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An Overview of Anaerobic Digestion of Cow Dung

V. M. Nekhubvi*†
*Department of Science Foundation, Faculty of Science, Engineering and Agriculture, University of Venda, South Africa
†corresponding author: V. M. Nekhubvi; vhutshilo.nekhubvi@univen.ac.za

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ABSTRACT

In the past decade, governments and development agencies have contributed significantly to society through anaerobic digestion technology (ADT). Anaerobic digestion technology (ADT) has become an important tool in the fight against global poverty and environmental issues, leading to positive change in communities around the world. The technology works as a wet or dry process, depending on its classification. The process is complex and yields multiple benefits, such as creating a natural fertilizer that can be used to help crops grow, as well as generating renewable energy sources. It is common knowledge that many household-sized digesters installed in different areas are one-stage digesters. One-stage digesters do not require a separate pre-treatment stage before the digestion process. This makes them simpler and more cost-effective to install and operate than traditional two-stage digesters. Thus, some drawbacks are associated with these systems since they feed on just one type of feedstock. Many researchers fail to adequately address interactions critical to ADT's operation, including interactions among growth factors and operating parameters. In a single-stage and one-substrate digester, researchers commonly neglect to study the digester feeding and operational conditions. Anaerobic digestion was the subject of this review, covering research conducted between 2001 and 2022. The study identified a significant drawback associated with mono-digestion and single-stage digestion. The findings illustrate that mono-substrate and single-stage digestion are worthwhile approaches, even though they have their challenges. However, adding a further digestion stage can significantly improve biogas production.

INTRODUCTION

Anaerobic digestion technology (ADT) for biogas production provides solutions to the increasing problems associated with energy production (Sawyerr et al. 2019). As global energy consumption increases due to population growth, more biogas projects are urgently needed (Abanades et al. 2021). Anaerobic digestion technology (ADT) has received financial assistance from development donors and government agencies. It is mainly used in rural households because feedstock is readily available (Roubík et al. 2018, Pandey et al. 2021, Lohani et al. 2021). By reducing dependence on fossil fuels and creating jobs, biogas energy can be an essential part of the future of renewable energy technologies (Begum & Nazri 2013). In the long term, greenhouse gas (GHG) emissions will be reduced (Anukam et al. 2019), thus reducing global warming (Sadeleer et al. 2020). Roubík et al. (2018) found that households without biogas emit more greenhouse gases than households with biogas. Several applications for raw biogas include heating, cooking, and lighting (Black et al. 2021). In Contrast to raw biogas, it is possible to convert it into biomethane that can be used for electricity generation or transportation (Gaby et al. 2017, Abanades et al. 2021). A volume of purified biogas has an energy equivalent to 1.1 liters of gasoline or 0.97 liters of natural gas, according to (Rajendran et al. 2012). Anaerobic digestion (AD) plants requiring small-scale conversion of biogas require a higher power consumption than large-scale plants (0.25-0.5 kWh per $1m^3$ of biogas) (Li et al. 2017). Depending on the methane (CH_4) content, which varies between 50 and 65% (Li et al. 2017), the value of raw biogas' calorific value ranges between 5.5 - 7.5 $kWh.m^{-3}$ (Okonkwo et al. 2018). Khan et al. (2018) reported a biogas density of 1.15 $kg.m^{-3}$ and a calorific value of 11.06 $kWh.m^{-3}$. Methane content is determined by the material used to feed the digester. A recent study suggests that all agricultural waste can be converted into biogas (Łochyńska & Frankowski 2018). An examination of the CH_4 yield of the feedstock is crucial for assessing the economic viability of a biogas investment (Kozłowski et al. 2018). In the study by Anderman et al. (2015), participants showed that they spent significantly less time cooking and collecting firewood in households with biogas. Biogas production is highly influenced by two key aspects of AD: feeding and operating conditions (Ignatowicz et al. 2021, Nsair et al. 2020). Therefore, this review focuses on the factors related to feeding the digester, with pH and temperature regulation. Furthermore, the influence of these components on biogas production's efficiency and productivity is evaluated to gain a comprehensive understanding of the subject.

