BIOMETHANE PRODUCTION FROM FOOD WASTE MIXTURE BY ANAEROBIC DIGESTION REACTOR

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ABSTRAK

Apabila populasi dunia bertambah dan bandar berkembang dalam saiz, makanan menjadi sia-sia. Sisa makanan telah menjadi isu alam sekitar yang utama di setiap negara. Sisa makanan ialah masalah alam sekitar yang semakin meningkat yang menyumbang kepada peningkatan pelepasan gas rumah hijau (GHG) di tapak pelupusan sampah dan kesan ekologi negatif kepada masyarakat. Kajian semasa menyemak prestasi pengeluaran biometana daripada sisa buah-buahan yang digabungkan dengan pisang pseudostem dalam reaktor pencernaan anaerobik. Biogas dihasilkan melalui pencernaan anaerobik dalam reaktor pencernaan anaerobik selama kira-kira empat minggu. Buah-buahan dan sisa pisang pseudostem terurai dalam persekitaran anaerobik, kekurangan biogas penghasil oksigen. Dalam eksperimen ini, sisa yang ditapai dalam reaktor dalam tempoh 28 hari, pH dan isipadu biogas sehari diperlukan untuk memantau dan mengesan perubahan proses dalam reaktor, yang boleh menyebabkan kekurangan pengeluaran metana. Untuk menghasilkan gas metana, pra-rawatan adalah perlu kerana sesetengah bahan buangan terdiri daripada hemiselulosa, yang mempunyai struktur ikatan berganda. Rawatan fizikal telah digunakan dalam kajian ini untuk memecahkan ikatan berganda kerana ia berkesan meningkatkan luas permukaan yang boleh diakses memecahkan kompleks lignin-hemiselulosa dan bahan selulosa yang boleh digunakan. Keputusan yang ditunjukkan dalam kajian ini boleh digunakan untuk penyelidikan lanjut untuk meminimumkan pengeluaran sisa makanan.

ABSTRACT

As the world's population grows and cities grow in size, the food is wasted. Food waste has become a major environmental issue in every country. Food waste is a growing environmental problem that contributes to rising greenhouse gas (GHG) emissions in landfills and negative ecological impacts on society. The current study checks the performance of biomethane production from fruit waste combined with pseudostem bananas in an anaerobic digestion reactor. Biogas is produced through anaerobic digestion in an anaerobic digestion reactor for about four weeks. Fruits and pseudostem bananas waste decomposes in an anaerobic environment, lacking oxygen-producing biogas. In this experiment, the waste fermented in the reactor within 28 days, the pH and volume of biogas per day are needed to monitor and trace the process changes in the reactor, which could lead to a lack of methane production. To produce methane gas, pre-treatment is necessary as some of the waste consists of hemicellulose, which has a double bond structure. Physical treatment was applied in this study to break down the double bond as it effectively increases accessible surface area breaks down lignin-hemicellulose complexes and the usable cellulosic material. The result shown in the study can be used for further research to minimize the food waste production.

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LIST OF ABBREVIATIONS

AD	Anaerobic Digestion
CO_2	Carbon Dioxide
C/N	Carbon to Nitrogen
CH_4	Methane
FW	Food Waste
GHG	Greenhouse Gas

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Food waste includes any food that is suitable for discarding after being consumed by humans, regardless of whether it has been allowed to decay after its expiration date. There are several possible explanations for this, including oversupply in the industry, changes in shopping or eating habits among specific consumers for various reasons, and other factors. Extreme economic growth, combined with increasing commercialization and urbanization, has resulted in significant and increasing quantities of food waste in Malaysia, which is a problem that is only getting worse. Malaysia wastes 15,000 tonnes of food every day, including 3,000 tonnes of food that is already fit for consumption and should not be thrown away, according to the United Nations (The Star 2016). Every day, the average Malaysian discards 1.64 kg of waste, compared to a global average of 1.2 kg per person. According to the statistics, the figures above are alarming, as Malaysia's waste production is expected to increase by 65 percent by 2020, to 30,000 tonnes per day (Khor 2014). Over the past three years, the amount of unconsumed food waste, which includes expired bread, rotten fruits, and eggs (but not leftover food), has more than doubled (Jereme et al., 2016).

