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ANAEROBIC DIGESTION OF WATER HYACINTH - A REVIEW

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ABSTRACT

This paper reviews the experimental and theoretical studies conducted on different parameters of anaerobic digestion. The aquatic plant water hyacinth (Eichhornia crassipes) is one of the fastest growing aquatic weed is used for Anaerobic digestion with different inoculum such as poultry litter, cow dung, and primary sludge. The interactions various biochemical processes associated with anaerobic digestion are discussed together with other relevant aspects. The effects of pH, temperature, C/N ratio, consistency and dilution of feedstock, total Solid concentration, free ammonia, seeding, particle size, agitation, water content, oxygen concentration on the yield of methane production are discussed in this paper.

Keywords: Anaerobic digestion, Eichhornia crassipes, inoculum, biochemical processes, methane production.

I. INTRODUCTION

Global depletion of energy supply due to the continuous over utilization is being major problem of the present and future world community. Energy is one of the most important limiting factors to global prosperity. Currently, the global mix of fuels comes from fossil (78%), renewable (18%) and nuclear (4%) energy sources. As far as fuel is concerned, the rural population in developing countries heavily depends on traditional fuels, such as firewood, animal wastes and agricultural residues. The dependence on fossil fuels as primary energy source has led to global climate change, environmental degradation, and human health problems. Moreover, the recent rise in oil and natural gas prices may drive the current economy towards alternative energy sources such as biogas. Security of energy supply especially sustainable energy and reduction of CO_2 emission are priorities on agenda worldwide globally biogas fuel helps to reduce greenhouse gas emissions. Domestic biogas installations can reduce greenhouse gas (GHG) emissions in three ways: by changing the manure management modality; by substituting fossil fuels and non-renewable biomass for cooking (and to a smaller extent for lighting) with biogas, and; by substituting chemical fertilizer with bio slurry. Utilizing biogas as an alternative to fossil based fuels reduces the net amount of carbon dioxide emitted to the atmosphere. Biogas is regarded as carbon neutral fuel because CO_2 released is utilized by plants for photosynthesis which creates organic matter from it. The use of renewable energy sources can contribute to solve the present and future energy problems. Among the alternative energy sources, biogas production from green energy crops and organic wastes has world wide application as it yields a good quality fuel and fermented slurry, which may be used as a manure or soil conditioner. In addition, it helps to a great extent in the abatement of pollution. Biogas is an alternative and renewable energy source produced through anaerobic digestion of organic matter by various specialized groups of bacteria and fungi (e.g. *Neocallimastix frontalis)* in several successive steps. The end product of this anaerobic digestion is production of mainly the combustible gas, methane (CH_4) and a liquid effluent [4]. Biogas technology is a modern and eco-friendly technology based on the decomposition of organic materials in anaerobic environment at suitable and stable temperature by anaerobic bacteria. Anaerobic digestion consists of several interdependent, complex sequential and parallel biological reactions in the absence of oxygen, during which the products from one group of microorganisms serve as the substrates for the next, resulting in transformation of organic matter (biomass) mainly into a mixture of methane and carbon dioxide commonly referred to as biogas. In general, biogas consists of 55 to 75% methane and 30 to 45% carbon dioxide. However, depending on the source of organic matter and management of the anaerobic digestion process, small amounts of other gases such as ammonia (NH_3), hydrogen sulfide (H_2S), and water vapor may be present. Biogas is also a proven technology that contributes to the reduction of the deforestation rate and helps to save the trees to sequester more carbon from the atmosphere and the local effects of trees being cut down that otherwise cause soil erosion, desertification, loss of soil fertility, and landslides.