DIGESTER FEEDING

To feed the digester, the substrate is fed into the biogas digester immediately after mixing it with water. This helps to ensure that the substrate is evenly distributed and that the bacteria in the digester can access it quickly and efficiently to produce biogas. It has been found that the feeding of biogas digesters varies depending on the availability of substrates. The main substrates for biogas digesters are organic matter such as food waste, agricultural waste, and animal manure. The biogas digester can be fed more frequently if these substrates are abundant. If not, then the biogas digester must be fed less often. Wang et al. (2021) have shown three types of feeding mixtures (singular, binary, and ternary). A singular process uses one feedstock, a binary process uses two, and a ternary process uses three.

In most cases, mono and co-mixtures of feedstocks are the most common, with singular feedstocks falling under mono and binary or ternary feedstocks falling under co-mixture. In addition to ternary mixtures of feedstocks, Kim et al. (2019) have also demonstrated applying such a method using agricultural and food wastes and dairy manure from a small anaerobic digester. Castano et al. (2014) used a 1:1 ratio waste mixture to feed the digester. During the experiment, the digester was fed three times per week. The mixture was effective, as biogas production increased significantly with the addition of the waste mixture. Obileke et al. (2020) used cow dung with water at a 1:1 (waste: water) ratio before digestion. Ramaswamy & Vemareddy (2015) fed a 1 m^3 biogas digester with a mixture of cow dung and a water ratio of 1:10. When it comes to the feeding of the digester. It may be fed more than once per day (Achu Nges et al. 2012). This will help ensure that the digester runs at optimal efficiency and performance. In essence, it is the inoculum-to-substrate ratio (I/S) that is usually fed more than once in anaerobic digestion as the substrate alone may present some difficulties, such as changing the properties of the substrate (Parra-Orobio et al. 2016), in addition to differences in the amounts of three main organic components: carbohydrates, lipids, and proteins (Khadka et al. 2022). Ofosu & Aklaku (2010) considered biogas production from lipids attractive because they are reduced organic materials with high methane yields. It has been suggested by a recent research study published by Rivas Solano et al. (2016) that the use of a single substrate (e.g., livestock manure) is not commendable because some substrates have a low methane yield compared to others (Song et al. 2021). Therefore, it is important to consider the relative methane yield of each substrate when selecting the optimal mix for anaerobic digestion. Biogas production is inadequate with the digestion of cow manure alone (Elsayed et al. 2022). Again, Mata-Alvarez et al. (2014) highlight some drawbacks associated with the anaerobic digestion of single substrates. It has been established that using manure only results in low performance (Mao et al. 2015). Specifically, they noted that nitrogen imbalance and ammonia inhibition were major causes since livestock manure contains a high nitrogen content, such as goat manure (1.01%), chicken manure (1.03%), and dairy manure (0.35%), and swine manure (0.24%). When selecting feedstock, factors such as availability, cost, biogas yields, and environmental benefits should be considered (Bhatnagar et al. 2022).

Furthermore, feedstock selection should be tailored to the specific requirements of the biogas production process for optimal results. In a technical study on household digesters, Tumutegyereize et al. (2017) established a baseline for future research on factors influencing their adoption, use, and management decisions of biogas technology. Cow dung dominated the feedstock list. However, if the mixing ratios are used appropriately, the risk of the anaerobic digestion system failing is eliminated because if the feed material is too diluted, it will be washed out, and then system failure will occur (Kim et al. 2019). Cow dung and water composition must be in the right proportion.

Consequently, it is essential to ensure that all components are correctly balanced to optimize biogas production. This will eliminate the risk of system failure and establish a successful biogas production plant. Berhe et al. (2017) showed that the most effective promotional tool is an efficient biogas digester, while satisfied users are the best advocates for biogas technology.