Food waste harms the environment in numerous ways. A landmass equivalent to China must grow food that will undoubtedly never be eaten in one calendar year. When food waste is disposed of in the landfill, where it accounts for the vast majority of all food waste disposed of in this manner, not only are all the resources used to produce unfilled food wasted (land, water, labor, electricity, manufacturing, packaging, etc.), but it also decomposes due to the lack of oxygen exposure. It emits toxic methane at a rate 23 times greater than that of carbon dioxide. Whatever way you look at it; food waste is a significant contributor to the degradation of our environment.

Biogas is also one method of reducing food waste. Over one-third of all food produced in the world is discarded or wasted. Such food waste has enormous potential to generate untapped electricity, which is commonly referred to as waste-to-energy (WTE) systems. Microorganisms are used in anaerobic digestion to remove organic matter from food waste and produce methane, which can be used to generate energy, fuel for transportation, and heat. Because organic matter in food waste is suitable for anaerobic microbial growth, anaerobic digestion is regarded as an effective method of treating food waste (Kwasny et al., 2017). Anaerobic digestion converts organic waste to biogas through biodegradation involving hydrolysis, acid-genesis, and methanogenesis (Appels L et al., 2011). The rate-determining stage in anaerobic digestion, hydrolysis of high molecular weight organic substrates, occurs through the action of fermentative bacteria and produces low molecular weight substrates (Coelho NMG et al., 2011). These common organic molecular weight materials degrade into volatile fatty acids (VFAs) and other byproducts like carbon dioxide, ammonia, and hydrogen sulfide. These products are digested further to produce acetate, hydrogen, and carbon dioxide before methanogenesis to produce methane (Chu J & Li YR, 2008).

Acetate is the main intermediate in the development of methane since VFAs are the main products formed during anaerobic digestion (Appels L et al., 2011). While most advanced anaerobic digesters are single-stage processes (Nagao N et al., 2012), feedstock types are highly dependent on the characteristics and operating conditions of anaerobic digesters (Sosnowski P et al., 2003). But it is still possible to increase the efficiency of biogas production by anaerobic digestion. Biogas is a clean and sustainable source of energy derived from organic matter such as fruit and vegetable waste, scrap wood, and forest debris. Scientists have found an innovative way to harvestall of the energy stored in the waste of organic food, leaving no emissions behind for landfills and oceans, according to the tired earth post. During this process, the waste is incinerated to produce synthetic oil which can be converted into biofuel. The residue is then used for the production of methane which can be used as a source of power and heat.

1.2 Problem Statement

Food waste is widespread throughout the world. According to these estimates, one-third of edible food intended for human consumption is thrown away globally. This equates to approximately 1.3 billion tonnes per year (FAO, 2011). Every day, Malaysia wastes 15,000 tonnes of food, including 3,000 tonnes that are still edible and should not be discarded (The Star 2016). The average Malaysian generates 1.64 kg of waste per day, compared to the global average of 1.2 kg. Malaysia's waste production will increase by 65 percent by 2020, reaching 30 000 tonnes per day (Khor, 2014). Food for human consumption is lost during the five major stages of the food supply chain: agricultural production, after harvesting, storage, and distribution (Gustavsson et al ., 2011).

Food waste sources are divided into three categories, food losses (food lost during storage, processing and production), unavoidable food waste (the spoiled portionof food lost during the consumption phase, such as fruit peel and core) and avoidable food waste (food lost during the consumption phase, such as waste) (Thi et al., 2015). Waste and inedible sections of waste are not included, because waste is determined by items related to human consumption. Higher income countries such as those in Europe contribute the largest amount of food waste from distribution and consumption areas (i.e., household level).

