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A review on comparison of bioreactors to increase methane content and produce biogas for anaerobic digestion of food waste

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Abstract
It has been reviewed the single phase and two-stage bioreactors in the anaerobic digestion of food waste as well organic loading rates and the rate of methane produced. Anaerobic digestion can be used to degrade food waste and recover energy. Organic loading rate, temperature, time, pH, carbon to nitrogen ratio are important factors to be operated in the bioreactors and still are challenges in this process to increase biogas production. Methane is a biogas that can be efficiently converted in electricity.

Keywords: anaerobic digestion; biomass; biogas; bioreactors

Introduction
Greater attention is given to the biological production of biogas by means of anaerobic digestion processes. Food waste is rich in organic matter and when it releases methane, it is a greenhouse gas. The characteristics of the raw material, the reactor design and the operating conditions play an important role in the production of biogas and the stability of the process in the anaerobic digestion process.
In consideration of the above, this study examines previous studies on the use of anaerobic digestion for processing fruit and vegetable waste and discusses the problems and the typical solutions in the application of the technique. This facilitates the study of an optimal design for anaerobic digestion reactors, as well as methods for the pre-treatment of raw waste. Furthermore, we analyze the dominant microorganisms involved in the fermentation process and suggest an approach for future studies.
The reduction of CO2 emissions, the high demand for fossil fuels and environmental issues are the reasons why the studies have to develop new technologies to obtain energy from biomass. Biomass is the organic matter of crops and agricultural waste, animal waste, forest and wood residues, plants and urban waste and is stored as chemical energy. This energy can be released as biogas as methane (CH4), hydrogen (H2) and carbon dioxide (CO2) through the anaerobic digestion process [1].
The use of anaerobic digestion to generate methane is considered the most promising technique for processing fruit and vegetable waste; As such, waste has high moisture content and is easily biodegradable. Anaerobic digestion is certainly not a new technique, as it has historically been used to process a variety of solid and liquid waste and has been widely used in municipal waste disposal. The technique has several advantages, including low energy consumption, low input, low sludge production and a high organic load, among others [9]. Furthermore, it is useful for energy recovery and control of greenhouse gas emissions. In general, anaerobic digestion systems are classified as wet, with 20% of TS. As for other aspects, such as ambient temperature, the classification is at medium temperature (35-40 ° C) or high temperature (> 55 ° C). Moreover, such systems can be fed in series, fed continuously or fed continuously; it can be single-phase or two-phase; and may be single or hybrid anaerobic digestion systems [10].
According to the Council for the Defense of Natural Resources [1, 2], more than 40% of food in the United States is wasted during harvest, production, transport and the final consumer, which represents $ 165 billion each year in the trash addition, most of these food waste ends up in landfills that release methane into the atmosphere. The treatment of food waste and its conversion into biogas is carried out in high-speed single-phase anaerobic digestion processes in which micro-organisms decompose the biodegradable material in the absence of oxygen [3].

Material and Methods

Anaerobic digestion

Anaerobic digestion (AD) occurs in the absence of oxygen and produces methane for energy recovery and treats waste for environmental benefits. It is applied to food waste, one of the largest waste streams destined for landfills.

The organic loading rate (OLR) refers to the rate at which volatile solids (VS) are added to a digester. It is calculated by dividing the pounds of volatile solids added to the digester a day from the digester's volume [4, 5]. The OLR VS should be standardized to maximize methane production and avoid system shutdown.

Among the methods of pre-treatment of fruit and vegetable waste, heat treatment is an important technique that has been studied and developed in the last 5 years. Zhou *et al*. [13] used pirroidolysis to pre-treat a mixture of kitchen waste, FVW and municipal sludge. The result was that 38.3% of volatile suspended solids were dissolved and the digestion yield increased to 115%. Compared to the same digestion without a pretreatment phase, the biogas yield did not increase, but the digestion rate doubled, while the digestion was more stable, the AGV accumulation was lower and the AGV / alkali ratio was reduced. Liu *et al*. [14] found that heat treatment at 175 ° C for 60 minutes could improve the physical and chemical properties of fruit and vegetable residues, decrease viscosity, improve dehydration and increase solubility of soluble COD, soluble sugar and proteins Soluble and organic (molecular weight> 10 kDa). In total, 58.5% of the organic compounds were separated from the liquid phase after the waste had been thermally pretreated. Ruggeri *et al*. [15] compared the effects of physical, chemical, heating and ultrasound pre-treatment methods to digest fruit and vegetable residues and compared production rates with and without pretreatment methods. They discovered that a combination of alkaline pretreatment and heat treatment generated the highest production rate, which was up to 10 times higher than the production speed without pretreatment.

Figure 1 illustrates the process in which the first two phases operate within defined parameters that guarantee the optimal production of biogas.

In the United States most often used mesophyll digester due to minor capital and ease of operation and the digester operates in the range 35 ° C to 40 ° C. Food waste time completely degrades in the digester depends on temperature, process system and from its properties.

In a single stage reactor, an OLR of 7.4 kg VS / m3D was found with a high VS 94.9% reduction and a high methane yield of 484 ml / g / VS / d.

Relative residence time is required for total degradation. The effects of the gradual increase in integrated systems OLR two stages Kondusamy and Kalamdhad [6] indicated that the steady state would be optimal OLR 26.62 kg VS / m3d (162 h) of the fermentation hydrogen reactor and 4, 61 for the fermentation reactor of methane.

