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Review Article

Comparison between different parameters for anaerobic digestion technologies

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Abstract

Due to the increased demand for energy and the near depletion of fossil fuel sources, in addition to the problems of global warming, the world has turned to renewable energy sources as an alternative solution. One energy source is the anaerobic digestion of organic matter, such as animal or food waste. Biogas is produced from this process, used to generate electricity and heat, or processed for use as a transportation fuel and compost production for agriculture. This process is affected by many factors like the potential of hydrogen (PH), temperature, carbon/nitrogen ratio (C/N), and other factors. Dry anaerobic digestion has higher total solid content (TS) than wet anaerobic digestion. On the other hand, it has lower maintenance and construction costs compared with wet anaerobic digestion. In this research, we will highlight the operational conditions of the process in addition to its different types. It also contains an overview of this system, its working principle, its advantages, and the system component and show the best ways to improve its efficiency.

Introduction

The industrial revolution and the massive increase in population have increased the amount of solid waste around the world. And due to the great demand for energy, attention has been paid to making use of these wastes, extracting the available organic matter, and converting it into biogas through the anaerobic digestion process [1-4]. Energy extracted from this source is one of the most widely used renewable energy sources due to its continuous availability compared to wind and solar energy. This type of power has three objectives: providing large amounts of clean energy, improving waste management systems, and improving agricultural systems by providing fertilizers resulting from waste treatment [5]. One of the attractive factors for the process is the availability of the feedstock material for free or pay to the energy facility instead of taking it due to the high fees for landfilling waste in some countries [6-9]. Anaerobic digestion plants have spread worldwide, with an estimated production of 87 TWh of electricity [10]. Agricultural waste, food waste, and sewage sludge are the most important sources of biodegradable waste and, thus, biogas production [11].

Working principle of Anaerobic digestion technology

Anaerobic digestion: It is a natural process in which bacteria convert organic matter (potential energy) into biogas, and it occurs in the absence of oxygen through the activities of microorganisms by breaking down organic matter and producing biogas consisting of methane (CH_4) and carbon dioxide (CO_2) and some parts of other gases such as hydrogen sulfide (H_2S) and nitrogen (N_2), organisms use only a tiny amount of the energy during decomposition (digestion), and the rest of the decomposition energy is stored in the produced gas. Figure 1 describes an overview of AD and the potential usage of the final products.

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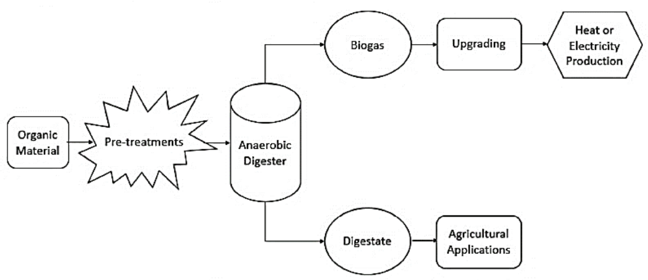

Figure 1: The overview of AD and the potential usage of the final products.

Anaerobic digestion consists of 4 stages, and each stage has a group of microorganisms. They are called primary fermentation bacteria and secondary fermentation bacteria. The other two groups are called (Al-Mutaqa), a complex process that depends on the microbial situation and internal operating conditions.

First Stage: Primary fermenting bacteria break down the complex substrate into smaller pieces [12]. The second stage: causes acidification and the formation of volatile fatty acids, ketones, and alcohols. The third stage: the construction of acetate, occurs through the fermentation of primary bacteria and secondary fermentation bacteria, which convert solutes and mono-soluble substances into acetic acid, hydrogen, and carbon dioxide, which begin to convert fatty acids into acetic acid, carbon dioxide and molecules of hydrogen. Fourth stage: methane (CH_4) is formed, and acetic acid, hydrogen, and carbon dioxide are converted into biogas [13].

The whole process can be summarized with this chemical equation (1) [12]:

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$

Advantages of anaerobic digestion technology

1. Anaerobic digestion has many advantages, including [14This process helps dispose of waste and utilize the methane gas stored in it by treating it in specific ways.
2. This process reduces the percentage of greenhouse gases in the atmosphere and unwanted odors.
3. Reducing the pollution of water sources by treating organic fertilizers and wastewater before using them in agricultural activities.
4. Converting nutrients found in organic waste, such as phosphorous and nitrogen, into more biologically active and soluble forms helps plants to absorb them easily.
5. It is an inexpensive process.