The banana stem is another waste abundant in agriculture, particularly in plantations. The pseudostem of the banana plant grows a single bunch of bananas before dying and being replaced by a new pseudostem (Anhwange et al., 2009). According to reports, the banana is the world's second most-produced fruit in volume, accounting for approximately 16% of total fruit production (Mohapatra et al., 2010). Because each plant produces only one bunch of bananas, this crop generates a significant amount of residue. Following harvest, the bare pseudostem is removed and either left on the plantation or burned, potentially causing environmental problems such as contaminating water bodies and endangering the atmosphere and the health of living microorganisms (Cordeiro et al., 2004). (Aziz etal., 2011, Hossain et al., 2011). If banana tree waste is not handled correctly, such as spilled in wet weather, it can emit greenhouse gases. Farmers also dumped banana tree waste in river sand wetlands, where it eventually dissolved and produced methane and other gases that dispersed putrid odors and harmed the surrounding environment (Ahmad & Danish,2018).

1.3 Objective

This research aims to produce methane from the fruits and pseudo stem banana waste. The particular objectives listed below

1) To check the stem performance of the methane production from fruit and pseudo stem banana waste within 28 days.
2) To identify the methane production from fruit and pseudo stem banana waste in an GC-anaerobic digestion reactor.

1.4 Scope of Study

This study focused on methane generation primarily from fruit and pseudo banana waste. Biogas is composed of 60-80 percent methane and is produced through a process known as anaerobic digestion; at the end of the digestion period, it leaves a nutrient-rich substance known as digested. In the absence of oxygen, a variety of bacteria perform anaerobic digestion. Carbon dioxide is initially produced aerobically by decomposing organic matter until an anaerobic environment is formed. Following the initial digestion, a methanogen bacterial group converts the feedstock into methane and carbon dioxide (Arsova et al., 2008).

In anaerobic digestion, there are three primary operating conditions: psychrophilic (10-30 °C), mesophilic (30-40°C), and thermophilic (50-60°C). Raising the temperature in the reactor would increase the output of methane gas up to around 60 degrees Celsius (Labatut and Pronto 2018). Fruit waste will be added and mixed with the pseudostem banana. According to a previous study from Chen year 2021 titled "Methane production and characteristics of the microbial community in the co-digestion of potato pulp waste and dairy manure amended with biochar," a 3:1 ratio is quite balanced for the production of methane gas due to the wastes' different pH. Those studies revealed that the pH of the anaerobic digestion process is neutral to acidic. For this study, the pH of the fruit waste was 6.5, which is suitable for methanogenic microorganisms to produce methane. In contrast, the pH of the pseudostem banana was 5.99 to 6.00, which is slightly acidic and may affect methane gas production. The optimum value of the anaerobic digestion process is 6.8 to 7.2.

1.5 Significant of Study

Bacteria produce biomethane during organic materials anaerobic (without air) biodegradation. Methanogens (methane-producing bacteria) are the final link in a chain of microorganisms that degrade organic matter and return the decomposition products to the environment. Biogas, a renewable energy source, is produced during this process. This process generates a mixture of gases, most of which is methane. As a result, it can be used to create biogas for other purposes. At the same time, it can contribute to a clean and healthy environment.

Biogas is a renewable and clean energy source that can help society reduce its reliance on fossil fuels like coal, oil, and natural gas. Biogas reduces greenhouse gas emissions by preventing additional fossil fuel combustion, making it an excellent tool for combating global climate change. Biogas produced from renewable sources ensures its dependability. As a result, the production of biomethane reduces the amount of food waste in landfills. Biogas can be used in all-natural gas-based applications, such as heat and steam, electricity generation, and vehicle fuel.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses food waste handling method, which was anaerobic digestion. After that, it goes to the characteristic of food waste, Biogas energy, biochemical process, and the biogas process stages, which were hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Next, several factors affect biomethane production, such as pH of feedstock, temperature, retention time, mixing, and oxygen.