ANAEROBIC DIGESTION OPERATION

Due to its simplicity of operation and the diversity of materials used as feedstock, anaerobic digestion (AD) is a widely researched technology (Bhatnagar et al. 2022). The organic materials are broken down in a digester or lagoon to produce biogas and fertilizer through wet and dry processes. Elsharkawy et al. (2019) categorized AD as dry and wet. Dry AD processes waste with a total solid content greater than 20%, and wet AD processes waste with less than 10% TS content. Uddin et al. (2021) indicated that the solid content of a dry AD system is between 20 and 40%. The study by Kassongo et al. (2022) said that AD reactors are categorized as wet (≤ 10% TS), semi-dry (10-20% TS), and dry (≥20% TS) systems. The anaerobic digestion process applies immediately after the mixture substrate has been poured into the digester. The core of AD operation is feedstock disintegration, digestion, and operational conditions. According to their feed arrangement, anaerobic digestion operations are categorized into batch, continuous, and combined digestion (He et al. 2022). A batch mode can be used for anaerobic degradation, inoculum activity, and inhibition (Raposo et al. 2011). Achu Nges et al. (2012) showed that it is possible to predict full-scale methane yield using a batch mode approach. In a batch mode, complex organic matter is fed once in the digester (Uddin et al. 2021). Continuous mode operation is when the digester feeds more than once a day. Anaerobic digesters can be configured as single-stage, two-stage, or multi-stage reactors. The steps of hydrolysis/acidogenesis and acetogenesis/methanogenesis occur in either the same or separated digesters (Rabii et al. 2019).

Feedstock Disintegration

It has been well-documented that different bacteria respond to diverse environmental conditions in an assembly-line manner, involving four biochemical steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Filer et al. 2019). Interestingly, each of the above biochemical sequential steps is executed by different microbe species with various characteristics, growth rates, and substrate affinities (Duan et al. 2017).

Hydrolysis

Hydrolysis transforms complex carbohydrates, fats, and proteins into soluble monomers and dimers, including sugars (glucose, sucrose, and fructose), fatty acids, and amino acids (Rajendran et al. 2012). Hydrolysis is often considered a simple first-order process due to the vast variations in substrate composition and is not applicable in all situations (Mani & Sundaram 2016). This is because some compounds are resistant to hydrolysis or may undergo other reactions that are more favorable under certain conditions. For example, hydrocarbons (compounds consisting of hydrogen and carbon atoms) are generally not susceptible to hydrolysis because they do not contain any functional groups that can be readily hydrolyzed. The hydrolysis of particulate matter has been identified as the rate-limiting step in AD (Mani & Sundaram 2016) when the particulate matter cannot degrade readily or in systems with high loading rates. During the hydrolysis process, it is essential to maintain uniform mixing and temperature within the digester system. The extracellular hydrolytic enzymes produced by the bacteria can have intimate contact with complex organics without limiting the overall stabilization reaction (Mani & Sundaram 2016). The rate of the hydrolysis process is determined by the particle size, along with the pH value (Ziemiński & Frąc 2012). This negative relationship between solids' size and the rate of the hydrolysis process can, therefore, affect the overall performance of the entire process. It is important to note that the adverse effects of large solids are minimized by conducting expensive pre-treatments to disintegrate and dissolve the substrates before AD. Approximately 20 to 40% of the total process costs are attributed to pre-treatments to improve hydrolysis (Menzel et al. 2020). Even though some organic substrates are particulate, some tend to dissolve quickly when immersed in water (Panico et al. 2014). Hydrolytic microorganisms are favored to grow in slightly acidic conditions (Menzel et al. 2020). Myint et al. (2007) developed a mathematical model for the hydrolysis and acidogenesis reactions of anaerobic digestion of cattle manure. However, due to its poor statistical significance, they did not account for pH's influence on the hydrolysis rate from the linear regression. The process of hydrolysis can be viewed from a chemical perspective (Anukam et al. 2019);

$$(C_6H_{10}O_5)n + n\,H_2O \rightarrow n\,C_6H_{12}O_6 + nH_2 \quad \ldots(1)$$

Where $C_6H_{10}O_5$ stands for cellulose via the addition of water (H_2O) to form glucose ($C_6H_{12}O_6$) as the primary product and give off hydrogen (H_2). A first-order kinetic model can accurately predict hydrolysis involving concentrated degradable organic materials (Mani & Sundaram 2016);

$$\frac{dS}{dt} = -k_{hyd}S \quad \ldots(2)$$

where S is the volatile solids (VS) concentration, k_{hyd} is the first-order coefficient, and t is time in days. Batch experiment data can be fitted to a first-order equation to find hydrolysis rate coefficients (Moestedt et al. 2015). Eqn (2) shows that the observed conversion rate of hydrolysis is affected by the amount of solid substrate in the reaction chamber (Guo et al. 2021). Integrating Equation (2) yields the following result.

