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Operational Conditions of Anaerobic Digestion and their Optimization for Enhanced Biogas Production – A Review

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Abstract- In 21[st] century, sustainable development has a colossal and crucial role to play in global environmental apprehensions such as GHG emission from fossil fuel combustion, damage to the environment by the haphazard disposal of waste. Under these current circumstances, biogas production technology has flourished and has proved to be a meritorious success story today. Biogas is produced by microbial anaerobic digestion of organic wastes such as animal waste, plant material, sewage crops etc. Biogas principally comprises of 50% -60% of methane and 25%-45% of CO_2. In the recent past, research on this technology has been limited to some extent due to the complex phenomenon existed with various factors and parameters influencing it. Optimization of parameters like organic loading rate, pH, C/N ratio, total solids, volatile solids content hydraulic retention time and temperature of the digester will have a synergistic effect on the yield. Adopting the principle of co-digestion, for biogas production from mixture of wastes is found to be an effective solution for optimization of various factors. Hence, this paper reviews the research carried on biogas production from various bio degradable waste mixtures in different operational conditions. This review has also emphasized on several physical, thermo-chemical and biological pre-treatments and alterations carried during the anaerobic digestion for enhance result. Micronutrient supplementation for the mixture of wastes is expected to have a synergistic effect on microbial growth. The future research in renewable energy studies targeting this arena are the need of hour

Index Terms- Biogas: Anaerobic digestion, Renewable energy, Micronutrient supplementation.

I. Introduction

Sustainable development is the major agenda for the developing countries like India. Environmental challenges are arising from the disposal of waste produced by the anthropogenic activities. Methods like anaerobic digestion will serve as a green alternative to treat these wastes. Anaerobic digestion workstation ends up with carbon dioxide and methane production. Amplifying the methane content of biogas is one of the existing goals of bio gasification research, methanogen bacteria convert organic compounds to methane [2]. Co digestion of waste material is generating unsought difficulties like bacteria inhibition, toxicity etc., particularly in biogas production [5]. Taking in to account the huge water and biological content, they decompose quickly and end up with rotten stink. The procedure is broadly used for energy production because the methane-rich biogas produced is treated a renewable energy resource. [3] A typical example is the anaerobic digestion of vegetable and fruit residues, the availability of which is dependent upon both climatic conditions and the season of the year. Therefore assessing the potential contribution of co-digestion in alleviating any adverse economic impacts of feedstock seasonable variability will also require an in-depth understanding of the effects of operating anaerobic digesters in time variant cycles involving one or more of the contributing feedstock [10].Qualitative and quantitative improvement of biogas and methane yield from anaerobic co-digestion is known to show high stability. The thermal analysis technique is proven to be a novel and practical tool for assessing the stability of biological residues [11]

1.1 Anaerobic digestion: Anaerobic digestion can be used to breakdown biodegradable waste and convert to energy. Methane is a biogas that can be efficiently converted in to electricity [12]. Anaerobic Digestion (AD) is carried out in the absence of oxygen and it ends up with methane generation and treats waste for environmental welfare. Total atmospheric methane exhalation ranges from 15% to 45 % are mainly based from flooded soils with 100-200 CH4Tg per year, Cattle (65-100 Tg/y) and rice fields (25-150 Tg/y) [13] Four different steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis are the main reduction process involves in AD listed in "fig 1" [14]

Hydrolysis: Process carried out by bacteroides, clostridia and facultative bacteria that involve transformation of insoluble organic material in to soluble compounds. Importance of this stage is very high due to degradation of large organic molecule by microorganism and degradation rate is highly depended able on nature of substrate

Acidogenesis (acidification phase**):** During this stage, simplified organic compounds taken over by facultative and obligatory anaerobic bacteria end up with formation of organic acids , alcohols and hydrogen production

Acetogenesis: During this process organic matter which cannot be converted to methane by methanogenic bacteria were supplemented in to methanogenic substrate. Later on, acetate bacteria convert the acid phase products into acetates and hydrogen

Methanogenesis: Most important chemical conversion process among entire anaerobic digestion end up with methane and carbon dioxide. [17]