Influences factors in a process

This process is affected by several factors that affect its productivity; it is also can be summarized as follows:

1- PH and acidity: the AD process is sensitive to pH, and its best performance values are between (PH 5-6) [15].

Temperature: generally, the higher the temperature, the faster the process. This process can be classified according to temperature into three categories; psychrophilic (below 20 °C), mesophilic (20°C - 45 °C), and thermophilic (55 °C - 70 °C) [15].

2- Substrate properties: the material used in the digestion process, whether it is food waste, agricultural waste, or sewage water, has a significant impact on the outcomes [15].

3- C / N ratio: carbon to nitrogen ratio must be adjusted to improve this process, and the ideal ratio ranges are between 20 and 35 [15]. Hydraulic retention time: The average time spent by the substrates inside the reactor varies according to the type of waste and the digester [16].

4- Organic loading rate: the number of materials fed to the digester, and biogas production increases with an increase [16].

System components

The anaerobic digestion system consists of the preparation tank, silo, biodigester, digestate storage tank, gasholder, and combined heat and power system. Figure 2 describes Agricultural biogas plants which use agricultural waste as feedstock, which have 12 main parts, arranged according to the sequence of events, starting from No. 1 cattle stables up to No. 12, which is heat utilization [17].

Types of anaerobic digestion systems

Anaerobic digestion is divided into different categories according to its total solids content: Wet (0.5% ~ 8% TS) and AD Dry (> 15% TS) [18]. Or according to the digestor stage; either single stage or co-digestion [19]. Or according to feeding systems, batch or continuous systems [20].

Dry anaerobic digestion

It is the fermentation process of waste with a large

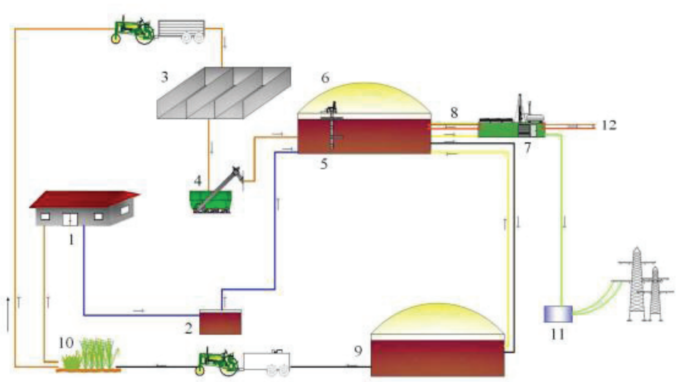

Figure 2: 1. Cattle stables 4. Solid feedstock supply system 7. Combined Heat and Power system (CHP) 10. Agricultural crops 2. Manure collection tank 5. Anaerobic digester 8. Electricity and heat consumed by the AD system 11. Transformer/Electricity to the grid 3. solid feedstock storage 6. Biogas storage 9. Digestate storage 12. Heat utilization

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proportion of solids and is characterized by the high productivity of biogas. Figure 3 shows the parameters that affect dry anaerobic digestion [21]; this type is of limited use worldwide as it is used in municipal solid waste and agricultural waste. And it has several drawbacks. Its high solids content reduces its stability, high start-up period, high inhibition effect, and poor operational strategies. Despite that, this process is more economical because its need for water is less than other types, as many countries of the world suffer from a shortage of water sources [22]. Also, with an increase in TS content, the Digestor volume and capital cost will decrease, so it's affected by a number of factors such as TS content, temperature, pH (C/N ratio), and mixing (Figure 2) [23]. These processes can produce methane gas at a rate of 0.2 and 0.6 m³/kg of volatile solids (VS) according to raw materials, optimal C: N ratios of 20 to 30, and the temperature values range between (35 °C – 57 °C) depending on the mesophilic digestion or thermophilicity, and the ideal PH values range between (6.8 and 7.2) [24].

Wet anaerobic digestion

Wet waste can be extracted from food residues, animal waste, fats, oils, and sewage sludge[24]. Here the input material shows liquid properties and must be constantly stirred [25]. The maintenance and construction cost of wet digestion plants is high due to the need for pipes and pumps. Figure 4 represents an Illustration of a sewage treatment plant [26]. But the main advantages are the high yield of methane that can be produced from the unit substrate, easy operation, generation, and maintenance, and low sludge productivity [27]. These processes can produce methane gas at a rate of 0.28 L/g [28]. C: N ratios (24.6 ± 0.2). PH value about (7.62 ± 0.10) [29].