1.1 Water Hyacinth (*Eichhornia Crassipes*)

Water hyacinth (*Eichhornia crassipes*) is a fast growing perennial aquatic plant widely distributed throughout the world [7]. This tropical plant which belongs to the family Pontederiaceae can cause infestations over large areas of water resources and consequently lead to series of problems. These include reduction of biodiversity, blockage of rivers and drainage system, depletion of dissolved oxygen, alteration on water chemistry, and involvement in environmental pollution. Therefore, on one hand, attempts have been geared towards the use of biological, chemical and mechanical approaches for preventing the spread of, or eradication of water hyacinth. On the other hand, much attention has been focused on the potentials and constraints of using water hyacinth as a biomass for biogas production. Several authors have tried to put an approximate figure to the economic consequences caused due to water hyacinths problem specifically on utilization of water for irrigation. The annual water loss through evapo-transpiration due to water hyacinth in Sudan would be enough to irrigate more than 400 ha of land. Water Hyacinth proves to be a promising renewable source of energy in the form of biogas. . It was found

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through laboratory experiments that the rate of biogas production as well as the quantity of biogas is higher upon using dry water hyacinth as compared to fresh water hyacinth [12].

1.2 Biogas

Biogas is an alternative and renewable energy source produced through the anaerobic digestion process, which is a natural biological process in which an interlaced community of bacteria cooperates to obtain a stable fermentation through assimilation, transformation and decomposition of the organic matter present in waste into biogas. This is a complex multistep process in terms of microbiology, where the organic material is degraded to obtain methane gas under the absence of oxygen. Biogas consists primarily of utilizable methane (CH_4) and inert carbon dioxide (CO_2), which are both colorless and odorless. However, depending on the source of the organic matter and the management of the anaerobic digestion process, small amounts of other gases may be present. Methane has 20 times more greenhouse gas potential than carbon dioxide, so the capture and burning of methane significantly reduces the greenhouse gas effect [9].

II. ANAEROBIC DIGESTION

The anaerobic digestion process involves a high number of microorganisms, which convert the feedstock to the methane and carbon dioxide rich biogas through a series of biochemical reactions that can be described by four steps, viz. hydrolysis, acidogenesis, acetogenesis and methanogenesis. These microorganisms include hydrolytic bacteria, acid forming bacteria (acidogens), acetic acid-forming bacteria (acetogens) and methanogenic bacteria (methanogens).

2.1.1 Hydrolysis

In the first step, the hydrolysis, the complex molecules of carbohydrates, proteins and lipids are split into simple components (sugars, fatty acids and amino acids) by the help of extra-cellular enzymes secreted by microorganisms which are mostly obligate anaerobes. A complex consortium of microorganisms participates in the hydrolysis and fermentation of organic material. It is first step is inhibited by lignocellulose containing materials, which are degraded only very slowly or incompletely [6].

2.1.2 Acidogenesis

It is second phase; the monomers produced in the hydrolysis phase are further degraded by fermentative bacteria into short-chain organic acids, with one to five carbons (valeric acid, butyric acid, propionic acid, acetic acid, and formic acid), alcohols, hydrogen, ammonia, and carbon dioxide. In a stable process, with low partial pressure of hydrogen, the main products formed by the fermentative bacteria are acetate, carbon dioxide, and hydrogen. Acidogenesis products are volatile fatty acids (VFA), alcohols, aldehydes, hydrogen and carbon dioxide. Decomposers are fermentative bacteria or anaerobic oxidizers. When the partial pressure of hydrogen is high, more intermediates such as volatile fatty acids and alcohols are formed.

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2.1.3 Acetogenesis

In the third step, acetogenesis, the products of the acidification are converted into acetic acids, hydrogen, and carbon dioxide by acetogenic bacteria. Acetogenic bacteria such as *Syntrobacter wolini* and *Syntrphomonas wolfei* convert volatile fatty acids (e.g. propionic acid and butyric acid) and alcohol into acetate, hydrogen, and carbon dioxide, which are used in methanogenesis. The acetogenesis is regarded as thermodynamically unfavorable unless the hydrogen partial pressure is kept below 10^{-3} atm, by efficient hydrogen removal pathway of hydrogen-consuming organisms such as hydrogenotrophic methanogens and/or homoacetogens. The first three steps of anaerobic digestion are often grouped together as acid fermentation. In the acid fermentation, no organic material is removed from the liquid phase: it is transformed into a form suitable as substrate for the subsequent process of methanogenesis.