However, few studies have investigated the digestate generated after anaerobic digestion to address problems such as how this could be used as a resource, p. as a fertilizer Furthermore; it has not yet been studied whether there is a risk of pesticide residues. If such a risk exists, investigations should focus on methods to prevent and mitigate the effects of pesticide residues. A large number of studies indicated that a carefully controlled quantity of additional microelements could be useful for stabilizing digestion and decreasing the concentration of VFA. However, the effects of these micro-elements on the anaerobic digestion of fruit and vegetable waste should be further studied [7]. As mentioned, the possible effects of pesticides, preservatives and chemical additives, widely used in agriculture, in anaerobic digestion have not been adequately studied. So far, the goal of anaerobic digestion of fruit and vegetable waste has been biogas production. However, an important question is whether other products could be generated by the process. For example, since fruit and vegetable waste is easily acidified, it may be possible to maintain acidification during anaerobic digestion to produce other chemicals, such as polyhydroxyalkanoate (PHA) or lactic acid raw materials. Furthermore, although numerous studies have documented the co-digestion of different materials, quantitative analysis is not yet available, such as the precise determination of percentages of chemical indices, which include proteins, fats, hydrocarbons and water.

This information includes moisture content (MC), volatile solids (VS), nutrient content, particle size and biodegradability. Under a given temperature and a certain amount of time, the amount of methane and biogas produced is measured.

Reactors

Single stage reactors have the hydrolysis, acidogenesis, acetogenesis and methanogenesis happening at the same place. It can have the acidification of the digester due to shock loading.

Two stage reactors have the hydrolysis and acidogenesis taking place in an initial reactor and then these acids are used by methanogenesis in the final reactor. According Kondusamy and Kalamdhad [6] the two stage reactor is more efficient because the dynamics of the process allows the individual bacterial species to separate from hydrolysis and methanogenesis.

Grimberg *et al*. highlight that two stage digester for food waste treatment is stable while highly variable loading. Also, two stage systems are more efficient for resolving pH inhibition issues of one stage systems.

Experimental work

In this study the amount of anaerobically digested food residues was assessed, which showed a potential of 367 m3 of biogas per dry ton with 65% methane. The two-phase anaerobic digestion system has an acidogenic reactor in the first phase that maintains low pH and short hydraulic residence times (2-3 times) and produces hydrogen and a methanogenic reactor in the second phase which is operated with HRT of 20-30 days and pH of 6-8 to produce methane.

Kondusamy and Kalamdhad [6] reported that the overall two-stage reactor gas production rate is four times higher than the single-phase reactor.

The experiments were conducted by Zhang *et al*. [7] at 50 ° C, single-stage reactor with OLR of 7.4 and 12.1 VS-l results were 3.63% TS, 85% VS / TS and 72% MC. The obtained C / N ratio was 16.5 and 442 ml / g VS of methane yield after 28 days. The average digester load for the single stage system was 28.89-27.78 kg day-1 and 25.26-35.41 kg day-1 for the two-stage system. The temperature for both reactors was maintained at 37.4 ° C. The yield in methane was 384 and 446 LCH4 KgVS-1 for single-stage reactors and two-stage reactors, respectively.

Grimberg *et al*. [8] did research in single and two-phase reactors, loading the individual system with a capacity of 50% for 6 months and with 20% capacity of the acid fermentation reactor. The methanogenesis reactor was loaded with a 90% capacity that receives the effluent from the fermentation reactor.

Result and Discussion

Indicates that food waste is a highly desirable raw material for anaerobic digestion, due to its high biodegradability, nutrient content and methane production [3]. Experiments with food residues showed that after digestion at retention times of 10 and 28 days, the methane yield was determined at 348 and 435 ml / g of volatile solids (VS), respectively. The average methane content was 73%, with an average VS destruction of 81% at 28 days after digestion.

Zhang *et al*. [16] reported 66-73%, 23% and 84-87% VS / TS respectively for MC, VS and VS / TS, respectively. The MC range shows that the moisture contained in food waste is sufficient to perform anaerobic digestion. After 28 days of digestion with 6.8 and 10.5 g VS / L, the average yield of methane was 435 ml / g VS at 50 ° C. It can be presumed that the biogas composition is 73% of the content of methane and 37.3 MJ / m3 and C / N 14.8.

The acidification reactor operates with a retention time of 5 days and a pH of 6.5, while the methane reactor works with a retention time of 15 days and in a pH range of 7.4 to 7, 8. The maximum organic load rate was determined at 7.9 kg of VS / m3 / day and the methane content in biogas was around 70% [21].

Therefore, the fermentation phase acts as an equalization damper in the event of a shock load, guaranteeing safety to the anaerobic digesters system. Grimberg *et al*. [23] did not observe significant differences in the effluent concentration of both systems with an average elimination of VS 96% in a single stage and 93% in two-stage systems. Furthermore, the production of methane was higher in the two-stage reactor than in that in which the production of gas was normalized at the entry of raw material.

Conclusion

Based on the research, it is suggested that the anaerobic digestion of food waste to recover energy depends on optimal conditions, temperature and methodology, as well as on the loading of raw material. Further research must be done to increase the methane content in the biogas and reduce operating costs. Research has shown that a two-stage reactor leads to higher biogas and methane yield compared to single-stage reactors. However, dual reactors increase construction and material costs, while single-stage systems are more common due to lower capital costs.

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