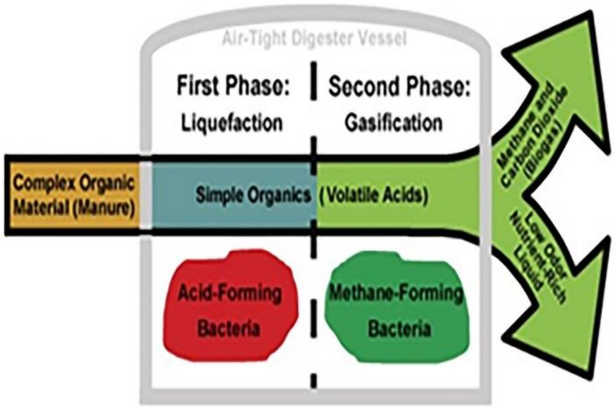

Fig 1. Biogas production methodology

1.2 Different waste material for biogas production

Animal waste: The capability of cow dung for biogas production was explored, effective methodology to utilize cow dung for biogas production was reported [23] poultry waste yields biogas, around 60% methane, 38% carbon dioxide because of the high availability and it is an easy method for disposal [24] swine manure is the major source of toxic gas emission and foul smell generation, biogas production can be a promising technology to rectify the same [25]

Vegetable waste: Higher Moisture content in the vegetable waste promotes the anaerobic digestion. Fruit and vegetable wastes co digestion with cow dung is an alternative way to improve biogas production, elemental analysis of vegetables waste showed (65–70%) of biodegradability as a feedstock for anaerobic digestion [26]

Agriculture waste: Rich in carbon and nitrogen making them suitable for biogas production. Studies reports shows various methods for utilizing agricultural and forestry waste in Europe, energy value of Europe from biodegradable waste estimated to $4.5x10^{12}$MJ/year. Greenhouse gas, big threat to climatic change should be reutilized with various methods comprise aerobic digestion and anaerobic digestion. Studies shows and average range between (18,630KJ/m^3-26,081 KJ/$m^{3)}$ energy can be derived from bio waste yearly. Anaerobic methods happens in open atmosphere release methane gas to environment directly and leads to drastic climatic changes more than carbon dioxide, methane gas can be produced using bio digesters[15]

II. REVIEW OF THE CO DIGESTION MATERIALS

SajeenaBeevi.B, et al utilized organic municipal waste degradation with a retention time of 100 days under room temperature. Fabricated digesters of 2 liter capacity were used at anaerobic condition and the contents were restricted to 1.6 liters. pH inside the digester decreased initially, due to higher volatile fatty acid concentration in municipal solid waste. Hence regular pH alteration were carried out to maintain range 6.8 to 7.4 using 6N NaoH buffering solution. Results have revealed decreased Biogas production with reduction in substrate concentration and low C/N ratio. Municipal waste after final degradation was suitable for organic manure. Organic loading rate of 99gm TS/liter was optimum for efficient degradation of municipal solid waste [1]

Salma A. Iqbal et al studies on anaerobic digestion of kitchen waste with cow dung reported positive. The study was conducted to evaluate the influence of organic loading rate and temperature on biogas production. The experiment is initially carried out at atmospheric temperature and later on at constant temperature of 37^0C. Maximum yield of biogas production is noticed at constant temperature. OLR at 200gm/L had higher yield than other loading rates. 0.8 – 5.5 times increase in the biogas yield is noticed due to co-digestion when compared to mono digestion. The experiment has also studied the effect of sodium hydroxide addition to increase biodegradability and bio gas production, with different NaoH doses of 1.0%, 1.5% and 2%. Optimum output obtained at 1.5% NaoH solution. [4]

Sanaei-MoghadamA et al made a study on biogas production using potato pulp and cow dung, the experiment is conducted to evaluate energy production from potato waste collected from chips factory, by introducing laboratory plant setup of Continuous Stirred Tank Reactors (CSTR) to different ratios of substrate 20:80,50:50,80:20,0:100 (potato :cow manure). Parameters like (pH, temperature, water content, stirring) were maintained within in the optimum range for gas production. Adding sodium bicarbonate solution with 10% concentration to all substrates for maintaining pH was done throughout the process. Finally, the best methane results was production of 348L (kg/VS) from the ratio of 20:80, with a methane quality of 62.1%.Other combinations yielded more bio gas than cow manure alone[5]

