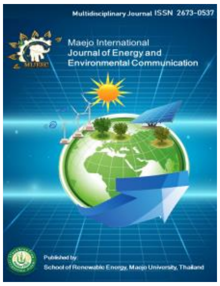
Maejo International Journal of Energy and Environmental Communication 4-1 (2022) 55-60

Maejo International Journal of
Energy and Environmental
Communication

Journal homepage: https://ph02.tci-thaijo.org/index.php/MIJEEC



ARTICLE

Anaerobic digestion of food waste from fruits and vegetables to improve stability and effectiveness

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ARTICLEINFO

Article history:
Received 04 March 2022
Received in revised form
18 April 2022 Accepted
29 April 2022

Keywords:
Fruits wastes
Vegetable wastes
Anaerobic digestion
Biogas

ABSTRACT

Anaerobic digestion is a process that may be used to handle food scraps, and it is a method that is both effective and efficient. The biogas that is generated as a byproduct of this process has the potential to be utilized as a renewable source of bioenergy. Anaerobic digestion is a promising option to manage and treat food wastes and recover resources. To determine the efficiency of methane production, batch biochemical methane pot testing was performed. This paper reviews the system stability and efficiency of additives in anaerobic digestion. It is possible to produce biogas at different temperatures (27±2°C, 35±2°C, and 45±2°C). Biogas enhancement is dependent on temperature. The experiments were conducted for a 45-day digestion period. The 35±2°C fermenter produced the highest total biogas yield of 13093.55 ml and the highest methane content of 63.71%. The study was designed to determine the optimal temperature for increasing household levels in future applications.

1. Introduction

Food loss is a major concern in the fight against hunger, income generation, and food security for the poorest countries around the world. There are many factors that can cause food losses to have an adverse effect on food security, food safety, and economic development (Chalak et al., 2018). These factors vary greatly and are dependent on the country. Losses in food production result in the loss of resources, including water, energy, and inputs. The production of food that is not needed can result in an increase in CO_2 emissions and a loss of economic value (Xu et al., 2020; Trejo et al., 2022). Both producers and consumers suffer from the direct and negative effects of food losses that can be prevented. Many smallholders are living on the margins of food poverty. It is possible that a decrease in food loss could have a significant impact on their daily lives. Low-income households, also known as those who are food insecure or at high risk, need to have easy access to affordable food products (Shinwell & Defeyter, 2021). Keep in mind that an inadequate supply of food is often less of a problem than it is with access (the ability and cost to purchase food). It could be possible to lower the cost of food for consumers if we improve the efficiency and accessibility of the food supply chain. A profitable investment in efficiency and cutting waste is one way to lower the cost of food (Cattaneo et al., 2021). This assumes that the financial gains from reduced losses are not less than the expense.

Food waste can be caused by uneaten food, food that has been precooked, or food that has expired. After that, it is disposed of from a variety of sources, including households, hospitals, and industries, among other places. It has been determined by the FAO and other organizations that focus on food and agriculture that around 1.3 billion tons of food are wasted at each stage of the supply chain for food. This figure has been steadily climbing for the past many years (Ananno et al., 2021). The FAO estimates that one-third of the food that is produced worldwide is wasted. The

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term "circular bioeconomy" refers to a system that incorporates environmentally friendly technology in order to produce products that are commercially viable from trash. The most common types of food that get thrown out are fresh produce, meat, dairy items, and baked goods. According to Kannah et al. (2020), the amount of food thrown out could increase from 278 million to 416 million tons between 2005 and 2025. Additionally, the amount of food waste produced yearly is increasing due to economic development, urbanization, population growth, and other lifestyle changes. The production of greenhouse gases from food waste in landfills contributes to global warming and necessitates the garbage being processed to reduce environmental degradation (Bouallagui et al., 2009). Food waste generally contains high levels of total solids and volatile solids (VS) as well as applicable renewable energy.

