Biogas Generation and Its Usage to Save Conventional Energy Resources

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A B S T R A C T

With the rising demand for renewable energy and environmental protection, anaerobic digestion of biogas technology has attracted considerable attention within the scientific community. This paper presents a comprehensive review of research achievements on anaerobic digestion developments for biogas production. The review includes a discussion of factors affecting efficiency (temperature, pH, C/N ratio, OLR and retention time), accelerants (greenery biomass, biological pure culture and inorganic additives), reactors (conventional anaerobic reactors, sludge retention reactors and anaerobic membrane reactors) and biogas AD processes (lignocellulose waste, municipal solid waste, food waste, livestock manure and waste activated sludge) based on substrate characteristics and discusses the application of each fore mentioned aspect. The factors affecting efficiency are crucial to anaerobic digestion, because they play a major role in biogas production and determine the metabolic conditions for microorganism growth. As an additive, an accelerant is not only regarded as a nutrient resource, but can also improve biodegradability. The focus of reactor design is the sufficient utilization of a substrate by changing the feeding method and enhancing the attachment to biomass. The optimal digestion process balances the optimal digest conditions with the cost-optimal input/output ratio. Additionally, establishment of theoretical and technological studies should emphasize practicality based on laboratory-scale experiments because further development of biogas plants would allow for a transition from household to medium- and large-scale projects; therefore, improving stability and efficiency are recommended for advancing AD research.

Keywords: Biogas, Factors affecting efficiency, Accelerants Reactors Processes, Biogas generation rate

1. Introduction

Here introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the paper. The paragraphs continue from here and are only separated by headings, subheadings, images and formulae. The section headings are arranged by numbers, bold and 9.5 pt. Here follows further instructions for authors. Anaerobic digestion process has widely been employed for treatment of various organic wastes because the process can be used for production of value-added products such as an energy-rich gas and bio-fertilizer. This process is carried out by a complex microbial community which degrade various organic compounds into final products such as methane and carbon dioxide, collectively called biogas. There are presently many research efforts worldwide on anaerobic digestion of food waste to improve processefficiency, stability and economic competitiveness. Studies of co-digestion of food waste generally found that inclusion of food waste was beneficial for methane yield1–3, while digestion processes with food waste as the so lesubstrate were often found to be unstable3–5. Several researchers have reported the benefits of using mixed feedstock's, including increased biogas production, enhanced degradation rates and higher digester capacity1,6,7. The beneficial effects of co-digestion are mostly related to a balanced availability of macro- and micronutrient required by the microbial community, optimal moisture content, buffer capacity and dilution of inhibitory or toxic compounds. Additionally, co-digestion may improve the process kinetics rather than the bioavailability of the feedstock.

Ebner et al.8 measured hydrolysis rates using bio-methane potential assays, and found that co-digestion increased hydrolysis rates when food waste and manure was co-digested compared to mono-digestion in BMP assays. The synergistic effect was attributed to dilution of inhibitory compounds and improved nutrient balance due to co-digestion .The enzymes involved in hydrogenotrophic methanogenesis and syntrophic acetate oxidation requires trace elements such as selenium (Se), molybdenum (Mo) tungsten (W), cobolt (Co), nickel (Ni) and iron (Fe). Lack of these trace elements can limit the syntrophic acetate oxidation as well as formate.

2. Formation of Biogas

Microbial composition of the mesophilic reactors.- Statistical analysis demonstrated that the anaerobic co-digestion process resulted in a significantly (pvalue < 0.005) higher microbial richness compared to the digester fed with food waste alone (see Supplementary Fig. S1). The major bacteria in both mesophilic digesters included Firmicutes, Chloroflexi, Bacteroidetes and Actinobacteria. However, the distribution of these major bacteria in the digesters was different. Chloroflexi, which in the final phase constituted 54% of the sequences, was the dominant phylum in MDi, followed by 25% Firmicutes and 15% Bacteroidetes. Firmicutes (60% of the sequences in the final phase) was the dominant phylum in McoDi, while the relative abundance of Chloroflexi (22%) and Bacteroidetes (8%) was noticeably lower in McoDi than MDi. Additionally, the candidate phylum WWE1 was identified in McoDi and accounted for 5% of the relative abundance. Limam et al.21 investigated the metabolic function of WWE1 members and suggested that the members of this division were involved in hydrolysis of cellulosic materials. WWE1 was also found in mesophilic co-digestion studies of manure with various agricultural residues22,23. Thus, the addition of cow manure to the co-digestion system seems to spur the growth of WWE1 members, probably involved in decomposition of cellulose content of the manure. It should be noted that WWE1 was not detected in the cow manure in the current study. The dominance of Chloroflexi in MDi which was mainly made up of the T78 group of family Anaerolinacea, was probably due to the presence of fermentable carbohydrates in the preprocessed food waste probably indicates involvement of their members in degradation of intermediate degradation products of carbohydrates and proteins.