Xue Qin et al has conducted an experiment to study the biogas production potential of 12 food wastes, which are divided into 4 categories i.e., staple food, vegetables, meat and fruits. Digesters were placed inside water bath and maintained at constant temperature of 35^0C with a speed of 100 rpm inside and biochemical methane potential test was carried out to find out methane yield. Initial pH was measured and Na2CO3 buffer solution was added at regular intervals to maintain the pH around 7. Carbohydrates content was high in vegetables, protein was abundant in meat and fruits had high moisture content. Fermentation nature for food substrate varied with total days of HRT. Final results showed that all pH values ranged from 7.02-7.35 lowest being for apple waste and highest for cooked chicken respectively. Final ammonia concentration of vegetables , chicken and steamed bread had increased which ranged from 60.46 to 259.8 mg ammonia –N/L, and showed no major impact on anaerobic digestion with this huge variations methane quality is better for meat waste[6]

Marta Oleszek1 et al studies from biogas production from waste materials which are unsuitable for the preparation of silage due to low sugar and high protein content. Waste material mainly consisted of cucumber and tomato residues in the form of shoot stems and leaves. Post fermentation sludge collected from active agricultural biogas plant was used as inoculums with substrate ratio of (1:1). Studies were carried out with different combinations of fresh substrate ,ensiled residues and inoculums under controlled parameters like temperature maintained at 37°C, pH at 7 (initially) and total solids and volatile solids of inoculums showing 3.8 and 2.5% respectively .Volume of biogas was measured on a daily basis by water displacement method . Samples of tomato and cucumber residues were dried, milled and made into capsule form using tablet press. Later on, lower heating values were calculated with moisture level (0%,25%,75%) for calorimetric analysis, results showed fermentation of fresh tomato residue yielded maximum (606.9ml g^{-1}VS) and ensiled cucumber waste was the least (327.3ml g^{-1} VS). Ensiled waste began to ferment faster than fresh residues and best biogas quality was obtained from fresh cucumber. [7]

XumengGe et al has studied anaerobic digestion of tropical biomass like forestry waste, alibiza and food waste limited to taro, papaya and sweet potato for conversion of waste into green energy. The experiment is carried in two different conditions i.e., solid state AD and liquid state AD. Reaction temperature was kept at 37^{o}C with constant stirring mechanism kept at 100 rpm for all digesters .Biogas composition and volume was measured every 2 days and hydraulic retention time was maintained for 24 days. Pretreatment methods were opted with environmental fungi to speed up reaction rate and methane yield. Co digestion of different combinations of papaya, sweet potato, taro and taro skin values ranges with 371 to 411kg^{-1}VS and methane yield varied initially but became linear after 8 days. Methane yield from food waste content reached within the limits of 70%-80% which is much greater when compared to yield derived from fallen tree leaves of Alibiza and chips .Anaerobic digestion of Alibiza showed highest volumetric production compared to other tropical bio waste. Thus, it can be concluded that this has a promising future in the field of bio energy inputs. [8]

Efisio Antonio Scan et al studied the biogas production from the anaerobic mono substrate digestion of fruit and vegetable wastes. The temperature is maintained at mesophilic conditions (35 ± 0^{o} C) throughout the study with a HRT of 27 days. The optimum OLR is 2.5 to 3.0 Kg VS/m^3 and the average biogas production was about 0.78 Nm^3/Kg VS. The optimum combination was used to evaluate the performance of a full scale power plant. [9]

Zhang Zhengyun, et al carried research was on anaerobic digestion for methane production from banana stalk and peel with different concentration ratios at mesophilic temperature (35ºC). The main obstacle during initial days was acidification due to organic acids developed by hydrolytic bacteria. After the 12th day of conducting the process, methanogenic bacteria was getting cultivated more and overcame low pH due to initial acidification. Different concentrations of banana stalk and peel (5% and 7%) were used for both digesters and it was observed that increase in concentrations delayed biogas production. To attain peak condition, the process favored cumulative gas production. Banana stalk showed an average gas production of 6788ml from 400ml substrate with a total hydraulic retention time (HRT) of 58 days to arrive at a figure of 230ml per day as maximum gas production. Comparative study showed that banana peel failed to meet gas production at initial days due to higher sugar content present in it, but later on, the process achieved a gas production of 5620ml with a biogas yield showing 65% of methane. [16]

GizemAlkanok, et al article outlines the best methods for waste disposal from supermarkets in Turkey. Studies materials like fruits, flowers, vegetable waste (FVFW), and dairy product waste (DPW), mixed waste (Mix.W), meat waste and sugar cane waste. Experiments were carried out using two sets of digesters named (R1-R2, R3-R4, and R5-R6, R7-R8) Substrate inoculum ratio was restricted to (9:1) with an average pH alteration using 1N potassium hydrogen carbonate ($KHCO_3$).The temperature was maintained at 37ºC and daily gas production was measured using water displacement technique. Highest gas production observed was from FVFW having 6175ml with 57.6% methane composition .The paper investigates on proper methods of waste disposal and prevention of greenhouse gases, which are being exposed into the atmosphere. [18]