2.2 Food Waste Handling Method

Anaerobic digestion was one of the environmentally friendly food waste disposal methods. These are potential sustainable food waste management system options for future implementation in Malaysia, rather than incineration or landfill, which have negative environmental consequences. (Thi et al., 2015).

2.2.1 Anaerobic Digestion

Anaerobic food waste digestion is a biological process that involves the biodegradation of putrescible organic substrate into biogas via four significant steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. (2014) (Zhang et al.). Thailand has a special implementation of anaerobic digestion technology for food waste. Rayong municipality, for example, has established a full-scale biogas plant that uses food waste, including vegetable and fruit waste, in conjunction with night soil waste, to produce biogas and provide electricity to rural areas (Juanga et al., 2006)

There is currently no fully developed and operational anaerobic food waste digestion plant in China. Still, more than 20 national projects are in the works, including anaerobic digestion and composting of significant food waste, manure, and municipal solid waste substrates. Christian and Dubendorf (2007) Despite numerous development projects for food waste anaerobic digestion in India, most projects have been hampered by technical failure, poor management, and insufficient regulation and policy (Christian and Dubendorf, 2007). Vietnam and the Philippines use an integrative technology that combines anaerobic digestion and composting to reduce food waste in landfills (Thi et al., 2015). Many small-scale food waste anaerobic digestion plants have been established in Sri Lanka due to collaboration between government and non-governmental organizations (Christian and Dubendorf, 2007).

2.3 Characteristic of Food Waste

Food Waste (FW) is characterised by complex components and organic material. There are several types of FW such as fruit and vegetable waste, household and restaurant FW, brewery waste, and dairy waste (Xu et al., 2018). Studies havefound that the composition of FW varies based on geographical changes, seasonal changes, cooking procedures, and consumption patterns (Xu et al., 2018). They reportedthat FW consists of various organic components such as proteins, carbohydrate polymers (starch, cellulose, hemicelluloses, and lignin), lipids, and organic acids. Fisgativa et al. (2016) studied 102 different FW samples and reported that the characteristic of FW displayed high coefficient of variance (CV).

They observed that FW has an average pH of 5.1 (CV 13.9%), carbon and nitrogen ratio of 18.5% (CV 31.8%), 36% of carbohydrates (CV 57.2%), 26% of protein (CV 62.2%), 15% of fats (CV 52.0%), and bio-methane potential of 460.0 NL CH_4/kg VS (CV 19%). The percentage range of degradable carbohydrates, proteins, andlipids is (5.7%–53%), (2.3%–28.4%), and (1.3%–30.3%), respectively. Meng et al. (2015) and Xu et al. (2018) indicated that carbohydrates and proteins have a higher hydrolysis rate due to its rapid degradability compared to lipid. Thus, quickly degradable carbohydrates and lipid rich food wastes can produce high methane yields.

Bong et al. (2018) reported that fruit and vegetable waste has low lipid content but relatively high cellulosic content, whereas FW and kitchen waste have high lipid content because of the presence of animal fat and oil. Studies have reported that fruit and vegetable waste had a lipid content of 11.8%, whereas FW and kitchen waste were reported to have 33.22% and 21.6% of lipid content, respectively (Wang et al., 2014; Yong et al., 2015).

FW rich in lipids could produce a higher amount of methane compared to carbohydrates and proteins (Y. Li et al., 2017). However, high lipid content can cause system failure due to the formation of long chain fatty acids. This occurs when the mass transformation of soluble organics into bacteria decreases due to the destruction of the cellular membrane (Leung and Wang, 2016). Y. Li et al. (2017) stated that FW rich in carbohydrate content will affect the carbon and nitrogen ratio (C/N), and thus, nutrient restrictions and quick acidification could occur due to increased organic matter.

