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Review Article

Biogas Development and Usage Current Perspectives and Opportunities, Future Outcomes and Prospects

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Abstract. Biogas production uses well-developed technology for the production of renewable energy and utilization of organic waste for monetary benefits all around the world specifically in third world countries. Biogas is produced by anaerobic digestion from microorganisms that follow different metabolic pathways so that organic matter may get decomposed. In recent times, this sector of renewable energy development has been growing rapidly since ancient times where households used it for power generation for many years. This review is a summary of the current trailblazing opportunities, future outcomes and prospects of what biogas development actually is and its retrospective throughout the years has also been viewed and summarized so that a fresher outlook can be given for better optimization of the process for utilizing this energy. This review also states how biogas can be utilized in third world countries for better energy generating outcomes.

Keywords: biogas, renewable energy, biogas development

Introduction

Anaerobic digestion historically has been associated with treating sewage and animal manure with the help of waste water treatment that maybe aerobic (Meegoda *et al*., 2018). In recent times, most biogas plants digest manure from cows, chicken and even pigs, this alongside the incorporation of co-substrates which help increase organic material content. Common co-substrates include certain parts of sugar beets such as the bottom and top of their leaves, waste that may be obtained from certain agricultural related industries, food waste from domestic households and bio-waste from energy crops (Moraes *et al*., 2015) which is shows in Fig. 1. The yield of biogas can be different for each of the substrates mentioned above, the yield may vary substantially due to some factors such as the amount or content of organic substance and the composition of the substrate alongside its origin. Proteins and carbohydrates have been studied to show higher rates of conversion to energy but the gas yields that they give are too low. In contrast, fats are said to provide a better yield output for biogas but the bioavailability is not good enough and the retention times seem to be too long to function (Alves *et al*., 2009). These alongside having substrates that are clean of other organisms and are not contaminated by pathogens are also extremely important to not affect the yields of biogas.

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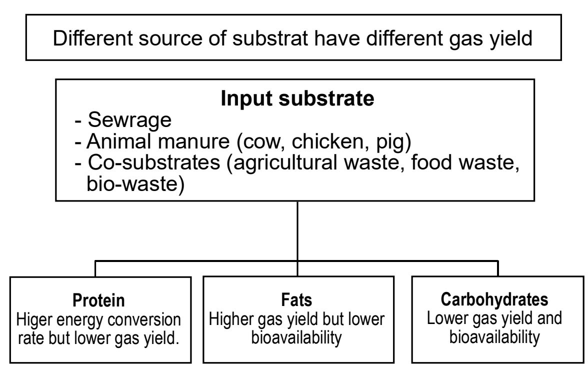

Fig. 1. Show's flowchart illustration the trade-off between input substrate their energy conversion rates, gas yield and bioavailability for proteins, fats and carbohydrates.

Materials and Methods

In all the given papers multiple different crops were used. These included the winter wheat, Triticale, winter rapeseed and spring barley. These were isolated in September, 2009 reported by (Ahlgren *et al.*, 2010). Afterwards, the three additional crops such as rye, oats and spring wheat were also isolated in the November, 2010 of the given year. This was done to increase the number of raw materials for the production of biogas. Moreover, five other crops that can be utilized for better biogas production were picked up in November, 2010. This was done after which the yield produced was measured using a metric based on a specific text that was part of a directive in the (Achinas *et al.*, 2017). Furthermore, other methods were also designed to produce and detect biogas production (Ahlgren *et al.*, 2010).

In this scientific research reported by (Elijah *et al.*, 2009) measured the total amount of solid and how the changing proportions of biomass were co-digested including the detention time which was kept constant. Samples were taken from the Choba community that was present in the state river in Nigeria. 1.5 Kg of cow dung was obtained, it was sun dried and then crushed mechanically. Slurry was made with excess addition of solids and with mixing of water that was equal in amount to the content of the solids and then the mixture was sent into a digester. A brine solution which was acidified was also added until a supersaturated solution was made. A built up pressure was provided from a second chamber to help solubilize the biogas. Finally in most other papers such as (Yono *et al*., 2010). Cattle manures and rumen fluids (Rumen fluid is a liquid located in the rumen, the big first compartment of the stomach in mammals such as cows, where cellulose is stored and broken down by microbes before being chewed it again) had to be taken in random from slaughter house which was located in the Semarang city or any other places (Fortina *et al*., 2022). Most raw manure was taken from animal holding pen and rumen fluid was poured and mixed with tap water for smoothness and better usage.