Anaerobic co-digestion

The co-digestion of waste involves the use of two different substrates at the same time, such as food residues and sludge, which in turn leads to stability and improvement of the efficiency of the process due to its ability to reduce the organic load. Studies have shown its ability to increase biogas production by 26% of the traditional system, Figure 5 shows the path of the process and the two reactors in which

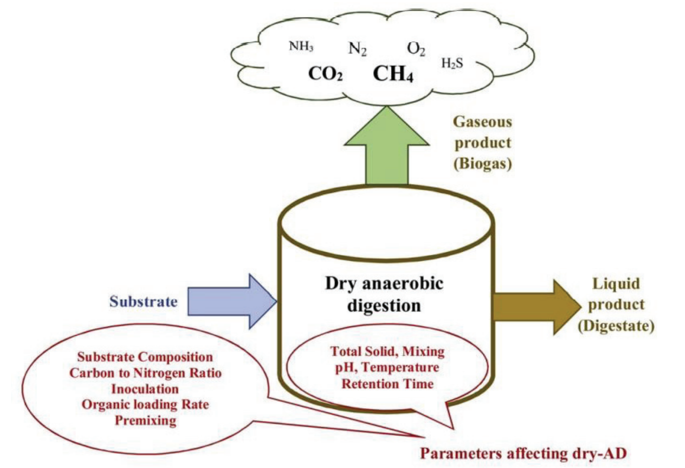

Figure 3: Dry anaerobic digestion operational parameters [21].

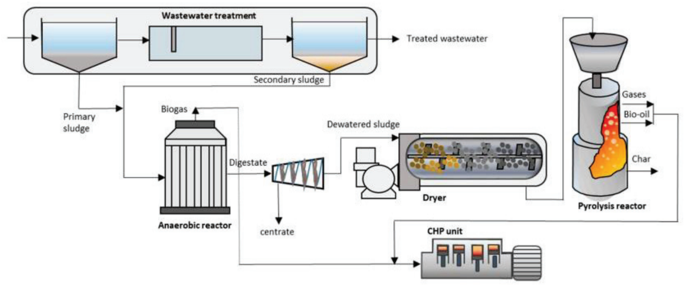

Figure 4: Illustration of a sewage treatment plant.

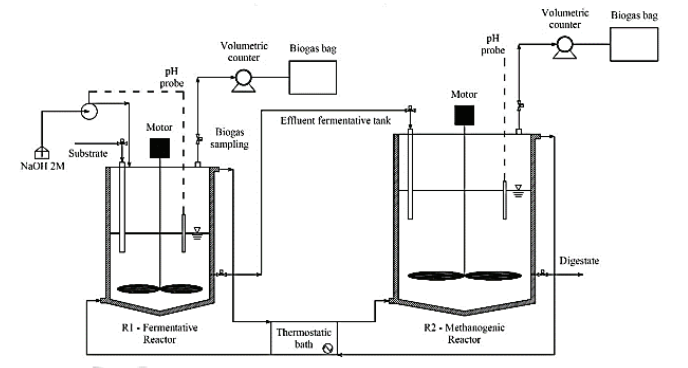

Figure 5: Anaerobic co-digestor.

this process takes place. In the first reactor, each hydrolysis, acidogenesis, and acetogenesis occur. But on the second reactor, methanogens arise [30]. This process can also reduce both emissions to the environment and the cost of the process. Still, on the other hand, this process has some negatives, such as the high cost of the initial establishment and that it is a complex process [31]. In addition to the factors affecting anaerobic digestion, consideration should be given here, such as the choice of materials to be mixed and the mixing ratio, such as combining the first substrate with a low C/N ratio with another substrate with a high C / N ratio, to reach the ideal ratio also the PH in the first stage is between 5 and 6. Figure 6 shows that more than one feedstock can be used in a co-digestion system [32]. The methane production here is higher due to the hydrolysis and the improved fermentation of the substrates, where some studies indicated its ability to produce 380 NL CH_4/kg. This system consists of two separate reactors. In the first reactor, bio-hydrogen can be produced by the need for dark fermentation and some special operating conditions [19].