The total solids and volatile solids of each type of FW fall in the ranges of 10.7%–41% and 10%–34.4%, respectively, indicating that water accounts for 60%– 90% in fruit and vegetable waste, kitchen waste and FW. FW is considered to be a readily biodegradable organic substrate because of its large quantity of moisture content(Zhang et al., 2014). The characteristics of FW also define the relative quantities of organic carbon and nitrogen present in the FW. The C/N ratio for each type of FW was found to vary in the range of 12.7–28.84, and displayed an acidic pH of 4.1–6.5. The methane production of every category of FW fall in the range of 346–551.4 mL/ g VS_{added}, which is higher compared to cow manure (233 mL/ g VS_{added}), grass silage(306 mL/g VS_{added}), and oat straw (203 mL/ g VS_{added})(Huttunen and Rintala, 2007).

2.4 Biogas Energy

Biogas originates from biogenic material and is a type of biofuels, usuallyreferred to as a gas formed by bacteria that ferment organic material under anaerobic conditions (without oxygen). It can be manufactured from a wide range of available organic materials and waste including sewage sludge, animal manure, and municipal organic waste. It is also possible to use materials such as biodegradable waste, wheat, manure, sugarcane and goods from agricultural and industrial processes and specially grown energy crops for energy production. Anaerobic digestion is a simple technique that is commonly used to treat biodegradable, organic waste for the production of biogas. The thermophilic conditions improved the yield of biogas by around 92%. Organic waste fermentation requires biological and chemical contaminants, and the process is equally useful in waste management. Throughout the process, the chemicals and microorganisms break down large organic polymers that make up biomass into smaller molecules. Biomass is converted into biogas (methane, carbon dioxide and traces of other contaminant gases) as well as liquid digestate (nutrient-rich fertilizer) upon completion of the anaerobic digestion process.

2.5 Biochemical Process

Anaerobic digestion is a complex mechanism that takes place in four biological and chemical phases (N. J. Themelis & P. A. Ulloa, 2007), hydrolysis, acid genesis, acetogenesis and methanogenesis, respectively. Different consortia of micro-organisms perform the individual degradation steps, which are partly in syntrophic interrelation and position specific environmental requirements (I. Angelidaki et al., 1993).

Hydrolyzing and fermenting microorganisms are responsible for the initial attack on polymers and monomers, and mainly produce acetate, hydrogen and varying amounts of volatile fatty acids such as propionate and butyrate. Hydrolytic microorganisms, such as cellulase, cellobiase, xylanase, amylase, lipase, and protease, excrete hydrolytic enzymes. Hydrolysis and fermentation of organic material requires a diverse group of microorganisms. Most of the bacteria are strict anaerobes such as Bacteriocides, clostridia, Bifidobacteria and others. In addition, there are several facultative anaerobes including Enterobacteriaceae and Streptococci.

The higher volatile fatty acids are converted by mandatory hydrogen producing acetogenic bacteria to acetate and hydrogen. Hydrogen build up can inhibit the acetogenic bacteria's metabolism. Maintaining an extremely low partial hydrogen pressure is important for the bacteria which produce acetogenic and H_2. Though in a methanogenic consortium many microbial specifics of metabolic networks are not clear, present information suggests that hydrogen may be a limiting substrate for methanogens(Z. Bagi et al., 2007). Two classes of methanogenic bacteria produce methane from acetate or hydrogen, and carbon dioxide at the end of the degradation chain.

2.5.1 Stages of Biogas Production

The anaerobic digestion is involved in four essential steps. Such four basic stages reflect the process of creating biogas from various organic materials as it occurs in an anaerobic digester. As outlined in Figure 1 (Tutuk, 2011), these four stages are hydrolysis, acidogenesis, acetogenesis, and methanogenesis. In an anaerobic climate, the AD cycle is characterized by the decomposition of organic matter into methane, carbon dioxide, inorganic nutrients and compost (Arsova, 2011, Ayu and Dyan Aryati, 2010).

