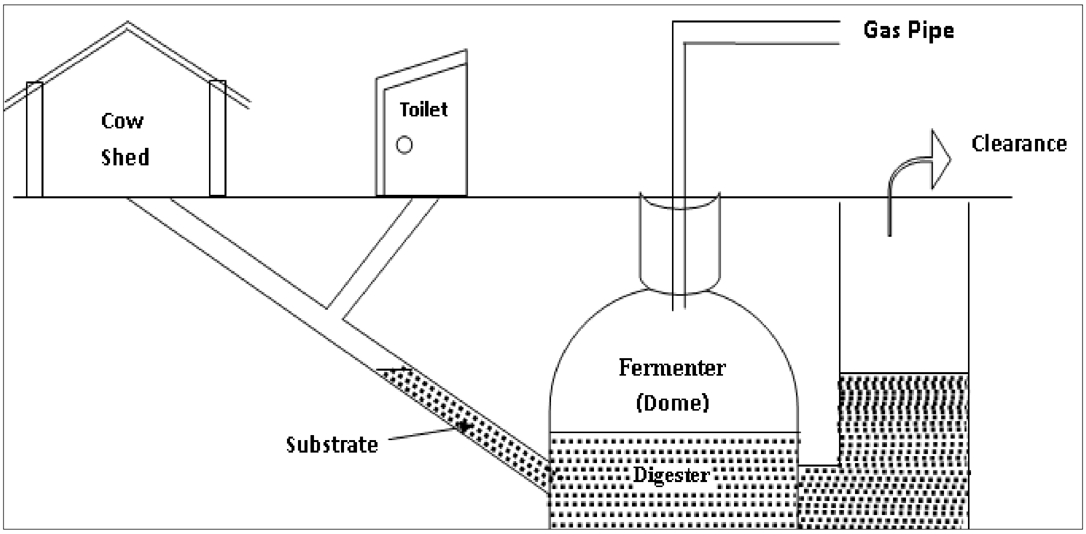

Figure 4: Dom biogas plant for developing countries

The cattle count in India is massive (250 million). The utilization of 1/3 volume of annual cattle manure can enable the installation of 12 million biogas plants, rendering about 17000 MW biogas potential. India, being a nation with increased rural regions, can adopt biogas technology to a greater extent. The reason is that the people of the rural regions can use the biogas produced from neighboring resources (like, organic as well as cattle waste) for cooking and satisfying other basic energy requirements.

2.6 The fermentation principle

Fig. 4 reveals the principle, being adopted for the fermenting process. The figure also depicts a close inter-dependence and control among the bacteria in a specific phase. The increased feeding of digestible matter renders methane, as fast as possible.

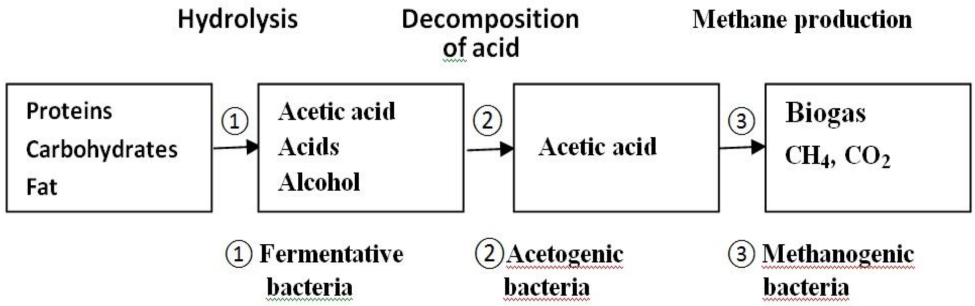

Figure 5: The fermentation principle

As the initial step, the carbohydrates to saccharide conversion [10], proteins to amino acid conversion, fats to fatty acid conversion and polymer to monomer conversion takes place. This conversion procedure is termed as hydrolysis, wherein the bacteria supporting fermentation remains active. NH_4, CO_2, hydrogen, water, alcohol and acetic acid are obtained as the intermediary products.

During the second stage, acetic acid formation from the rest of the complex organic molecules (such as, alcohol) takes place with the aid of acetogenic bacteria. Hence, the final decomposition product is the acetic acid. Once the acetic acid formation has been achieved at satisfactory levels, the methanogenic bacteria begin the conversion to methane. This final stage is solely responsible for producing methane, since the complete conversion of decomposed carbon into methane occurs at this stage. Finally, biogas with combustible nature is yielded as the output of fermentation.