$$InS = -k_{hyd}t + b \quad \ldots(3)$$

This is where b is the constant of integration. (ln S) can be plotted against t to find the slope ($-k_{hyd}$) and intercept b. The hydrolysis rate coefficients increase with a rise in temperature, which translates to (Luo et al. 2012);

$$Ink = \frac{E_a}{RT} + InA \quad \ldots(4)$$

A stands for the pre-exponential factor, E_a ($Jmol^{-1}$) is the energy of activation of a reaction, $T(K)$ is the absolute temperature, and R is the gas constant($J{\cdot}K^{-1}{\cdot}mol^{-1}$). The slope of the line predicted by the Arrhenius equation can be used to calculate the activation energy. Kothari et al. (2018) showed that the following expression could be used to find the activation parameter enthalpy;

$$\Delta H = Ea - RT \quad \ldots(5)$$

Where $\Delta H(\mathrm{Jmol}^{-1})$ is the enthalpy of a body at a specific temperature, $T(K)$ and R represent the gas constant ($\mathrm{J{\cdot}K^{-1}{\cdot}mol^{-1}}$), respectively. Based on what has been found so far, hydrolysis is a bottleneck stage that requires higher temperatures to accelerate degradation. Hydrolysis requires breaking the glycosidic bonds that link the monomers together. This requires higher temperatures to increase the reaction rate and make it more efficient. In general, AD is run at three temperature levels: psychrophilic (<20°C), mesophilic (20-43°C, and thermophilic (50-60°C (Nie et al. 2021). In unheated digesters, heat is generated by solar radiation in mesophilic or psychrophilic conditions. This heat is then utilized to produce the necessary temperature for anaerobic digestion, with the optimum temperature depending on the type of microorganisms in the digester. Methane yields can be increased with thermophilic digestion temperatures. Rapid hydrolysis, however, can result in the accumulation of ammonia and volatile fatty acids, which can lower pH and methane productivity (Kassongo et al. 2022).

In contrast, Ahring et al. (2001) reported a lower methane yield at 65°C than 55°C. Thermophilic temperatures are widely employed in large-scale digesters (Ahring et al. (2001). This is because thermophilic bacteria are more efficient at breaking down organic matter, such as animal and food wastes, into biogas than other types of bacteria. Furthermore, thermophilic temperatures reduce pathogen risk in biogas, making it safe to use. Anaerobic digestion on a large-scale digester is most effectively accomplished by a continuous two-stage configuration consisting of a thermophilic first and a mesophilic second stage.

Cow Dung as Feedstock for Anaerobic Digestion

Due to its availability and as an inexpensive source of organic material rich in methane-producing bacteria, cow dung is the most common feedstock used in household biogas digesters in rural areas. Cow dung is lignocellulosic and has enough nutrients, making it a low-cost input with valuable outputs through the AD process (Zeb et al. 2022). It has carbohydrates, lipids, fats, and proteins (Saady & Massé 2015). So, cow dung consists of 1.6-23.5% cellulose, 1.4-12.8% hemicellulose, and 2.7-13.9% lignin (Zeb et al. 2022). In India, fixed dome biogas digesters are fed only animal manure (Khan & Martin 2016). Akbulut et al. (2021) showed that a family-size biogas digester could produce biogas volumes like 3,816.85 $m^3.a^{-1}$ from only cow manure. The investigation results of the study by Baba and Nasir (2012) showed that cow dung might be one of the feedstocks for efficient biogas production and waste treatment. Fresh cow dung is estimated to have 28% water Sruthy et al. (2017). However, Raja et al. (2021) and Szymajda et al. (2021) showed that fresh cow dung has approximately 80% water. Haryanto et al. (2018) reported an average of 80.12% of water in fresh cow dung. For AD to generate biogas energy, fresh cow dung is mixed with water at a widely used ratio of 1:1 (Baba & Nasir 2012).