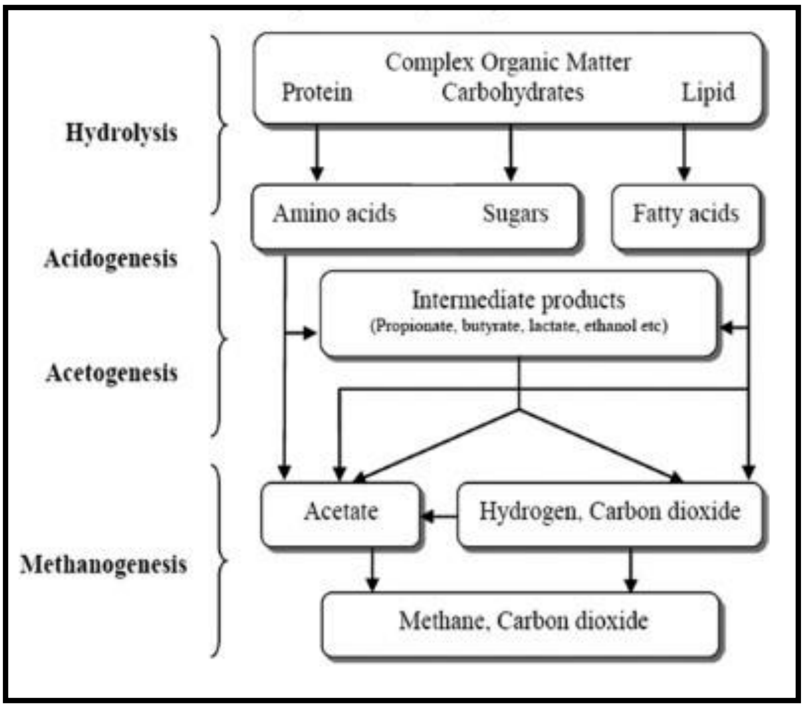

Figure 2.1 Stages of anaerobic digestion
Source: Jewitt et al., (2009)

1. Hydrolysis

The first step in the cycle is hydrolysis at AD. This is achieved by solubilizing and degrading organic particulate biopolymer compounds and colloidal waste into soluble monomeric or oligomeric organic compounds (Gerardi, 2003). This method includes the decomposition of complex polymeric organic materials such as carbohydrates, proteins, and lipids. Such complex organic compounds are hydrolyzed by enzymes formed by the fermenting bacteria (microorganisms)into smaller, water-soluble compounds, such as carbohydrates, amino acids and long-chain fatty acids (Sawyerr et al., 2019). A basic, organic compound is formed at the end of the hydrolysis stage. These products subsequently undergo absorption and degradation by various optional and compulsory anaerobic bacteria in acid-genic phase, forming volatile fatty acids (VFA) in the short- chain. These alcohols are mixed and converted to acetate, hydrogen, and carbon dioxide (Chandra et al., 2012). This process includes the hydrolyzing of polysaccharides into monosaccharides, glycerine and fatty acid fats, and amino acid proteins (Lyilade, 2009). The enzymatic catalysis accelerates the hydrolysisprocess by oxidising the organic matter through a process called biological aerobic processes (Pisano, 2007). The process of hydrolysis and aerobic degradation is a quick process and the biogas produced is converted from oxygen into carbon dioxide (CO_2) (Pisano, 2007). When the substrate has been hydrolysed, it is usable for cell transport and these substrates can then bedestroyed by the fermentative bacteria during the stage of acidgenesis. However,optimizing the hydrolysis process is important in order to avoid inefficient degradation of the macromolecules, which could have a negative impact on the rate of digestion or other biological activity, and consequently on the yield of biogas. Therefore it is important to ensure that the microorganism culture is fully operational in order to allow the second process (acidogenesis) to take place. Physicochemical treatments may also be employed to facilitate organic matter solubilization. Nonetheless, air intake in the system will not occur, since the presence of air in the biomass does not enable the biomass to perform its duties as anaerobic units.