2.1.4 Methanogenesis

The last step in the anaerobic digestion is the methanogenesis. The methanogenic microorganisms work under strictly anaerobic conditions. The methanogens, which belong to the group archaea, differ from the other organisms in the anaerobic reactor, which are bacteria. Archaea are more sensitive than bacteria with regards to environmental stresses in the reactor, such as pH, or toxic compounds such as heavy metals or different toxic organic materials. The methanogens mainly use acetate, carbon dioxide, and hydrogen, but also methylamines, alcohols, and formate for the production of methane. About 70% of the methane production arises from the acetate, and about 30% of the methane arises from hydrogen and carbon dioxide. The methanogens have the longest generation times (2-25 days) of the microorganisms in the reactor, which makes this step the most time-limiting step for easily hydrolyzed materials.

2.2 Factors Affecting Biogas Production

2.2.1. pH

The substrate's acidity is measured by pH, which is an important parameter affecting the growth of microbes during anaerobic digestion [5]. Different researchers forward the optimal pH for optimal performance of the microbes. According to Yadvika *et al*. (2004) [5] the pH within the digester should be kept in the range of 6.8 - 8.0. The pH value below or above this interval may restrain the process in the reactor since micro-organisms and their enzymes are sensitive to pH deviation. The highest production of biogas occurs at neutral pH value of 7[14]. The pH of the digester will decrease initially when organic material is first loaded into the digester and volatile acids are produced. However, as the methane-producing bacteria consume the acids, alkalinity is produced and the pH of the digester will increase and then stabilize.

In a properly operating anaerobic digester, a pH of 6.8 to 7.2 occurs as volatile acids are converted to methane and carbon dioxide. How much a digestion process can tolerate changes in pH depends on the carbonate alkalinity. Alkalinity is mainly present in the form of bicarbonates in equilibrium with carbon dioxide gas at a given pH. Therefore, pH depends on the partial pressure of CO_2 and balance between acid

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and alkaline components in the liquid phase and can be used as indicator of methanogenic consortium performance. Therefore, to enhance the buffer capacity in an anaerobic system, an adequate ammonia concentration would be beneficial due to the formation of NH_4HCO_3.

2.2.2. Temperature

Temperature is an important extrinsic factor that significantly affects the reproduction and activities of anaerobic microbes. Depending upon the temperature at which the process is carried out, biomethanation or AD of organic wastes is basically of three types. Biomethanation carried out at a temperature range of 45–60 °C is referred to as 'thermophilic', whereas that carried out at a temperature range of 20–45 °C is known as 'mesophilic', which is the most used process. The AD of organic matter at low temperatures (<20 °C) is known as 'psychrophilic' digestion. Most reactors operate at either mesophilic or thermophilic temperature, with optima at 35 and 55 °C, respectively. The higher yield of biogas occurs at thermophilic range 56°C than the mesophilic temperature range. In general, high temperature gives a higher methane production rate and allows higher loading rate, thus decreasing the reactor volume needed for a specific material. The methanogens are inactive in extreme high and low temperatures. Anaerobic digestion at thermophilic temperature also gives a better sanitation, i.e., killing of pathogens. However, Yadvika *et al*. (2004) [5] reported that thermophilic processes are more sensitive to high levels of ammonia released from protein rich materials.

2.2.3. Carbon to nitrogen (C/N) ratio

The relationship between the amount of carbon and nitrogen present in organic materials expressed in terms of the Carbon/Nitrogen (C/N) ratio. A C/N ratio ranging from 20 to 30 is considered optimum for anaerobic digestion (FAO, 1996). If the C/N ratio is very high the nitrogen will be consumed rapidly by methanogens for meeting their protein requirements and will no longer react on the left over carbon content of the material. As a result gas production will be low. On the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of ammonia. Solid concentration in the feed material is also crucial to ensure sufficient gas production as well as easy mixing and handling. The concentration of total solids in the input suspension can be varied within the range of 20 to 100g/liter.