Physiochemical Properties of Cow Dung

Cow dung, also known as cow manure, is a mixture of organic and inorganic materials excreted by cows. The physicochemical properties of cow dung can vary depending on several factors, including the age and breed of the cow and its diet. It is estimated that the composition of cow dung consists of 1.8-2.4% N_2, 1.0-1.2% P_2O_5, 0.6-0.8% K, and 50-75% organic humus (Ogur & Irungu 2013). As a feedstock for digesters, cow dung must have a sure consistency, including a total solids (TS) or dry matter (DM) content, volatile solids (VS) or organic solids, moisture, pH, particle size, and chemical oxygen demand (COD) (Wang et al. 2019). Feedstocks with bulk solids are said to adversely affect anaerobic digestion performance (Yi et al. 2014). Low TS content can result in low biogas yield and reduced process efficiency. Thus, optimizing the feedstock's TS content is important for optimal process performance. Generally, a 6-10% TS content is considered optimal for AD performance. However, the optimal TS content may vary depending on the feedstock and AD system. Conducting a series of experiments to determine the optimal TS content for a given feedstock and AD system is recommended. The total solids (TS) can be determined after the feedstock is heated to 105°C for at least an hour and then cooled; the total solids (TS) can be determined. The total solids (TS) contain both organic and inorganic substances. This can be expressed mathematically as follows:

$$TS = \frac{[Weight\ after\ heating\ to\ 105°C]}{\text{Weight before heating}} \times 100 \quad \ldots(6)$$

The researchers in Nsair et al. (2020) mentioned that the size of the dry matter (DM) during wet fermentation plays an essential role. The researchers considered the dry weight value to be less than 15% during wet fermentation. A research study conducted by Triolo et al. (2013) suggested that 10% DM would be best. The dry matter value can estimate how much volatile solid is in the slurry. As an alternative, volatile solids (VS) are found when the dry matter is heated to 550°C. Equation (7) describes the volatile solids (VS).

$$\text{VS (\% of TS)} = \frac{[(Weight\ after\ heating\ to\ 105\ ^0C - Weight\ after\ heating\ to\ 550\ ^0C)]}{\text{Weight before heating}} \times 100 \quad \ldots(7)$$

Volatile solids (VS) are a mixture of biodegradable and nonbiodegradable organic matter in livestock manure (Appuhamy et al. 2018). This mixture can differ in its content and composition between types of livestock and even between different manure sources of the same animal species. Based on Saady and Massé (2015) study, a significant portion of the VS in dairy manure is lignocellulosic biomass. The VS content of cow dung will vary depending on what the cow feeds on. When a laboratory or pilot-scale anaerobic digestion or large-scale anaerobic digestion is performed, the total solids (TS) or volatile solids (VS) are often used to calculate the biogas yield results (Bedoić et al. 2020).

The Stoichiometric C: N Ratio of Cow Dung

The carbon to nitrogen (C: N) ratio of cow dung is an important parameter to consider in biogas production because it affects the rate and efficiency of the anaerobic digestion process. A ratio between 20:1 and 30:1 is ideal for producing flammable gases for any substrate. This range provides the necessary nutrients for the microorganisms involved in the anaerobic digestion process. As a result, when the C: N ratio is outside this range for more efficient biogas production, it will need to be co-digested (or mixed) with another substrate with a moderate C: N ratio (Zainudeen et al. 2021). There is evidence that the best C: N ratio in methane fermentation is 25:1-30:1. However, operating conditions, such as temperature, may affect the depletion of carbon and nitrogen, resulting in inhibitory effects on the process (Wang et al. 2014). According to Table 1, at least 28:1 and 20:1 ratios are suitable for anaerobic digestion. Therefore, adhering to these ratios is imperative for successful anaerobic digestion.

Organic Loading Rate

The OLR measures how much VS the digester can receive and how it influences the biogas production rates (Nsair et al. 2020, Haryanto et al. 2018). The organic loading rate depends on the types of feedstocks used; therefore, it can be considered a VS loading rate (kgVS.m^{-3}.day). The OLR is defined in mathematical terms using Equation (8) (Nsair et al. 2020):

Table 1: A comparison of the stoichiometric ratio (C/N) of cow manure.