DinhDuc Nguyen et al energy production through the technique of 'dry semi continuous anaerobic digestion'(DScAD) on food waste which has shown admirable results. DScAD method is carried out using 20 liter digester bottles with external jacket that can circulate hot water to maintain the whole unit at 55°C. Continuous mixing maintained at 30 RPM was carried out to make the substrate homogeneous. FW waste limited to 60kg with an organic loading rate (OLR) varying from (3.8kg-VS/m^3 day to 9.8 kg-VS/m^{3}day). Total experimental work was divided into 4 phases. The first two phases had temperature maintained at 38°C, whereas during the last two phases, a temperature of 55°C was maintained with a gradual increases of 2°C periodically .Owing to the presence of ammonia (3g/liter) in the substrate the results for the check of bacterial growth showed positive.(Ammonia facilitates the growth of methanogenic bacteria). Modified Gompertz model of regression analysis was carried out for prediction and comparison of biogas production. Organic loading rate (OLR) ranged from (7.5 to 8.4) VS\m^3 per day and this obtained the highest amounts of volatile fatty acid (VFA) concentration with an average methane yield of 62%. If monitored diligently, 15,330 kWh of energy can be produced in a year from 1m^3 size DScAD plant, which equals 1.16 tons oil per year. This study shows that the technique of using DScAD is 11.6 times more efficient than carrying out the same in an ordinary anaerobic digester in wet conditions [19].

N.V.Deshpande et al described biogas production from Mahua and Hingan non edible de oil cake waste with cow dung in different ratio .Single-phase digestion system with working volume of 20-l transparent plastic bottle designed for experimental work, anaerobic digestion was carried out, in mesophilic temperature scaling from 20°C to 40 °C. Optimum biogas yield find maximum between 36°C to 40°C and methane ranges 68-72%. Author has reported presence of minerals like copper, iron, zinc, manganese, calcium and magnesium in the digested slurry of Mahua and Hingandeoiled cake. Hence, it is fit for agriculture purpose [28].

III. Factors Influencing the Biogas Production

A number of outside parameters make a powerful result on the biogas production by anaerobic bacteria. Parameters like co-digestion, temperature inside digester, pH, Hydraulic retention time, and variation in organic loading rate has an enormous impact on biogas production, average biodegradation of waste material can be done with proper environment creation on bacteria growth. Parametric study is a possible option for capable management of anaerobic digestion

3.1. Effect of co digestion

Cindy Priadi et al, observed a gradual increase in the quantity and quality of the biogas production by the co digestion of paper sludge with cow dung. Anaerobic digestion (AD) of paper sludge alone produced 14.7 mL/g VS when compared to methane production from sludge seeded with cow manure of 269 mL/g volatile solid (VS). The cumulative production of Reactor 2 showed 3.5 times more than Reactor 1 in "fig.2" (a) [20]. Different waste material co digestion for biogas production reported [22].

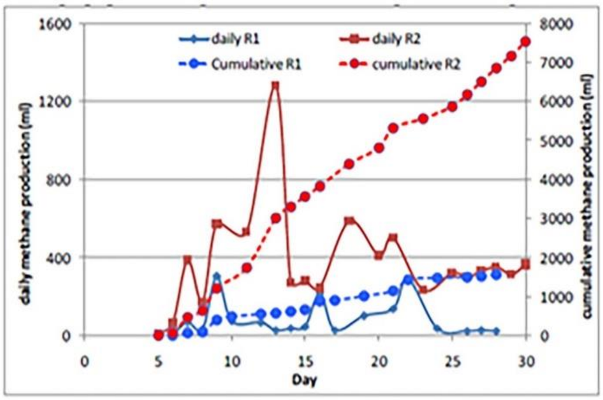

Fig 2 (a) daily and cumulative biogas production R1=Reactor one containing only paper sludge and R2= reactor 2 containing paper sludge and cow manure

3.2. Effect of temperature inside digester

Initially, work was carried out at atmospheric temperature and later on at constant temperature of $37^{0}C$ for biogas production from co digestion of kitchen waste with cow dung. Later experiment has produced more volume and showed stable gas production [4]. The variation is as shown in the Fig"3 (a)", "3(b)"