Notably, the relative abundance of Fimicutes increased in the final phase of McoDi compared to MDi. This could be due to the addition of manure which is a potential source of Firmicutes, as organisms belonging to this phylum dominated the microbial profile of the manure feedstock with 78% of all sequences (Fig. 5). To evaluate this, the genus level distribution of the sequences was investigated and a high diversity within the Firmicutes-phylum was noticed (Fig. 6A). An unclassified genus of the family Tissierellaceae accounted for 32% of the sequences assigned to the phylum Firmicutes in the final phase of MDi, while this value was much lower in McoDi (11% of phylum) where the main genus was Clostridium (42% of phylum).

In compliance, three OTUs assigned to Clostridium were significantly more abundant in McoDi compared to MDi (Supplementary) Thus, it would appear that Firmicutes in general and Clostridium in particular played an important role in McoDi system. This genus was also represented in the cow manure samples, accounting for 9% of the Firmicutes-related sequences. A principle component analysis (PCA) was used to investigate possible links between microbiome and performance. Based on this analysis an association of Clostridium to the concentration of n-Butyrate was observed, although only low levels of butyrate were measured in both mesophilic digesters (Fig. 7B). Notably, a correlation was observed between the abundance of Clostridium and the cow manure used in the feedstock mixture of the co-digestion system. It is therefore reasonable to believe that the increase in relative abundance of Clostridium in the co-digestion system was originated from the cow manure as a feedstock.

It should nevertheless be mentioned that some Clostridium species can form endospores that enable them to tolerate moist heat30 and pasteurization pretreatment applied on the food waste collected from the processing center. The food waste can therefore not be eliminated as a source of Clostridium.

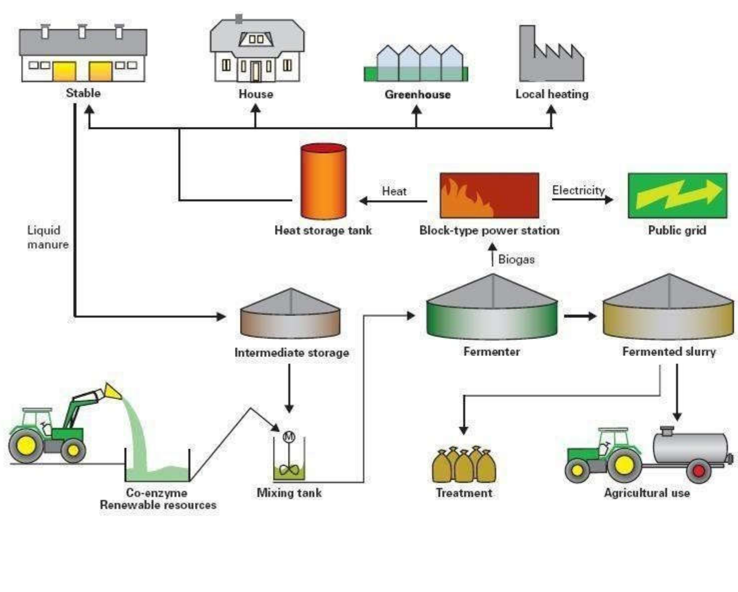

Figure 1 : Line diagram of Bio gas Generation plant

However, a carry-over from the cow manure used seems more likely due to the abovementioned increase of Clostridium in McoDi. This was further supported by the correlation of higher numbers of Clostridium with the addition of cow manure.
Crop residues can include stalks, straw, and plant trimmings. Some residues are left on the field to retain soil organic content and moisture as well as prevent erosion. However, higher crop yields have increased amounts of residues and removing a portion of these can be sustainable. Sustainable harvest rates vary depending on the crop grown, soil type, and climate factors. Taking into account sustainable harvest rates, the U.S. Department of Energy estimates there are currently around 104 million tons of crop residues available at a price of $60 per dry ton. Crop residues are usually co-digested with other organic waste because their high lignin content makes them difficult to break down.