C	N	C:N	Reference
43.08	1.53	28.16	(Fajobi et al. 2022)
47.83	3.95	12.10	(Aravani et al. 2022)
45.47 ± 0.03	2.94 ± 0.09	15.45 ± 0.12	(Zhang et al. 2022)
-	1.16 ± 0.08	16.26 ± 0.14	(Rahman et al. 2021)
-	-	20.6	(Dhungana et al. 2022)
-	-	41.43	(Bella & Rao 2022)

$$OLR = \frac{m_{cd}C_{OM}}{V_D} \quad \ldots(8)$$

Where m_{cd} is the amount of mass of feedstock that is consumed in a given period (kg d^{-1}), C_{OM} is the proportion of dry organic matter in the digester (%), and V_D is the digester's volume (m^3). It is noteworthy that (Bedoić et al. 2020) defined OLR using Equation (9).

$$OLR = \frac{Q}{V_D} \quad \ldots(9)$$

The feedstock volumetric flow rate is Q, and V_D is the digester's volume. This equation only focuses on the ratio of fresh feedstock to water without considering total VS, COD, or BOD. Jaeger and Blanchard (2022) reported using a digester with an 8 m^3 and a practical volume of 6 m^3, fed with 3.8 kgVS.m^{-3}day. Some authors refer to OLR as the COD loading rate. Researchers refer to OLR as the COD loading rate because the OLR is directly related to the COD concentration of the wastewater being treated. By knowing the COD concentration and the flow rate of the wastewater, the OLR can be calculated. OLR is important in wastewater treatment because it is a key factor affecting the treatment process's performance and efficiency. High OLRs can cause operational issues such as poor treatment efficiency, reactor instability, and accumulation of toxic compounds, while low OLRs can result in underutilization of the treatment capacity. Therefore, measuring OLR and COD loading rates is important for designing, optimizing, and operating biogas digester systems.

This is especially true for those operating wastewater treatment plants (Khan et al. 2022). As shown by Ünyay et al. (2022), an increase in OLR dramatically reduces methane yield, so finding the optimal OLR for a given digester configuration is imperative. In a study by Obileke et al. (2020), the organic loading rate was recommended to be between 1.6 and 4.8 kgVS.m^{-3} per day. Some authors have misrepresented the OLR units in their works. In their paper, Menacho et al. (2022) represent OLR as a flow rate to refer to the studies of others who expressed OLR in terms of (gVS.day^{-1}) and (gCOD.day^{-1}) as the reference for their validation tests. However, the flow rate is not a suitable unit of measure for expressing OLR. There was another error in the representation of the organic loading rate in the study by Ansar (2022), which mentioned a rate of 3.06 kg.m^{-3}day^{-1} for organic loading. To help prevent confusion, the organic loading rate should be distinguished from the volumetric flow rate(VFR) or just the volumetric loading rate. Volumetric flow rate (VFR) is a measure of the volume of fluid that flows through a system per unit of time. It is typically expressed in units of m^3.h^{-1} or m^3.day^{-1}. It is considered that the organic loading rate (OLR) is the main parameter in determining the design in the continuous AD (Rocamora et al. 2020).

The Flow Rate of the Substrate

Equation (10) describes the total volumetric flow rate ($m^3.day^{-1}$) to the digester as the ratio of the overall feeding mass rate ($kg.day^{-1}$) and the density of the feedstock ($kg.m^{-3}$) (Wresta et al. 2015).

$$Q = \frac{(m_f + m_w)}{\rho_{f+w}} \quad \ldots(10)$$

Where m_f, m_w, and p_{f+w} stand for the feedstock mass, water mass, and the density of the mixture of water and feedstock, respectively. The volumetric flow rate is the most used by households when feeding the digester.