Table-9 Various manure types and their associated compositions

	Pig manure (%)	Cow manure (%)	Chicken manure (%)
Ash	19	21	27
Crude fiber	20	40	15
Protein	19	15	29
FAT	4	4	4
Carbohydrates	38	20	15

3. EFFECT OF TEMPERATURE, PRESSURE, PH ETC

3.1 Temperature

The biogas quantity and quality is greatly influenced by the setting as well as the management of temperature in the process of anaerobic digestion [2]. Naturally, the microorganisms (specifically, the methanogenic kind of bacteria) that take part in anaerobic digestion are largely categorized into three types as follows:

- Thermophiles: It occupies the area of thermophilic digestive regime and the range of temperature for its operation is between 50°C and 60°C [27].
- Cryophiles (Psychrophiles): It occupies the area of cryophilic digestive regime and the range of temperature for its operation is between 12°C and 24°C.
- Mesophiles: It occupies the area of mesophilic digestive regime and the range of temperature for its operation is between 22°C and 40°C.

Fig. 6 is a graph, showing the traits exhibited by the aforesaid temperature regimes. The methanogenic bacteria are observed to have an increased growth rate, at this temperature regime. So, almost all biogas plants of recent years use this temperature range for their operation.

Experimental activities have shown that, a digester (with 1000 litres volume) involving the cryophile-type microorganisms has the ability of producing methane in the range of 200-300 liters, each day.

The merits offered by the anaerobic digestion process involving thermophilic regime, in comparison to the cryophilic/ mesophilic regimes are stated below.

1) Effective and rapid digestion with much decreased retention time (HRT)
2) Solid sublayers undergo improved digestion with significant utilization
3) Completely destroys the undesired pathogens as well as the seeds of weeds
4) Liquid isolation from solid fractions is highly feasible

However, demerits also occur during anaerobic digestion with thermophilic regime, as follows:

1) Elevated temperature levels cause energy to be consumed largely.

2) Stability levels are greatly affected

3) Inhibition of ammonia formation is large

As the temperature gets raised, so does the ammonia inhibition rate. So, choosing a low operational temperature decreases the inhibition rate. However, maintaining a temperature smaller than 500°C hinders the thermophilic microorganism growth. If the microorganism growth rate falls beneath the hydraulic retention time, the microorganisms start to get eliminated.

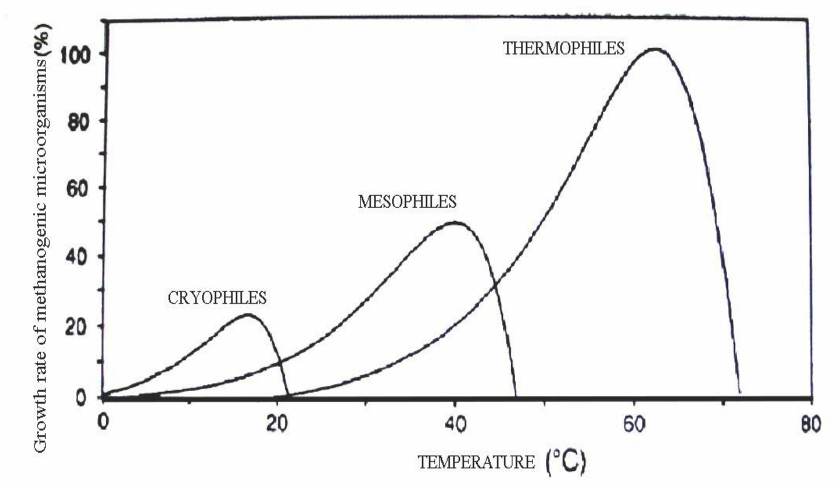

Figure-6: The temperature regimes, along with the methanogenic microorganism growth rate

The elevated temperature of the thermophilic regime induces more biochemical processes, causing massive production of methane for biogas with decreased viscosity and raised solubility.

Thermophilic regime consumes massive quantity of energy, which is counterbalanced by the massive biogas production.