3. Microbial composition of the mephitic reactor

Statistical analysis demonstrated that the anaerobic co-digestion process resulted in a significantly (pvalue < 0.005) higher microbial richness compared to the digesters fed with food waste alone (see Supplementary Fig. S1). The major bacteria in both mesophilic digesters included Firmicutes, Chloroflexi, Bacteroidetes and Actinobacteria (Fig. 4). However, the distribution of these major bacteria in the digesters was different. Chloroflexi, which in the final phase constituted 54% of the sequences, was the dominant phylum in MDi, followed by 25% Firmicutes and 15% Bacteroidetes. Firmicutes (60% of the sequences in the final phase) was the dominant phylum in McoDi, while the relative abundance of Chloroflexi (22%) and Bacteroidetes (8%) was noticeably lower in McoDi than MDi. Additionally, the candidate phylum WWE1 was identified in McoDi and accounted for 5% of the relative abundance. Limam et al.21 investigated the metabolic function of WWE1 members and suggested that the members of this division were involved in hydrolysis of cellulosic materials. WWE1 was also found in mesophilic co-digestion studies of manure with various agricultural residues22,23. Thus, the addition of cow manure to the co-digestion system seems to spur the growth of WWE1 members, probably involved in decomposition of cellulose content of the manure. It should be noted that WWE1 was not detected in the cow manure in the current study. The dominance of Chloroflexi in MDi (Fig. 5), which was mainly made up of the T78 group of family Anaerolinacea, was probably due to the presence of fermentable carbohydrates in the preprocessed food waste used (pasteurized at 70 °C). Anaerolinacea are mostly saccharolytic anaerobes and use a number of carbohydrates for growth24,25. Use of manure in the feedstock of the co-digestion systems resulted in a different relative abundance of bacterial communities in McoDi and prompted the prevalence of Firmicutes, which include members with very versatile metabolic characteristics and more potential to degrade the recalcitrant manure26,27. Firmicutes has been reported as one of the major microbial contributors in several studies carried out on anaerobic digesters, indicating that the phylum is common in both mesophilic and thermophilic processes28,29. Additionally, Firmicutes dominance has also been linked to better reactor performance20. The higher relative abundance of Bacteroidetes in MDi, which was fed with the preprocessed food waste, probably indicates involvement of their members in degradation of intermediate degradation products of carbohydrates and proteins.
The anaerobic digesters fed solely food waste performed better than the co-digesters (food waste and cow manure), most probably due to the addition of a more recalcitrant material in the form of cow manure in the co-digesters. Nevertheless, co-digestion resulted in a higher microbial diversity at both temperatures, compared to anaerobic digestion of food waste as sole substrate. This could be a reflection of the increased complexity of feedstocks in co-digestion, selecting for a richer microbial community. Although similar in the initial phase, the microbial community compositions diverged when cow manure was added at both temperatures. Based on our observations, we speculate that this variation is mostly explained by cow manure providing trace minerals and a balanced C/N ratio, rather than carry-over of microorganisms from the cow manure. However, the increased population Clostridium in both McoDi and TcoDi indicates that the establishment of this population is a direct result of microbiome transmission from the cow manure. Carry-over of methanogens from the cow manure, represented by Methan obrevibacter was also suggested for the mesophilic co-digestion system (McoDi), while only to a minor extent in the thermophilic co-digestion system (TcoDi). As higher microbial diversity often is associated with a microbiome that is more resilient to environmental changes and stress, co-digestion could potentially enhance the robustness of the anaerobic digestion process. Additionally, co-digestion at mesophilic temperature clearly showed a synergistic effect, yielded more methane than the digestion of manure-alone.
Avoid hyphenation at the end of a line. Symbols denoting vectors and matrices should be indicated in bold type. Scalar variable names should normally be expressed using italics. Weights and measures should be expressed in SI units. All non-standard abbreviations or symbols must be defined when first mentioned, or a glossary provided.