Single-stage anaerobic digestion

Ninety percent of European anaerobic digestion plants are in a single-stage system with lower operating and installation costs and less complex than a combined digestion system [20]. The process takes place in a single reactor and is influenced by several factors, such as organic loading rate, flow rate and time, and hydraulic retention time. To produce the most significant amount of methane, the hydraulic Retention time is preferable to be large and the organic loading rate low [33]. The pH here is (7 to 8), and this ratio is not suitable for the growth of bacteria that carry out the process of hydrolysis or

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fermentation. This is one of the reasons why a large amount of methane is not produced in this process. One study indicated its ability to produce 330 NL CH_4/kg [19]. Figure 7 shows single-stage digestion in which the whole anaerobic digestion stages can occur [30].

Continuous feeding system

One of the most important steps in establishing a digestion station is determining the feeding strategy, which impacts the whole process. In continuous feeding, the loads are regular [20]. Substrates are added continuously, and the same amount of material produced from the digester is removed. One of the studies indicated its ability to produce methane in an amount of 2.78 L CH/L/d [33]. The process parameters, methane production, and daily feed to the reactors must be monitored periodically, as well as the amount of fermentation in the digester that must be removed [34].

Batch feeding system

The reactor is fed to the substrate once and then shut down to start the process. Construction and maintenance costs are low, and energy losses are low. One study indicated its ability to produce methane by 1.51 L CH /L/d [35]. Suddenly increasing the ratio of substrates on the reactor affects the system, either negatively or positively, but this process takes a long time, which helps in increasing the ability of bacteria to break down complex compounds [36].

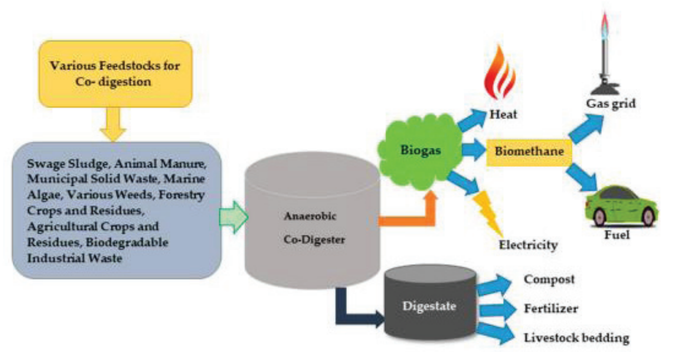

Figure 6: Multiplicity clarification for feedstock in co-digestion.

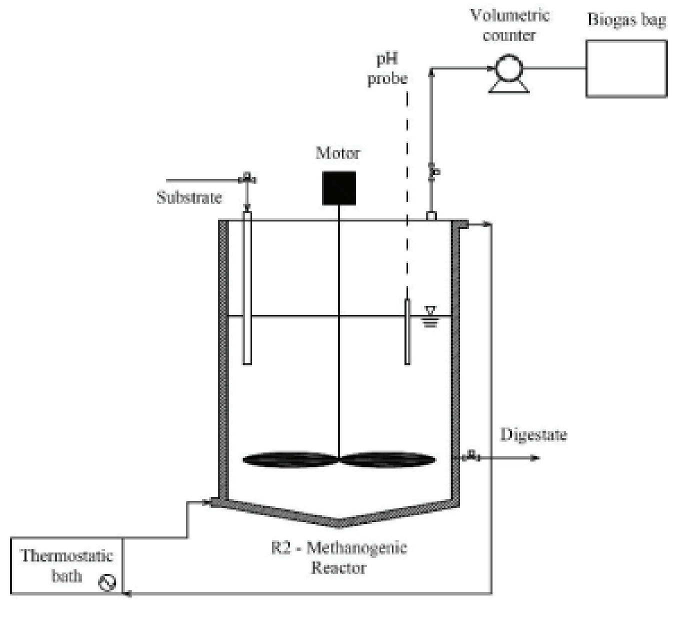

Figure 7: Illustration of single-stage digestion.

Comparative between different parameters for anaerobic digestion technology

The presented work summarizes the main difference between those parameters in the following tables. These tables and charts indicate that the system will operate more efficiently, and the methane output will increase during wet, co-digestion, and Continuous feeding conditions. Although the methane yield is higher in wet anaerobic systems, the maintenance and construction cost are higher than in dry anaerobic systems, and the total solid content is higher in the dry method. Methane yield and stability in anaerobic co-digestion are higher than in single-stage anaerobic digestion. However, 90% of AD plants in Europe operate at this range because of the complexity and high cost of the initial establishment of co-digestion. According to the feeding system, the continuous feeding system produces more methane than the batch feeding system, but the cost of construction, maintenance, and process time in the constant feeding system is more than in the Batch feeding system Tables 1-3, Figures 8-10.