As far as the temperature fluctuation is concerned, the thermophilic methanogenic bacteria shows increased sensitivity (even for +/-1^0 C change). Additionally, the adaptability to the new temperature takes more time, affecting biogas production to a greater extent. In contrast, the mesophilic type bacteria withstand a temperature change of +/-3^0 C, influencing the biogas production a little.

Practically, the thermophilic digesters outweigh the mesophilic digesters in conversion rate and biogas productivity with decreased hydraulic retention time or massive load.

3.2 Hydraulic Retention Time (HRT) and Retention time of the solids (SRT)

While biologically treating the organic remains, two parameters play a significant role and they are (i) the Hydraulic Retention Time (HRT) and (ii) the retention time of the solids (SRT). The HRT specifies the mean time of sublayer retention, along with the biomass contact, in the digester during anaerobic digestion. The HRT remains larger and smaller for compounds that are complex and simple, respectively. The reason is the hardness of decomposition associated with the compound.

The retention time of the solids (SRT) evaluates the ability of a biological system in meeting the effluent standards or the allowed pollutants' biodegradability levels. SRT has control over the microbe collection, residing within the reactor, to meet the waste stability levels. With larger SRT values, the operational stability is improved. Additionally, increased shock load as well as toxic tolerability occurs with rapid revival from toxicity. Hence, SRT and HRT takes control over the design procedure of easily and hardly digestible organic matters, respectively. The slowly-developing microbes like, the methanogenic bacteria is avoided from being removed out of the reactor, so as to yield a longer SRT. Longer HRT prevents the microbial mass eradication in greater amounts, when the digesters own stirrers and lack solid-separating facility as well as recycling. Yet, to retain prolonged HRT, the reactor should be of greater volume. Hence, the biogas production becomes expensive. So many rapid anaerobic digesters retain prolonged SRT, as the microbial mass are free of motion or heavily congested. Hence, HRT will be low enough to prevent the eradication of microbe collection in such digesters. The determination of HRT involves the digester volume as well the sublayer quantity being loaded in unit time, as follows:

$$\mathbf{HRT} = \frac{\mathbf{V_r}}{\mathbf{V_s}} \ \mathbf{[Days]}$$

where, V_S – the sublayer quantity loaded per time unit [m^3/t], V_r – volume associated with the digester [m^3] and HRT specifies the Hydraulic Retention Time [days].

With retention time, the count of eradicated microorganism in the digested matter (digestate) [30] is carefully observed to not exceed the microbe count after duplication. Usually, the anaerobic microbes involved in biogas production duplicates in not less than ten days. Maintaining the retention time to be smaller causes a smooth raw material flow and reduced biogas production. Hence, the retention time has to be chosen according tp the raw materials' decomposing rate.

3.3 Operating pressure

Pressure assumes a lead role in biogas production. Experimentally, it is confirmed that the biogas production halts with the hydrostatic pressure, which allows the methanogenic bacteria to raise across 400 - 500 mm H_2O. Lowering the hydrostatic pressure to the desired level resumes the production process. Hence, the digester design highly relies on the operating pressure.

The maximum depth of biogas production ranges between 4 m and 5 m (hydrostatic pressure below 400mm-500mm H_2O) during the vertical disposal of digesters with tens of meter height. The remaining substrate portion denies biogas production, unless the material is brought to surface through non-stop stirring.

The horizontal-flow digesters, wherein the height of the substrate is not greater the 3.5 m, tackles this issue of vertical digesters by releasing the biogas across the entire digest material.

3.4 pH associated with the reaction medium

The pH is well-set to enable all the processes of anaerobic digestion. For an optimum hydrolytic phase and the methane production phase, the pH is set as 5 and 6.5-8, respectively. A value of pH lower than six causes methane production to be greatly obstructed.

The acidogenic bacteria necessitate a pH between 5.5 and 7 during the hydrolytic phase [21], whereas the methanogenic bacteria desires the pH value to fall between 6.5 and 8 during the ending phase [22]. A single phase anaerobic digestion process prevents the organic sublayers to be digested, since the reactor owns a small pH value that falls rapidly with the Volatile Fatty Acid (VFA) generation. This, in turn, prevents the methanogenic bacteria from acting upon the organic matter. For single phase digesters with complete sublayer mixing, the pH and the needs of digester microorganism should be met.