4. End use of Biogas

With little to no processing, biogas can be burned on-site to heat buildings and power boilers or even the digester itself. Biogas can be used for combined heat and power (CHP) operations, or biogas can simply be turned into electricity using a combustion engine, fuel cell, or gas turbine, with the resulting electricity being used on-site or sold onto the electric grid.
Digestate is the nutrient-rich solid or liquid material remaining after the digestion process; it contains all the recycled nutrients that were present in the original organic material but in a form more readily available for plants and soil building. The composition and nutrient content of the digestate will depend on the feedstock added to the digester. Liquid digestate can be easily spray-applied to farms as fertilizer, reducing the need to purchase synthetic fertilizers. Solid digestate can be used as livestock bedding or composted with minimal processing. Recently, the biogas industry has taken steps to create a digestate certification program, to assure safety and quality control of digestate.

5. Discussion

Biogas production results in two products—biogas and digestate. The biogas can replace fossil fuels in the energy system, and the beneficial effects of this switch are relatively easy to assess. However, the benefits of using the digestate as fertilizer on farmlands are hard to assess, and hence a methodology for grasping the resource efficiency of biogas production is necessary. According to Börjesson and Tufvesson , contradictory results regarding, e.g., energy efficiency and greenhouse gas emissions have been shown in previous research. With a systematic research design for assessing the resource efficiency of biogas systems, as proposed in this paper, these inconsistencies can be avoided. The Scopus search performed indicates that there is a gap within scientific papers, concerning biogas production, energy, economy and environment together with resource efficiency. Of the scientific papers found when combining energy, environment and economy with biogas production and resource efficiency on Scopus, only three in fact addressed biogas production and resource efficiency. Of these three papers, only one included reduction of greenhouse gases when biogas replaces fossil fuels. Emissions connected to the production of biogas, or replacement of artificial fertilizer by the digestate, are not included in that study, and neither are the economic or energy perspective. The other two papers included the energy and environmental perspective, and one also includes the economic perspective, but not a system expansion. The other one includes a system expansion but not the economic perspective. For the other scientific papers presented in the section Previous research above, four include the energy perspective (all but one) and three include an environmental includes CO2-emissions only. Münster and Lund are the only ones to include the economy perspective in their study, and performed a system expansion in their studies. As can be seen, there is a lack of consistency in what to include when studying biogas systems. This paper proposes a new research design for assessing resource efficiency of biogas production. The design is created around biogas production, but the design may be applicable for other renewable fuels as well, with some alterations to the design. Biogas production can be used as the business as usual scenario, and the other scenarios could be, for example, different use of the biogas, different transportation distances to and from the biogas plant and different amount or composition of by-products treated. Biogas production can also be an alternative scenario to the business as usual scenario. This all depends of the scope of the study. Identification of cases may be done in many different ways. It is important to clearly define the case of study and to delimit it, to be able to do the analysis. The proposed research design enables studies of one case, or multiple cases, all depending on the scope. As mentioned above, the definition of scenarios can differ in many ways. Production of biogas from organic by-products should be in focus in one of the scenarios, since the research design is made for this, but the other scenarios could be for example incineration of the organic by-products or just a different use of the produced biogas, i.e., biogas for heat and electricity in one scenario and biogas for vehicle fuel in another. However, it is important to clearly describe the different scenarios used and to highlight the differences between the scenarios.

6. Conclusion

Sludge generated from primary and secondary pulp and paper industry wastewater treatment demonstrated a high potential for energy recovery. Anaerobic digestion (AD) using sludge seeded with cow manure showed methane production of 269 mL/g volatile solid (VS) compared to AD using only paper sludge which produced 14.7 mL/g VS. Uncontrolled temperature and primary and secondary sludge combined are also two additional advantage of this process which makes it more applicable to medium industries.

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