Different ways of fermentation. The other way in which fermentation takes place is said to be dry fermentation (the breakdown of organic feed-stocks to create biogas in anaerobic circumstances, without ambient oxygen). This utilizes percolation for mono fermentation of energy crops. A gas tight box is used as fermenter where the substrate, as a solid and mixed with in-oculum from the previous batch for digestion and is uploaded through a batch wise process (Weiland *et al*., 2010). The solid in-oculum needs to be determined prior to the process starting as it differs individually for each substrate. Moving forward, the digestion period requires that process water maybe recycled and sprinkled on top of the substrate so that a start-up may begin with in-oculation. So, that moisture content maybe controlled and the temperature of digestion maybe readjusted to what desired. When digestion is completed after 3-4 weeks, the material that is digested unloaded a new batch is then started. Constant gas production requires the running of at least three fermenters that maybe set up parallel to one another. The gas yields from this are almost the same when compared to wet digestion as a process (Yono *et al*., 2010).

This studies have been conducted prior shown trials of different substrates which maybe lignocellulose substrates or even organic household production of waste that can be associated with biogas production (Weiß *et al*., 2010). This is because the loss of hemicellulose increases the average size of pores of cell-wall structures, this then increases the probability of hydrolysis of cellulose in plant biomass structures. The point that was picked for the review is relevant to bacteria that produce enzymes which may degrade xylan. These tend to be bacteria which are hemicellulo-lytic. Although, there are problems when single and two stage reactors are used as plant cells and become a barrier in the biodegradation fermentation process (Wang *et al*., 2019; Weiß *et al*., 2010). Therefore, app-roaches that involve a faster rate of de-polymerisation with regard to cellulose and hemicellulose are needed to increase the yields of biogas produced.

The populations were hemicellulolytic from a biogas fermenter which were commonly called consortium, placed in batch cultures, enriched using a medium, which was a synthetic medium. The synthetic medium was xylan powder used a single carbon source which is under conditions like mesophilic and anaerobic. After this, the bacteria that were hemicellulolytic were immobilized on zeolite which is a trace metal so that storage remains stable and the application is easy. Xylanase activity was then observed which increased continuously during enrichment cycles and went up about 162%. This in turn also effected methane production which increased upto 53% without added microorganisms that maybe immobilized on zeolite.

The enrichment which was specific was confirmed by hemicellulolyticbacteria during the process of single strand conformation polymorphism (SSCP) (Weiß *et al*., 2010; Goyal *et al*., 2008). Sequential analysis showed patterns that maybe identified as being part of different bacterial groups like bacteroides and clostrodiales.

Bio digester. Another study was conducted about the kinetic production of biogas from cattle manure in batch mode (Yono *et al*., 2010). This study was intended to focus how rumen fluid can be used as inoculums in anaerobic digestion of cattle manure. This work aimed to test the effect of fluid concentration of rumen on biogas production. Kinetic parameters from models that involved advanced mathematics were made for concerning biogas production rate in the batch mode of the bio digester. It is interesting to note that numerous studies which were conducted by different researchers in order to optimize yield were involved in anaerobic digestion by improving contact between the involved bacteria and substrate and most had stirring immobilization microbe which used a fixed film reactor. This study gave a high yield of biogas as well as with Anaerobic Sequencing Batch Reactor (ASBR) which improved composition of substrate by helping it digest with other substrates and controlling the amount of ammonia present in the composition (Zupanèiè *et al*., 2017; Uddin *et al*., 2016). In addition to this other researchers also found an effective way to improve the yield of methane by increasing the content through bio digesters (Obileke *et al*., 2024; Yavini *et al*., 2014).

Moreover, several researchers did mention that in order to improve methane yield, in-oculum content had to be increased in the bio digester. This is because most studies mention that in-oculums are substantially needed for biogas production rate and the amount of methane made when proportioned next to manure. It was recognized that rumen fluid in-oculums have a strong influence on anaerobic bio-stabilization of solid waste specifically the organic part which leads to a higher production of biogas (Liu *et al*., 2017). This influence was studied and tests were done by mixing substrate with and without rumen fluid making an inoculum which was then placed in the bio-digester. Cumulative volume of biogas was measured alongside the performance of the bio digester at 760 mm Hg. Triplication was used to carry out this treatment.