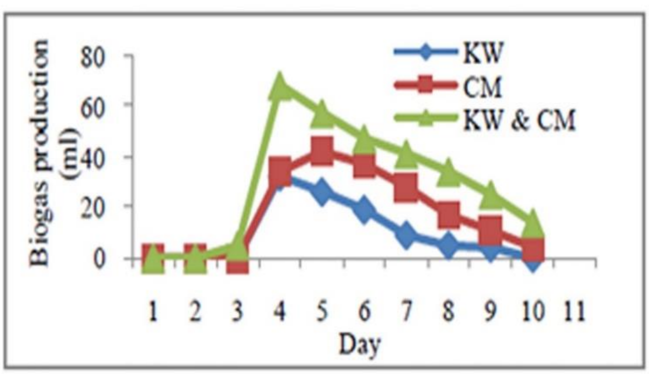

Fig 3(a) different digesters biogas production (ml) with atmospheric temperature

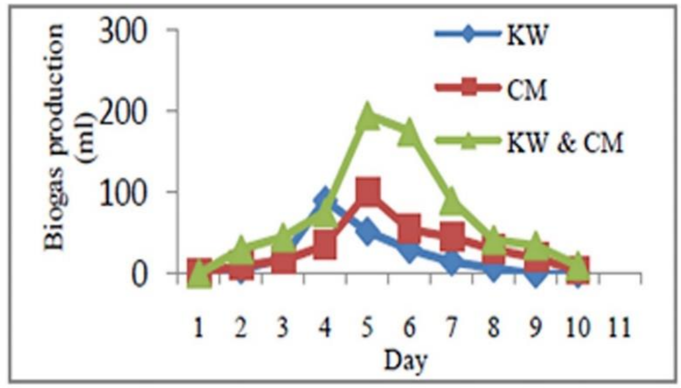

Fig 3(b) different digesters biogas production (ml) at 37ºc constant temperature

3.3. Effect of pH alteration in biogas production

The chemical balance of substrate must be maintained at neutral range for proper growth and multiplication of bacteria. Acidic condition inside working digester may destroy anaerobic bacteria, end up in failure of whole biogas production. Perfect pH alteration by sludge recirculation is reported [21]. M. Saev, B et al, explained the addition of chemicals will alter biogas yield from the anaerobic digester due to their response on the variation of pH. To sustain pH between 6.7 to7.9 throughout experiment, NaOH solution insertion at regular interval was reported [29]. In addition, to prevent harmful effects due to acidification and volatile fatty acid accumulation, sodium bicarbonate solution (NaHCO3) is added to correct the process [30]

3.4. Effects of hydraulic retention time

Average time reported to undergo liquid sludge inside digester is hydraulic retention time (HRT). The relationship between gas production, breakdown efficiency and retention time is mostly studied on laboratory scale, [31]. A study of HRT shows maximum daily biogas production curve obtained between 16-25 days and find linear till 40-50days [27]. Relation between specific gas production and HRT shows in "Fig4" (a)

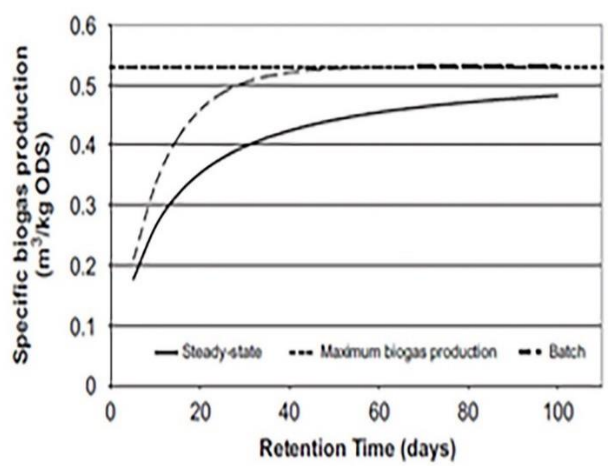

Fig 4(a) Bio gas production with Hydraulic retention time

IV. Conclusion

Although many experiments were carried for biogas production from various biodegradable waste materials, in this view point, canteen waste disposal need more attention. Vegetable left over with tea waste in different substrate ratio for anaerobic digestion is still unexplored. Both of these wastes are being profusely disposed by humans, there is a huge demand for an advantageous method of efficient bio gas production. Alternative energy generation from biogas will in turn reduce greenhouse gas emission helping to combat the climatic change. Alteration to the process reviewed in this paper can be made to build up a victorious implementation in the meadow of biogas production

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