Anaerobic Co-Digestion

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Contributor: Yongwoon Park, Jeehyeong Khim, Jong Doo Kim

The anaerobic mono-digestion treatment of organic waste can be challenging due to nutrient imbalances and a lack of microbial diversity. However, anaerobic co-digestion has been shown to effectively address both challenges without the need for additives.

Keywords: organic waste ; anaerobic co-digestion ; bio-gasification

1. Anaerobic Co-Digestion

Anaerobic co-digestion has been shown to improve the efficiency of organic waste treatments with different properties and complementary characteristics and offers significant economic advantages. The anaerobic mono-digestion treatment of organic waste can be challenging due to nutrient imbalances and a lack of microbial diversity. However, anaerobic co-digestion has been shown to effectively address both challenges without the need for additives [1][2][3][4]. Anaerobic co-digestion has many essential factors, the most important of which are described below.

Substrate is a crucial factor for anaerobic digestion efficiency. It is converted into biogas through biochemical processes, such as hydrolysis, acidogenic fermentation, acetogenesis, and methanogenesis, that accompany anaerobic digestion [5]. The velocity and rate of conversion into methane gas vary with the substrate's chemical composition. The substrate, largely composed of carbohydrates, proteins, and fats, is converted into simpler molecules through a biochemical process and finally into methane and other substances [6][7]. Protein-rich organic substrates, such as livestock manure, have a high energy content and produce relatively high volumes of methane. A high concentration of ammonia interferes with microorganism activity and increases the instability of anaerobic digestion, causing system failure. However, suitable co-substrate-like food waste can adjust the C/N ratio to its optimum value. Carbohydrate-rich organic substrates, such as food waste, contain considerable amounts of simple sugars and disaccharides that are easily decomposed by methanogenic microorganisms and can easily produce volatile fatty acids (VFAs). However, a decrease in pH because of VFA accumulation, a high carbon-to-nitrogen (C/N) ratio, and concentration of heavy metals and toxic substances can cause challenges in anaerobic digestion. Suitable co-substrate-like animal manure can adjust the VFA concentration. Additionally, fat-rich organic substrates can be easily decomposed and produce large volumes of biogas. However, challenges such as blocking, adsorption to biomass, and foaming may occur, where carbohydrate-rich co-substrate can be used to adjust the nutritional balance [8][9][10].

The optimal pH range for biogas production in an anaerobic digester is 6.8–7.2. Acidogenic microorganisms are less sensitive to pH and can tolerate a pH range of 4.0–8.5; the optimal pH for hydrolysis and acidogenesis is 5.5–6.5 [11][12]. In contrast, methanogenic microorganisms are highly sensitive to pH, and the appropriate pH is approximately 7. Therefore, a two-stage digester is sometimes used to divide the anaerobic digester into two parts with different pH ranges to maximize the efficiency of anaerobic digestion. Therefore, pH is an important factor in determining the health of anaerobic digesters. Methane production may not be successful if the pH is not maintained within the optimal range, such as when the pH drops as a result of excessive VFA during the anaerobic digestion of a single substrate, including high-concentration food waste [9][13]. Anaerobic co-digestion of food waste with a pH of <4 and livestock manure with a pH of >8 can lead to increased gas production compared to separate digestion provided that the feedstock mixture is adjusted to maintain an optimal pH of 6.5–7.5 throughout the process [14].

According to previous studies on biogas production through anaerobic digestion, the typical C/N ratio is 20–30 [11][15][16][17]. However, determining the optimal C/N ratio is challenging because it depends on the chemical composition and biodegradability of the substrate [18]. However, system instability can be reduced if the C/N ratio is maintained within the normal range [9]. The challenges that can occur when an appropriate C/N ratio is not maintained are as follows: a high C/N ratio may cause excessive VFA generation, and a low C/N ratio may lead to excessive generation of total ammonia nitrogen. These are intermediate products of the metabolic process that interfere with the production of methane [19]. Methane production can be increased by maintaining an appropriate C/N ratio in anaerobic co-digestion, such as swine manure, rice straw mix [19], cow manure, and energy crop mix [20].

2. Design of a Full Scale Anaerobic Co-Digester

Anaerobic digestion (AD) generally works well on a laboratory or intermediate scale, but problems may arise when scaling up to larger reactors [6]. Potential issues include unpredictable substance behavior in the mixture, leading to problems such as odor, fermentation cessation, or slowed fermentation rates; difficulty with solid waste processing, which can accumulate within the reactor and hinder the fermentation process; difficulties maintaining proper temperature control, which can lead to overheating in some areas and slow fermentation rates in others; and difficulty maintaining consistent flow rates, which can affect both the speed and stability of the fermentation process. To address these challenges, effective flow control and characterization of mixture properties are required in large-scale AD reactors. Additionally, appropriate technology and operational strategies must be adopted to ensure the stability and efficiency of large-scale anaerobic digestion.

In order to ensure the stable operation of large-scale anaerobic digesters, mixing is a crucial factor. Many mixing devices have been applied to anaerobic digestion; they can be classified largely as mechanical, hydraulic, and pneumatic mixing devices [21]. Most anaerobic digesters used in Korea are vertical-flow cylindrical digesters that use mechanical mixing. If not mixed properly, stratification occurs in the anaerobic digester, causing light materials to accumulate in the upper layer and heavy particles to sink to the lower layer. Subsequently, anaerobic digestion occurs only in the middle layer, resulting in a shorter retention time [22][23]. This phenomenon frequently occurs in anaerobic digesters installed in Korea, as reported in a Dongdaemun Environmental Resources Center case study, a food waste treatment facility in Seoul fitted with a dry anaerobic digestion system [24]. Mixing is crucial when treating food waste with high total solids (TS) rather than low TS [23]. Therefore, the shape of the anaerobic digester and the mixing of waste are important factors. A report has described the stable treatment of high-concentration food waste at 15 m^3/day using effective mixing with a horizontal anaerobic digester [25]. Thus, a horizontal anaerobic digester equipped with large impellers can be a viable alternative to solve the existing mixing problems.

With the recent development of computer models and the complexity of mathematical expressions for the anaerobic digestion process, full-scale performance can be predicted to a relatively meaningful degree through batch experiments and kinetic models [26][27]. In Korea, the size design and methane production rate of anaerobic digesters for various substrates are predicted using biochemical methane potentials (BMPs), specific organic loading, and kinetic models.

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