Duncan multiple range tests (DMRT) were done to see the difference between the treatments which were given. Data from observation related to biogas volume as a function of time was used for the study which was kinetic for biogas production. Nonlinear regression was used to determine different rate constants (Yono *et al*., 2010). In conclusion, Rumen fluid in-oculums caused biogas production rate to increase two or three times comparative to the non-rumen substrate in-oculum.

Optimization of anaerobic digestion. Another research was conducted where maize was used for optimization of anaerobic digestion using a laboratory digester. This was done so that it could be found that which particular maize class produced the highest rate of biogas and alongside this the composition of gases was also measured (Oslaj *et al*., 2010) shows in Fig. 2. Biogas from sewage digesters, organic waste and from landfills acquires a different composition for each component that it may possess. Usually, Biogas may also contain hydrogen sulfide and other Sulphur compounds such as compounds which maybe halogenated siloxanes. It was observed that although the amount of the compound mentioned above maybe in traces, the environmental impact such as ozone depletion and greenhouse effect does deteriorate the quality of air (Sihlangu *et al*., 2024; Li *et al*., 2019).

Out of all the crops that belong to the field maize is said to have the highest potential of yield for biogas. All the different types of varieties of maize have different capabilities of methane production which usually

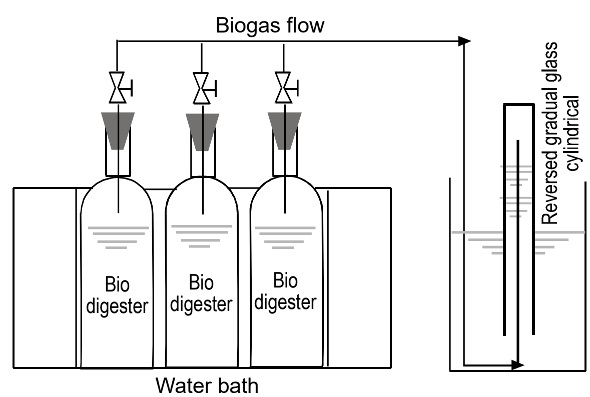

Fig. 2. Shows a schematic series layout of the laboratory for batch assessment of anaerobic digestion which has been adaptive from (Yono *et al*., 2010).

depends upon what they are composed of. The composition is mostly determined by different vegetation stages and dry matter content. Specific nutrients such as cellulose, hemicellulose, crude protein and crude fat have a huge impact on the amount of methane that maybe produced (Drehmel *et al*., 2018). Composition analysis was done in this experiment by gas meter where the data of the gas which was produced among the hybrids of corn was compared. Biogas composition was analysed eleven times for each experiment in the five week course of digestion. It was observed that with higher corn class maturity, the higher the yield of biogas and biomethane was present. According to laboratory experimental results, the hybrids which were tested [PIXXIA] and [CODISTAR] also suggested some amount of biogas production (Oslaj *et al*., 2010). This showed that the characteristics of methane that was being produced did depend on the content of crude protein which was part of their composition.

Furthermore, a study based on the production of biogas from fruits and vegetables and the way they effect plants when used as a fertilizer using un-digested and digested sludge was conducted. The effect of the waste was also observed on the plants (Sagagi *et al*., 2009) and shows in Fig. 3. The paper states that rate of biogas production depends upon multiple factors now such as digester size and construction, retention time, slurry concentration, carbon and nitrogen ratio, toxicity, pH, Temperature and loading rate etc. When the concentration of water-soluble substances such as amino acids, minerals and

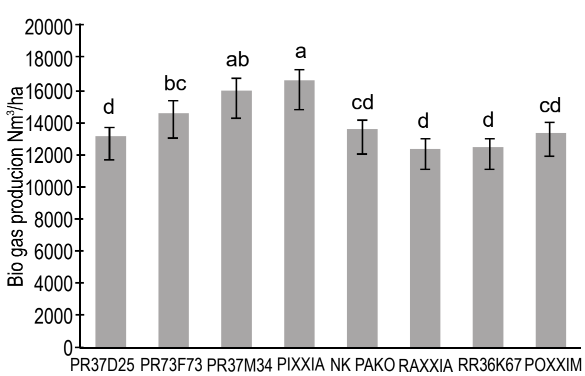

Fig. 3. Shows the production of biogas (Nm^3 ha/L) from hybrids with maturity classes FAO 400-FAO 500. Different letters represent significant differences at $P < 0.05$, where PIXXIA and PR37D25 shows significant results, reported in (Oslaj *et al*., 2010).