In practice it is recommended to limit the total solids concentration to the range of 20 to 30 g/liter. In Nepal, 6 kg of cow dung per m^3 of digester liquid volume is used (FAO, 1996). Cow-dung has a solid concentration of about 20% and therefore, it is recommended that dung and water are mixed in a 1:1 ratio to attain the desired level of solids. One kilogram of dung produces about 40 liters of biogas. A family size biogas plant (two cubic meters) requires 50 kg of dung and equal amount of water to produce 2000 liter of gas per day. This amount of gas suffices the daily cooking requirement of a family consisting of four to five members.

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2.3.4. Consistency and dilution of feedstock

All waste materials fed to a biogas plant consist of solid substance volatile organic matter and non-volatile matter (fixed solids) and water. During anaerobic fermentation process, volatile solids undergo digestion and non-volatile solids remain unaffected. According to a finding by The Energy and Resources Institute, fresh cattle waste consists of approximately 20% total solid (TS) and 80% water. TS, in turn, consist of 70% Volatile solids and 30% fixed solid. For optimum gas yield through anaerobic fermentation, normally, 8-10% TS in feed is required. This is achieved by making slurry of fresh cattle dung in water in the ratio of 1:1. However, if the dung is in dry form, the quantity of water has to be increased accordingly to arrive at the desired consistency of the input (i.e., ratio could vary from 1:1.25 to even 1:2).

If the dung is too diluted, the solid particles will settle down into the digester and if it is too thick, the particles impede the flow of the gas formed at the lower part of the digester. In both cases, gas production will be less than optimum [1]. It is also necessary to remove inert materials such as stones from the inlet before feeding the slurry into the digester. Otherwise, the effective volume of digester will decrease.

2.3.5. Water content

Bacteria take up the available substrates in dissolved form. Therefore, biogas production and the water content of the initial material are interdependent. Rilling (2005) [6] reported that when the water content is below 20% by weight, hardly any biogas is produced. Optimum moisture content has to be maintained in the digester and the water content should be kept in the range of 60-95 %. Anaerobic digestion of organics will proceed best if the input material consists of roughly 8 % solids.

For domestic digesters, TS content should not be too high, otherwise substrate would not slide easily through the inlet of the digester and if toxins are present, such as ammonium in high concentrations, high TS is likely to affect bacteria more than when the substrate is diluted. Alternatively, TS content should not be too low, otherwise the feedstock is very dilute, and a large digester volume is required. Water content is one of the very important parameters affecting AD of solid wastes. There are two main reasons viz.; (a) water makes possible the movement and growth of bacteria by facilitating the dissolution and transport of nutrient and (b) water reduces the limitation of mass transfer of non-homogenous or particulate substrates.

2.3.6. Free ammonia

A number of studies have cited the inhibitory effects of free ammonia (NH_3) on the metabolism of methanogens . As ammonia is added to a digester, the pH increases until a chemical equilibrium is reached. However, as ammonia inhibits methanogen metabolism, VFAs accumulate, resulting in a lower pH and a lower concentration of free ammonia. Sterling *et al*. (2001) [3] concluded that total biogas production was unaffected by small increases in ammonia nitrogen while higher increases reduces biogas production to 50% of the original rate. However, the underlying reason of this effect is still unknown. It

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was also found that the free ammonia concentration not only affects the acetate-utilizing bacteria, but also the hydrolysis and acidification processes. By controlling pH value lower it is possible to control the production of ammonia but it lowers yield of biogas production.

2.3.7. Seeding

To start up a new anaerobic process, it is critical to use inoculums of microorganisms to commence the fermentation process. The common seeding materials include digested sludge from a running biogas plant or material from sewage. Digested sludge is the best inoculum source for anaerobic thermophilic digestion of the treatment of organic fraction of municipal solid waste at dry conditions (30% TS). Inoculums caused biogas production rate and efficiency increase more than two times as compared to substrate without inoculums. The addition of fresh cow dung to the batch reactor as part of the starter improves the biogas production. When poultry litter was used as inoculum for anaerobic process methane yield was best on digester with content of 75% of inoculum [11].