The biogas processing systems may involve one or two phases. The two-phase systems have their methanogenic phase to be separated from the hydrolytic phase, in comparison to one-phase systems, enabling massive biogas productivity [20].

In such systems with two-phases, the pH varies as 5.2-6.3 and 6.7-7.5 for phase I and phase II, respectively. Further, the two phase systems have a prolonged methanogenic phase than the acidogenic phase. During the acedogenic phase, the suspended particles are retained by a separate digester. The two-phase systems hold good, when the cost of organic matter is high.

The operation and observation of two-phase systems is hard that the characteristics of the effluents in the acidogenic reactor (nutrients, VFS and pH) has to appropriately set, prior to charging of the methanogenic reactor.

The pH value undergoes changes with the change of temperature in the reaction medium. As the temperature rises, the soluble nature of CO_2 gets reduced. This may be stated as the reason for higher pH in thermophilic digesters, comparing the mesophilic digesters. In the mesophilic digester, carbonic acid is formed with increased CO_2 solubility, causing acidity raise.

While digestion takes place, ammonia that result from charging flux or protein degradation tend to raise the pH value. However, with VFA formation in the reaction medium, the pH is lowered. The reaction medium should possess adequate buffering potential for neutralizing the VFA formation.

In general, the management of pH is achieved with a bicarbonate buffer system. This buffer system has greater dependence on the acid/base constituents of reaction medium and the partial pressure associated with CO_2. The pH variations are tackled by the buffer system, in accordance with the accumulation of base/acid An exceeded buffer capacity usage cause high pH variation, resulting in the partial or complete halting of the process.

CONCLUSIONS

1. The anaerobic digestion involves raw materials of varied biomass resources, which should satisfy the following needs.
    - Possess organic matter of biodegradable nature
    - The pH should fall in-between 6.8 and 7.3
    - Should induce microbial growth through optimum C/N ratio selection
    - Should lack materials, hindering microbial growth
2. The sublayers formed of lignocelluloses [6] has to be heavily treated to decompose complex polymers into easily digestible elements.
3. Positive synergies of biogas yield occur with the utilization of co-sublayer. Additionally, the efficient supply of nutrients occurs with the presence of co-sublayers. The capacity of biogas manufacture, which is denoted by l/kg Organic Dry Matter (ODM), is large with co-sublayer fermentation. This increase of potential exceeds the arithmetic mean of the biogas produced by fermenting with only one sublayer.
4. The biogas yield highly relies on the raw materials' ratio of carbon to nitrogen. For an anaerobic digestion process with one stage, the optimal C/N ratio should vary between 15 and 25. In contrast, in case of a two-stage anaerobic digestion process, the optimal C/N ratio varies as 10-45 and 20-30 for stage 1 and stage 2, respectively.
5. The biogas quantity and quality is greatly influenced by the setting as well as the management of temperature in the process of anaerobic digestion. Naturally, the microorganisms (specifically, the methanogenic kind of bacteria) that take part in anaerobic digestion are largely categorized into three types as: *Mesophiles, Thermophiles* and *Cryophiles.* The elevated temperature of the thermophilic regime induces more biochemical processes, causing massive production of methane. Thermophilic regime consumes massive quantity of energy, which is counterbalanced by the massive biogas production.
6. The hydraulic retention time (HRT) assumes a lead role in the design of the anaerobic digestion process. A smaller HRT value induces well-defined raw material flux rate and decreased biogas production. In contrast, a prolonged HRT

causes the reactor volume to be large with increased expenses. The setting up of HRT has greater dependence over the volume of the digester as well as the loaded substrate in time unit. The anaerobic digesters, which are capable of owning prolonged Solid Retention Times (SRT) because of immobile or congested bacterial biomass, operate rapidly with smaller HRT and decreased expenses.

7. The pH is well-set to enable all the processes of anaerobic digestion. For an optimum hydrolytic phase and the methane production phase, the pH is set as 5 and 6.5-8, respectively. A value of pH lower than six causes methane production to be greatly obstructed. The acidogenic bacteria necessitate a pH between 5.5 and 7 during the hydrolytic phase, whereas the methanogenic bacteria desires the pH value to fall between 6.5 and 8 during the ending phase. In such biogas processing systems with two-phases, the pH varies as 5.2-6.3 and 6.7-7.5 for phase I and phase II, respectively.

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