sugars decrease with the given age of plants (Jameel *et al*., 2024) and non-water soluble substances such as lignin, cellulose, polyamides and hemi cellulose, this then proves that vegetable matter from younger plants produces more biogas when compared to plants which are older. For different types of animals, the age of the given animal, what they are fed and what are their living conditions etc. impact the yield of biogas that is produced. It was observed that products which maybe ground finely produce more yield then those which are larger in size as the surface area for contact with bacteria maybe less with sizes which are greater. The data for animal and vegetable waste utilization for biogas production was compared which stated that cow dung followed by pineapple waste, orange waste, pumpkin waste and spinach waste was the order with which most to least biogas production was observed. This therefore proves that there is a link between the different compositions of biogas and how to a large extent it impacts the substrates nature (Adamu *et al*., 2023).

Results and Discussion

Sustainable development can be achieved through multiple opportunities and biogas seems to be a viable way to help transition into that state by accelerating biogas production. We can actually provide a better world view of how things are going to be further on. The environmental impact of biogas alone stands to have positive reviews throughout the community and will help in growing a natural source of management, not only will it be profitable but it may also help decrease large amounts of economic implications by starting it off as a local level solution and helping push it into international situations too. Moreover, even though biogas may not be the most dominant way of utilizing energy for a better cause, it still is better than using fossil fuels that may lead greater monetary issues that may cause pollution in many shapes and forms (Kabeyi *et al.*, 2022; Theuerl *et al*., 2019).

Conclusion

The future prospects of Biogas rely heavily on modern design development of the equipment involved in biogas production. It needs to be heavily information driven, knowledge based and largely following an automated system or itself be automated. If this ends up becoming more advanced, the future of farmers and operators that work with plants may help the national and international economy altogether. Third world countries which are facing severe problems in energy deficiency have higher demands compared to other parts of the world. This may decrease if the waste from domestic households and livestock would be utilized immediately after waste is used for generation of energy and power. It may not only resolve the international future energy crisis but would also go a long way in reduction of pollution through greenhouse gas emissions.

Conflict of Interest. The author declare that thay have no conflict of interest.

References

Achinas, S., Achinas, V., Euverink, G.J.W. 2017. A technological overview of biogas production from biowaste. *Engineering*, **3:** 299-307.

Adamu, H., Bello, U., Yuguda, A.U., Tafida, U.I., Jalam, A.M., Sabo, A., Qamar, M. 2023. Production processes, techno-economic and policy challenges of bioenergy production from fruit and vegetable wastes. *Renewable and Sustainable Energy Reviews*, **186:** 113686.

Ahlgren, S., Aronsson, P., Hansson, P.A., Kimming, M., Lundkvist, H. 2010. Greenhouse gas emissions from cultivation of agricultural crops for biofuels and production of biogas from manure. *Report from Swedish University of Agricultural Sciences (SLU)*, 12-4067/08, Revised version 2009-09-08, 52.

Alves, M.M., Pereira, M.A., Sousa, D.Z., Cavaleiro, A.J., Picavet, M., Smidt, H., Stams, A.J. 2009. Waste lipids to energy: how to optimize methane production from long-chain fatty acids (LCFA). *Microbial Biotechnology*, **2:** 538-550.

Drehmel, O.R., Brown-Brandl, T.M., Judy, J.V., Fernando, S.C., Miller, P.S., Hales, K.E., Kononoff, P.J. 2018. The influence of fat and hemicellulose on methane production and energy utilization in lactating Jersey cattle. *Journal of Dairy Science*, **101:** 7892-7906.

Elijah, T.I., Ibifuro, A.M., Yahaya, S.M. 2009. The study of cow dung as co-substrate with rice husk in biogas production. *Scientific Research and Essays*, **4:** 861-866

Fortina, R., Glorio, P.S., Barbera, S., Tassone, S. 2022. Rumen fluid from slaughtered animals: a standardized procedure for sampling, storage and use in digestibility trials. *Methods and Protocols*, **5:** 59.