Resource recovery, or the conversion of food waste into energy, has received increasing attention. The generation of bioenergy from renewable resources is more eco-friendly than the production of bioenergy with fossil fuels (Ji et al., 2017; Palanisamy et al., 2021). It is also cheaper (Gotore et al., 2021). Effective food management techniques are essential to ensure the proper disposal of food scraps. In recent years, renewable bioenergy has received increased attention (Junluthin et al., 2021). There are also new technologies that can be used to synthesize many products using bioenergy (Chuanchai et al., 2019). Renewable bioenergy is essential for the transformation of food waste into useful products, as well as to reduce pollution and fuel costs. Renewable bioenergy can be made from naturally occurring materials (Lin et al., 2011; Palanisamy et al., 2022a; Palanisamy et al., 2022b). Because of all the positive effects on the economy and the environment, incineration not only causes the release of dioxins into the environment, which is a major contributor to environmental problems but also makes it harder to recover nutrients and chemicals from the garbage that has been burned. Pretreatment of food waste prior to burning helps reduce the release of toxic gases into the atmosphere. There are many management options available. These include feeding waste to animals and composting, landfilling, incinerating, and feeding waste anaerobically (Molino et al., 2013). These strategies reduce waste and recycle it, which results in useful byproducts like biobutanol and bioethanol (Bhuyar et al., 2022).

Although anaerobic digestion (AD), is a widely used technology to produce bioenergy (Unpaprom et al., 2021; Jadhav et al., 2021a, b, 2022), two main problems prevent it from being applied in food waste treatment. The first is poor system stability caused by the accumulation of volatile oils. The second is low reactor efficiency, which is low organic loading rates. This is due to the high level of easily biodegradable suspended substances in food waste. Apart from the pretreatment of food waste, factors like inoculum-to-substrate ratio, the particle size of the substrate, and the availability/supplementation of nutrients could influence the process stability, biodegradability of organic matter and methane production yield in anaerobic digestion of food waste. Many studies have been conducted to determine how to increase the stability and efficacy of food waste and anaerobic digestibility. By studying the impacts of biochar addition on biochemical methane potential, we hoped to assess the effect of biochar on potential methane production. Examples are pretreatments, additives, waste co-digestion, innovative digesters, testing different operation conditions, and so on. The stability and efficacy of anaerobic digestion from fruit and vegetable waste were investigated in this study.

2. Methodology

2.1. Feedstock preparation

In Chiang Mai, Thailand, close to the campus of Maejo University, there is a local traditional market known as "Kad Maejo." This is where the trash from a variety of fruits and vegetables was collected for use in the feed. The waste was collected using the grab sample method, and their make-up consisted of eighty percent waste from vegetables and twenty percent trash from fruits. The entire weight of the garbage was fifty kilograms, and it was blended by hand while being fed. The feeding was conducted for a total of fourteen days for the transfer to the fermenter. The starter in this study was a cow farm waste inoculum combined with the waste right before the digester was closed. Chemical analysis of initial waste and bioreactor slurry was performed using standard methods.

2.2. Biochar preparation and pretreatment

Maejo University in Thailand employed a small kiln to pyrolyze corncobs. The farmer's corncobs were dried outdoors for a week to remove extra moisture. The 20 L steel can pyrolyzed corncobs. They were stuffed with 1.7kg of corncobs. It was burning 20 kilos of firewood in the kiln. After 2 hours, the air supply was manually adjusted to maintain 600 °C in the kiln. Carbonized corncobs were weighed after pyrolysis. The carbonized corncobs were processed through two mesh sieves. It permitted 1.5-3mm particulates. Tap water and deionized water-washed biochar. Due to ash removal, the wash water pH rose to 7.2. The pretreatment was carried out with an alkaline solution (2% NaOH) and biochar additive for 48 h and applied to the crushed food wastes.