2.3.8. Particle size

The production of biogas is also affected by particle size of the substrate. Too big particle size is problematic for microbes to digest and it can also result in blockage in the digester, whereas small particle size gives a large surface area for substrate adsorption and thus allows the increased microbial activity followed by increase in the production of gas. Large amount of biogas was obtained from the grounded water hyacinth than chopped water hyacinth. Degradation of the substrate and biogas production potential of the water hyacinth could be significantly increased by pre-treatment such as reduction of particles size. These results suggest that reduction of the particles size of the substrate in conjunction with the optimized microbial growth could improve the methane yields in anaerobic digestion processes [15].

2.3.9. Agitation

The close contact between micro-organisms and the substrate material is important for an efficient digestion process. The agitation of the digester contents has a number of benefits, one of the most obvious being that it helps to mix up material, evening out any localized concentrations, thus also helping to stop the formation of ‘dead zones’ or scum. In addition, it increases the waste’s availability to the bacteria, helps remove and disperse metabolic products and also acts to ensure a more uniform temperature within the digester. There have been some suggestions that efficient mixing enhances methane production, but the evidence is inconclusive, so it seems likely that this may only be of noticeable benefit for some systems or operational regimes. Mixing also promotes heat transfer, particle size reduction as digestion progresses and release of produced gas from the digester contents. There is significant stirring effect on the anaerobic digestion only when seed sludge from a biogas plant was used as a starter. In this case, the experiments without stirring yielded, without starter, only about 50% of the expected biogas for the investigated substrates.

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2.3.10. Total solids

Total solids mean the amount of solid particles in the unit volume of the slurry and they usually expressed in the percentage form [2].The percentage of total solid should be between 5% and 12% while other source reported that the best biogas production occur when total solid is ranged from 7% to 10% because of avoiding solids settling down or impeding the flow of gas formed at the lower part of digester. Therefore; dilution of organic substrate or wastes with water to achieve the desirable total solids percentage is required. The total solid concentration of 99 g TS/l produces the maximum biogas yield as per the experiment done different concentration of total solid in anaerobic digestion process [13].

2.3.11. Effects of Oxygen in *AD*

It is quite natural that some amount of oxygen can reach anaerobic digesters unintentionally as the reactors are operated within an aerobic open environment, especially through interactions with the surroundings such as by feeding and mixing. Most anaerobic digesters are therefore subjected to minute and varying aerobic loading conditions. The possible effects of such aeration are neither extensively quantified nor handled in standard AD models. It is commonly perceived that oxygen acts as an inhibitory and toxic agent in AD due to the involvement of strictly anaerobic microorganism group of acetogens and methanogens [10]. Also, aerobic conversion of soluble organic matter into CO_2 by aerobic respiration is likely. Thus, it was believed that reactor instabilities, slow start-ups, low methane yields and even total reactor failures might occur due to oxygen entering anaerobic digesters . Due to this negative perception, inoculums used in anaerobic digesters are even de-aerated before commencing reactor operation; sometimes oxygen scavenging chemicals (e.g. sodium sulfide) are also being added. Conversely, improved hydrolysis of particulate matter in AD is observed in the presence of oxygen. All non- soluble and long chain organic matter should go through this initial hydrolysis stage before fermentation or methanogenesis, in which the particulate matter would undergo decomposition and solubilization by the activity of enzymes (such as *protease, amylase, etc*.) that are being extracellularly excreted by fermentative (acedogenic) bacteria. Since hydrolysis is often the rate limiting reaction stage when the substrate is composed of particulate organic matter enhanced hydrolysis can greatly benefit the overall process efficiency. It is commonly known that hydrolysis rates are significantly higher under aerobic and anoxic conditions compared to anaerobic conditions. Botheju *et al*. [10] demonstrated the possibility of the existence of an optimum oxygenation level which would yield a maximum methane generation in AD.

III. CONCLUSION

Biogas can be produced from Water Hyacinth. Water Hyacinth proves to be a promising renewable source of energy in the form of biogas. Dry water hyacinth produces more production of methane than fresh water hyacinth. Therefore the water hyacinth should be dried before use. Inoculation with poultry litter contents, cow dung and primary sludge will increase biogas rate of production and ultimate yield produces by poultry litter.