Goyal, M., Kalra, K.L., Sareen, V.K., Soni, G. 2008. Xylanase production with xylan rich lignocellulosic wastes by a local soil isolate of *Trichoderma viride*. *Brazilian Journal of Microbiology*, **39:** 535-541.

Jameel, M.K., Mustafa, M.A., Ahmed, H.S., Jassim, M.A., Ghazy, H., Shakir, M.N., Kianfar, E. 2024. Biogas: production, properties, applications, economic and challenges: a review. *Results in Chemistry*, pp. 101549.

Kabeyi, M.J.B., Olanrewaju, O.A. 2022. Biogas production and applications in the sustainable energy transition. *Journal of Energy*, **2022:** 8750221.

Li, Y., Alaimo, C.P., Kim, M., Kado, N.Y., Peppers, J., Xue, J., Kleeman, M.J. 2019. Composition and toxicity of biogas produced from different feedstocks in California. *Environmental Science and Technology*, **53:** 11569-11579.

Liu, T., Sun, L., Müller, B., Schnürer, A. 2017. Importance of inoculum source and initial community structure for biogas production from agricultural substrates. *Bioresource Technology*, **245:** 768-777.

Meegoda, J.N., Li, B., Patel, K., Wang, L.B. 2018. A review of the processes, parameters and optimization of anaerobic digestion. *International Journal of Environmental Research and Public Health*, **15:** 2224.

Moraes, B.S., Triolo, J.M., Lecona, V.P., Zaiat, M., Sommer, S.G. 2015. Biogas production within the bioethanol production chain: use of co-substrates for anaerobic digestion of sugar beet vinasse. *Bioresource Technology*, **190:** 227-234.

Obileke, K., Makaka, G., Tangwe, S., Mukumba, P. 2024. Improvement of biogas yields in an anaerobic digestion process *via* optimization technique. *Environment, Development and Sustainability*, pp. 1-27.

Oslaj, M., Mursec, B., Vindis, P. 2010. Biogas production from maize hybrids. *Biomass and Bioenergy*, **34:** 1538-1545.

Sagagi, B., Garba, B., Usman, N. 2009. Studies on biogas production from fruits and vegetable waste. *Bayero Journal of Pure and Applied Sciences*, **2:** 115-118.

Sihlangu, E., Luseba, D., Regnier, T., Magama, P., Chiyanzu, I., Nephawe, K.A. 2024. Investigating methane, carbon dioxide, ammonia and hydrogen sulphide content in agricultural waste during biogas production. *Sustainability*, **16:** 5145.

Theuerl, S., Herrmann, C., Heiermann, M., Grundmann, P., Landwehr, N., Kreidenweis, U., Prochnow, A. 2019. The future agricultural biogas plant in Germany: a vision. *Energies*, **12:** 396.

Uddin, W., Khan, B., Shaukat, N., Majid, M., Mujtaba, G., Mehmood, A., Almeshal, A.M. 2016. Biogas potential for electric power generation in Pakistan: a survey. *Renewable and Sustainable Energy Reviews*, **54:** 25-33.

Wang, Y., Leng, L., Islam, M.K., Liu, F., Lin, C.S.K., Leu, S.Y. 2019. Substrate-related factors affecting cellulosome-induced hydrolysis for lignocellulose valorization. *International Journal of Molecular Sciences*, **20:** 3354.

Weiß, S., Tauber, M., Somitsch, W., Meincke, R., Müller, H., Berg, G., Guebitz, G.M. 2010. Enhancement of biogas production by addition of hemicellulolytic bacteria immobilised on activated zeolite. *Water Research*, **44:** 1970-1980.

Weiland, P. 2010. Biogas production: current state and perspectives. *Applied Microbiology and Biotechnology*, **85:** 849-860.

Yavini, T.D., Chia, A.I., John, A. 2014. Evaluation of the effect of total solids concentration on biogas yields of agricultural wastes. *International Research Journal of Environment Sciences*, **3:** 70-75.

Yono, B., Widiasa, I.N., Johari, S., Sunarso. 2010. The kinetic of biogas production rate from cattle manure in batch mode. *International Journal of Chemical and Biological Engineering*, **3:** 39-45.

Zupanèiè, G.D., Panjièko, M., Zeliæ, B. 2017. Biogas production from brewer's yeast using an anaerobic sequencing batch reactor. *Food Technology and Biotechnology*, **55:** 187-196.