Conclusion

Anaerobic digestion has a significant role in reducing waste and environmental pollution and using it as a renewable energy source. This process has different operating conditions; in addition, the amount of energy generated varies according to the type of waste. The yield can be improved by adjusting

Table 1: The difference between dry and wet anaerobic digestion [19-29].

Spec.	Dry anaerobic digestion	wet anaerobic digestion
Methane yield	Lower	Higher
TS content	Higher	Lower
Maintenance and construction cost	Lower	Higher

Table 2: Shows the difference between co-digestion and single-stage anaerobic digestion [30-33].

Spec.	Anaerobic co-digestion	Single-stage anaerobic digestion
Methane yield	Higher	Lower
installation cost	Higher	Lowe
stability	Higher	Lower

Table 3: Shows the difference between continuous and batch-feeding anaerobic digestion [34-36].

Spec.	Continuous feeding system	Batch feeding system
Methane yield	Higher	lower
Cost of construction and maintenance	Higher	Lower
Process time	Higher	Lower

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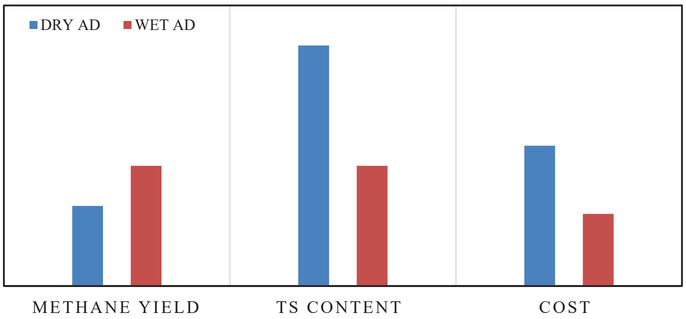

Figure 8: The difference between wet and dry anaerobic digestion.

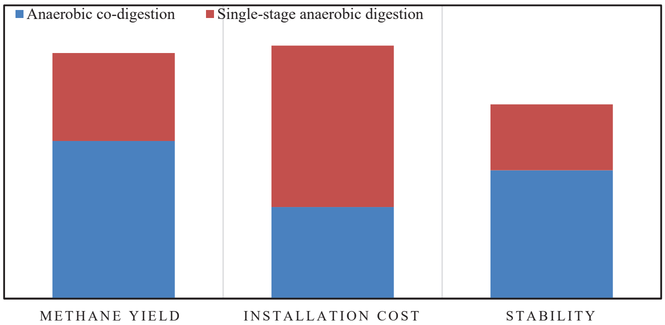

Figure 9: The difference between co and single-stage anaerobic digestion.

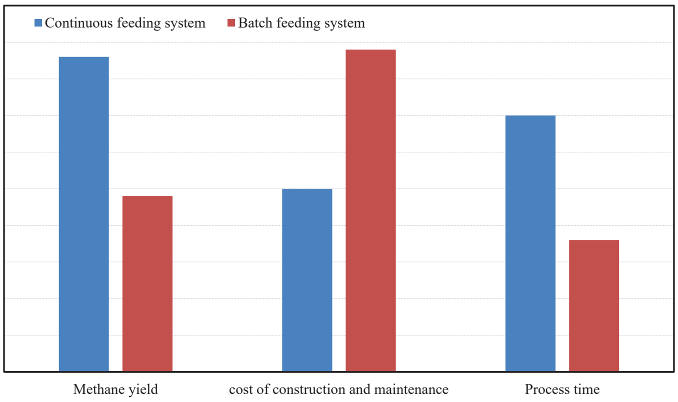

Figure 10: The difference between batch and continuous feeding system anaerobic digestion.

the temperature, and pH and regulating the organic loading rate. Anaerobic co-digestion has more stability than single-stage anaerobic digestion and can produce 380 NL CH_4/kg, but single-stage can produce 330 NL CH_4/kg. On the other hand, co-digestion Requires higher installation costs, but 90% of European anaerobic digestion plants are in a single-stage system. In a continuous feeding system, the cost of construction and maintenance is lower than in the Batch feeding system, but it takes a higher process time than the Batch feeding system. Wet, Continuous, and co-digestion are preferred to improve yield.

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