2.3. Experiment setup and analytical procedures

For this investigation, a single-stage fed-batch anaerobic digester with a total volume of 2L was utilized. It was run at an ambient temperature in the mesophilic range, which ranged from 27 to 45 °C with three different temperature conditions (27±2°C, 35±2°C, and 45±2°C) with controlled pH 9. A gas collector was made available to facilitate the gathering of biogas samples and the calculation of their total volume. Monitoring was done once a week on the amount of methane concentration that was produced in the reactor. The levels of chemical oxygen demand (COD), chemical oxygen demand (TS), volatile solids (VS), pH, moisture, and organic matter were all measured using the standard methods recommended by the APHA (2015). Feedstock contacting pH, TS (%), VS (%), COD ($g\,L^{-1}$) were 5.14 ± 0.06, 12.3± 0.14, 8.44± 0.17 and 135 ± 1.5, respectively. An automated gas analyzer was utilized to obtain CH_4, CO_2, H_2S, and O_2 concentrations from biogas samples tested in a laboratory (GFM 416 series, UK), and data presented only CH_4 in this article.

3. Results and discussion

Anaerobic digestion is the process of decomposition of organic matter by a microbial consortium in an oxygen-free environment (Sittisom et al., 2019). It is a process found in many naturally occurring anoxic environments, including watercourses, sediments, waterlogged soils and the mammalian gut (Van Tran et al., 2020). It can also be applied to a wide range of feedstocks, including industrial and municipal wastewaters, agricultural, municipal, food industry wastes, and plant residues. As can be seen, the growth potential for this technology is very important, especially because of the important factor of greenhouse gases emission reduction (Nong et al., 2020). The process of anaerobic digestion of municipal solid waste has the potential to contribute significantly to renewable energy production and to the reduction of landfill or other undesirable waste disposal routes. Anaerobic digestion of solid waste can be seen as a mature technology. Once produced, biogas is generally composed of 48–65 % methane, 36–41 % carbon dioxide, up to 17 % nitrogen, <1 % oxygen, 32–169 ppm hydrogen sulphide, and traces of other gases. Both carbon dioxide (CO_2) and methane (CH_4) are potent greenhouse gases and possibly 18 % of global warming is thought to be caused by anthropogenically derived methane emissions.

Carbon dioxide released through natural mineralization is considered neutral in greenhouse gas terms as the carbon has been recently removed from the atmosphere by plant uptake, to be released again as part of the carbon cycle. Production of CO_2 and CH_4 in the hydrolytic and methanogenic stages of anaerobic digestion of organic wastes or biomass processes are shown in Figure 1. Vegetable and fruit wastes have low total solids, and high volatile solids, and can be easily digested in an anaerobic digestion. These feedstocks can be rapidly hydrolyzed and acidified in digesters, which could lead to methanogenesis inhibition. To ensure stable performance, carbohydrate-rich feedstocks must be co-digested with other feedstocks.

Biogas produced have different characteristics depending on the types and diversity of biomass or feedstocks used (Ramaraj et al., 2016). It is important to be aware of the relationship between temperature and solid load in small-scale digesters. Because biomass's nature can change at any moment, this is essential. This is necessary to accurately predict the amount of biogas produced and increase the production. If it is possible to perform anaerobic digestion in a mesophilic or thermophilic setting, pathogens can be eliminated or significantly reduced. Ramaraj and Unpaprom (2016) states that anaerobic digestion requires a variety of factors both chemically and physically. These factors can include a variety of different ingredients. One of the most important variables to control when it comes to making a digester economically viable is the temperature within the digester. This is related to the speed at which biogas can be created. It is important to note that temperature is just as important as the other physical parameters. Two of the most important factors that affect the AD process's efficiency and consistency are the substrate's temperature and chemical composition. This study examined the impact of temperature on biogas and methane production during anaerobic digestion