Hydraulic Retention Time

The hydraulic retention time (HRT) is determined based on the feedstock flow rate (Tan et al. 2021). The HRT is an important parameter in the design and operation of biogas plants as compared to other parameters. It refers to the amount of time that the substrate (organic matter) remains in the digester, which affects the rate of biogas production (Obileke et al. 2021). It is emphasized that HRT is an important parameter that should be reviewed regularly for AD processes to be stable. The given Equation (11) below is one of the formulas that Kesharwani & Bajpai (2021) used to define HRT mathematically.

$$HRT = \frac{V_D}{Q} \quad \ldots(11)$$

Where Q ($m^3.day^{-1}$) is the volumetric flow rate fed to the digester of volume V_D (m^3). Variations in HRT have ranged between 20 and 100 days (Rajendran et al. 2012). In contrast, Nsair et al. (2020) have shown that the HRT varied from 0.75 to 60.00 days, with the optimal period of 16 to 60 days. Uddin et al. (2021) stated that a minimum of 10 days of HRT is necessary to ensure that bacteria are not washed away during the process. HRT is chosen according to the digester volume, digestion processes, and feedstock temperature. Using wet mass substrate instead of mass substrate VS in the OLR expression, HRT is equivalent to an inverse of OLR (Lissens et al. 2001).

Interestingly, OLR is directly related to HRT (Ruile et al. 2015). Experimentation and system performance monitoring typically determine the optimal HRT for a particular biogas plant. This involves gradually increasing or decreasing the HRT and monitoring the biogas production and process stability until the optimal HRT is achieved.

Challenges and Recommendations

Despite the worldwide popularity of the anaerobic digestion of cow dung, it still has some disadvantages, such as inhibition of the process, feedstock variability, process instability system design and management, and low biogas production due to the high C: N ratio. Addressing these challenges requires a thorough understanding of anaerobic digestion's biological and chemical processes and the factors that can impact system performance. Careful management of feedstock, process conditions, and system design can help optimize biogas production and reduce environmental impacts. Based on the literature reviewed AD, the following recommendations are made. Manure from livestock, especially cow dung, should be considered in waste management and biogas production. To maximize biogas production, the addition of other organic substrates and co-substrates, such as crop residues, should be considered.

Moreover, mono-digestion should be promoted and not neglected to combat the high nitrogen content in livestock manure. Mono-digestion is a process in which manure is fermented only once to produce biogas. This process helps to reduce the amount of nitrogen in manure, which can then be used as fertilizer and reduces the environmental impact of livestock farming. Overall, mono-digestion can be a useful strategy for optimizing the anaerobic digestion process and improving the efficiency and effectiveness of biogas production. However, it is important to carefully select the appropriate substrate and optimize the process conditions to ensure optimal performance.

CONCLUSIONS

Based on anaerobic digestion technology published between 2001 and 2022 in research articles searched for information about biogas feeding and digestion. The information was then used to draw insights into biogas feeding trends and anaerobic digestion technology over the past two decades. According to the review findings, the conclusion is that several factors can affect the digester stability and biogas production rate. These factors begin with volatile solids content. The volatile solids content is critical because it affects the number of microorganisms available for digestion. This directly impacts the production of biogas. In addition, the pH and temperature of the slurry inside the digester, as well as the amount of nutrients and oxygen, can also affect the stability and biogas production rate. In addition, digesters are fed differently depending on feedstock availability. Thus, the composition of the feedstock, including the volatile solids content, will directly impact the amount of biogas produced. Recent research shows that co-digesting feedstock is helpful because mono-substrates fed into AD systems present drawbacks like a low hydrolysis rate that leads to insufficient biogas production. This is because when a variety of substrates are co-digested, the microbial community within the AD system can more efficiently break down the feedstock and convert it into biogas.

Additionally, the complexity of the microbial community can be increased by adding more substrates, which can lead to better biogas production. Following recent research, keeping uniform mixing and temperature, particle size, and pH controls how fast organic matter hydrolyses in AD. Feedstocks that need pre-treatment before hydrolysis are expensive to process and account for 20-40% of the total process cost. Pre-treatment of feedstocks is necessary to break down the complex organic matter into simpler compounds, which then can be hydrolyzed. This pre-treatment step is energy and time-consuming and, therefore, expensive.

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ORCID DETAILS OF THE AUTHORS

V. M. Nekhubvi: https://orcid.org/0009-0004-7805-9501