The anaerobic digestion is affected by pH, at neutral pH value in the mehanogenesis process the production rate of methane is higher. The mesophilic temperature range is suitable for more yield of methane than mesophilic range. In consideration of C/N ratio the value 20-30 is optimum range for anaerobic digestion. Total Solid concentration should be in the range of 7% to 10% so that the yield of biogas more than any other concentration. Smaller particle size of feedstock gives more surface area to the microorganism for the process of decomposition of organic matter. Oxygen concentration in the process of anaerobic decomposition acts as toxic agent for anaerobic bacteria hence the overall production rate and methane yield gets lowered.

REFERENCES

[1] Anonymous, 1981. Biogas technology and utilization. A status Report. Department of Science and Technology, Government of India, New Delhi.20-46.098UUJK, L.

[2] FAO/CMS, (1996). A System Approach to Biogas Technology. Training manual for extension, http://www.fao.org

[3] Sterling, M.C., R.E. Lacey, C.R. Engler and S.C. Ricke, "Effects of ammonia nitrogen on H_2 and CH_4 production during anaerobic digestion of dairy cattle manure". Bioresource.Technol. 77:9-18. 2001

[4] Murto, M., L. Bjornsson and B. Mattiasson , "Impact of food industrial waste on anaerobic co-digestion of sewage sludge and pig manure". J. Environ. Manage 70:101– 107. 2004

[5] Yadvika, Santosh, T.R. Sreekrishnan, S. Kohli, and Rana, "Enhancement of biogas production from solid substrates using different technique". Bioresour. Technol. 95:1– 10. 2004

[6] Rilling, N., "Anaerobic Fermentation of Wet and Semidry Garbage Waste Fractions." Environmental Biotechnology. Concepts and Applications.: pp. 355-373: 2005

[7] Anushree, "Environmental challenge a vis opportunity: The case of water hyacinth". Environment International 33: 122–138. 2007

[8] Zaher, U., D. Cheong, B. Wu and S. Chen, Producing Energy and Fertilizer from Organic Municipal Solid Waste. Washington State University. Washington. 2007

[9] Atkins, M., M. Fuchs, A. Hoffman and N. Wilhelm, 2008. Plastic Tubular Biogas Digesters: A Pilot Project in Uru, Kilimanjaro, Tanzania.

[10] D.Botheju, B. Lie, and R. Bakke, "Oxygen effects in Anaerobic Digestion – II", Modeling, Identification and Control, vol. 31, no. 2, pp. 55-65, 2010

[11] Jagadish H. Patil, Malourdu Antony Raj, P. L. Muralidhara, S. M. Desai, and G. K. Mahadeva Raju, "Kinetics of Anaerobic Digestion of Water Hyacinth Using Poultry Litter as Inoculum", International Journal of Environmental Science and Development, Vol. 3, No. 2, April 2012

[12] Kunatsa T , Madiye L, Chikuku T, Shonhiwa C, Musademba D, "Feasibility Study of Biogas Production from Water Hyacinth", International Journal of Engineering and Technology Volume 3 No. 2, February, 2013

[13] Sajeena Beevi.B, Jose P.P , Dr.G.Madhu, " Effect of total solid concentration on anaerobic digestion of the organic fraction of municipal solid waste", International Journal of Scientific and Research Publications, Volume 3, Issue 8, ISSN 2250-3153, August 2013

[14] Bani.Kheiredine, Kerroum. Derbal, Mossaab. Bencheikh-Lehocine, "Effect of Starting pH on the Produced Methane from Dairy Wastewater in Thermophilic Phase", Chemical Engineering Transactions, Vol. 38,ISSN 2283-9216 ,2014

[15] Yasini Nalinga and Isack Legonda, "The Effect Of Particles Size On Biogas Production", International Journal Of Innovative Research In Technology & Science , Volume 4, Number 2, And ISSN: 2321-1156, March 2016