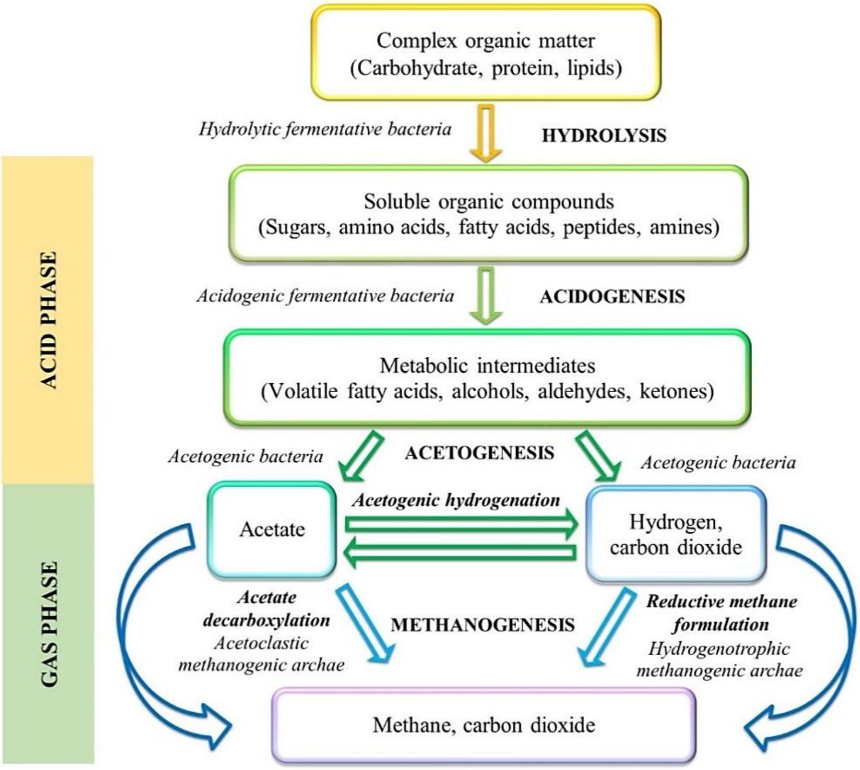

Figure 1 Overview of the anaerobic digestion process for producing biogas from complex organic materials

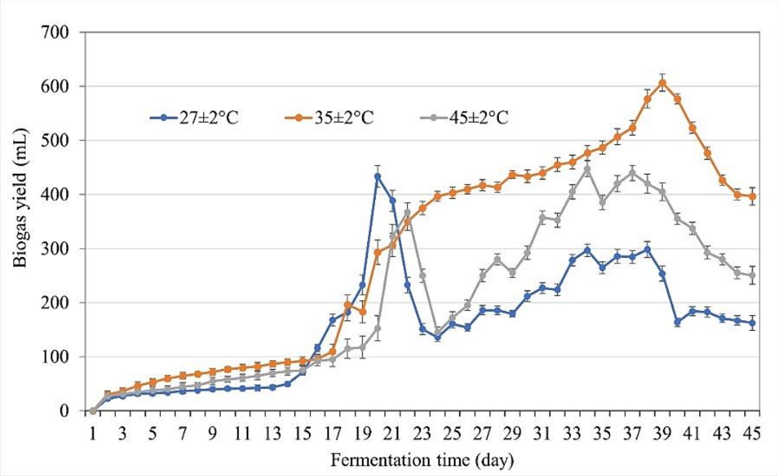

Figure 2 Daily biogas production with different temperature

Biogas produced has different characteristics depending on the types and diversity of biomass used or the feedstocks used (Chuanchai & Ramaraj, 2018). It is important to be aware of the relationship between temperature and solid load in small-scale digesters. Because the nature of biomass can change at any moment, this is essential. This is necessary to accurately predict the amount of biogas produced and increase the production. If it is possible to perform anaerobic digestion in a mesophilic or thermophilic setting, pathogens can be eliminated or greatly reduced. Anaerobic digestion is complex and involves many different steps. Each step may have a different microorganism, so they could require different environmental conditions such as temperature or solid load.

Numerous researchers have shown that temperature has significant impacts on the microbial community and process stability, methane yield, and process kinetics. This study was conducted at different temperatures for 45 days and was done at various temperatures (27±2°C, 35±2°C, and 45±2°C) Figure 2 shows daily biogas production at different temperatures and solid ratios. Figure 2 shows cumulative biogas production results after 45 days of fermentation. The data shown are the biogas generation from reactors incubated at 27±2°C, 35±2°C, and 45±2°C and total biogas yield were 7115.65 ml, 13093.55 ml, and 9226 ml, respectively, with various temperature conditions for 45 days. After biogas generation, the degradability of COD, TS, and VS and the better degradability performance were confirmed at 35±2°C (data were not presented here).

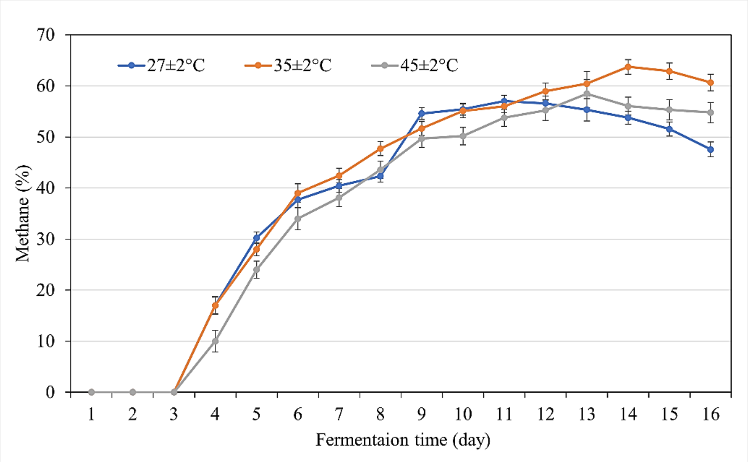

Figure 3 Daily methane production with different temperatures (measured 3 days interval)

Table 2 Comparison of methane yield from different feedstocks

Feedstock	Methane (%)	Reference
Sugar beet pulp, corn silage, carrot residues, cheese whey	61	Kacprzak et al. 2010
Sewage sludge	61	Świątczak et al. 2017
Municipal organic waste	61	Held et al. 2002
Cattle manure, agro-wastes, energy crops	52-61	Cavinato et al. 2010
Rice straw	61	Meng et al. 2019
Food waste	61	Park et al. 2020
Fruits and vegetables	63.71	This study

Daily methane production with different temperatures (measured 3 days interval) shown in Figure 3. The data shown are the methane generation from reactors incubated at 27±2°C, 35±2°C, and 45±2°C and total biogas yield were 56.99%, 63.71% and 58.44%, respectively, with various temperature conditions for 45 days. Fruits and vegetables had a greater maximum methane content than other feedstocks such as sugar beet pulp, maize silage, carrot residues, cheese whey, sewage sludge, municipal organic waste, animal manure, agro-waste, energy crops, and rice straw (Table 2). Preliminary studies on the possible yield of biomethane were conducted in this study to get toward a system that may be utilized to grow plants on a big scale. It would be useful to learn more about how AD works and what factors contribute to it. The chemical analysis of both the inoculum and the biomass provided us with knowledge that allowed us to better understand the components and the entire process. These findings demonstrate that AD may be used to successfully transform fruits and vegetables, and while additional research on the techno-economics is required, this technique is anticipated to be inexpensive and scalable. As a result, fruits and vegetables can be employed as substrates for future research into larger-scale biogas production.

4. Conclusions

Food waste is a growing problem, particularly in large cities. Anaerobic digestion can reduce solid waste and convert it into bioenergy. This sustainable and clean method for waste minimization and energy recovery is limited by the instability and low efficiency of the AD system due to food waste. Studies have shown that additives can compensate for the loss of food waste in AD processes. Experimentally, the effect of temperature on co-fermentation biogas yield was studied in two-liter batch anaerobic reactors. The highest performance was seen in digesters operating at temperatures of 35±2°C, which also includes the highest levels of methane (63.71%). These results suggest that temperature could be used to further scale up studies and biogas production by co-digestion of vegetable and fruit wastes.

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