2. Acidogenesis

The acidogenesis process transforms the organic acid produced during the second stage into acetic acid, acid derivatives, carbon dioxide, and hydrogen. According to (Fang et al., 2010), it is important that the H2 level be small for thermodynamically advantageous acid reactions. At this stage of the AD cycle, hydrolysis products are further broken down by a variety of mandatory and optional fermentative microorganisms to produce weak acids (mostly organic acids) such as acetic acid, propionic acid, butyric acid (VFAs), lactic acid, alcohols, hydrogen , and carbon dioxide (CO_2) (Kalyuzhnyi et al., 2000). The stage of acid-genesis includes the development of high hydrogen concentration by acid-producing bacteria called acid microorganisms, and is typically thefastest step in a controlled anaerobic cycle. Acidogenesis is characterized primarily by the accumulation of lactate, ethanol, propionate, butyrate, andhigher VFAs called electron sinks or intermediates. Acidogenesis is the bacterialreaction to increased concentration of hydrogen in the environment for thedevelopment of acetate by acetogenic microorganisms (Sawyerr et al., 2019). Biogas-generating degradation of organic matter often relies on the complex interaction of different classes of bacteria, with the two major groups being the acid-producing bacteria (acid gens) and the methanol-producing bacteria (methanogens). Maintaining a symbiotic relationship between the acidic and methanogenic bacteria is therefore essential to the efficient operation of any anaerobic digester (White, 2011). This stage is important, because it connects the process of fermentation with the process of methane production. Thus, more acid is produced to give birth to elements of methanogens which produce methane gas.

3. Acetogenesis

Throughout the acetogenesis stage, alcohols (ethanol), VFAs with more than two carbon atoms, are converted into acetate by acetate-forming bacteria, with the main products being hydrogen and carbon dioxide (Gerardi, 2003). This conversion is a critical process because the homoacetogenic micro-organisms constantly reduce hydrogen and carbon dioxide to acetate (Chandra et al., 2012), thus reducing the accumulation of hydrogen that can affect the functioning of acetogenic bacteria (Weiland, 2010). For the acetogenic reaction to continue, a low partial hydrogen pressure (10.4 and 10.6 atm) is required (Sawyerr et al., 2019). This is because acetogenic bacteria can live in a background with very low concentration with hydrogen. However, further increase in the concentration of partial hydrogen pressure can cause acetogens to lose their ability to produce acetate. A mutually symbiotic relationship between the acetogens and the hydrogenotrophic methanogens must exist in order to ensure that low pressure is preserved during the acetogenesis stage of the AD cycle, such that acetogens produce acetate that can be used as a substrate by methanogens (Nges et al., 2012). This stage forms the final fermentation processbefore methanogenesis.

4. Methanogenesis

Methanogenesis constitutes a crucial phase in AD. It has a significant impact on the AD process (De Vrieze et al., 2012), because from this stage approximately 70 percent of methane used in AD is produced (Sutaryo, 2012). During this stage, carbon dioxide-reducing and hydrogen-oxidizing methanogens convert to methane hydrogen and carbon dioxide, while acetate is used to produce methane (Sawyerr et al., 2019). Methanogens (Archaea) use acetate, hydrogen and CO_2, and methanol, methylamines and forms to a lesser degree, to contain methane and CO_2. Such end products are the main substrates for biogas processing by the methanogenic bacteria, which typically consists of 50–75% methane (CH_4), 50–25% CO_2 and trace quantities of nitrogen, hydrogen, and hydrogen sulphide. Methanogenesis shows the level of biological activity in an anaerobic environment as well as the digestive process. The more methane is produced the more stable and efficient the system becomes.

2.6 Main Factors Affecting the Biogas Production

Many factors such as nutrients, feedstock pH, temperature, feed flow rate (charge rate), and retention time affect biogas production. These factors can delay or halt the biogas production process if the factor values are not within a specified range (Angelidaki et al., 2009). This segment discusses some of the variables.

2.6.1 pH of Feed Stock

One of the essential factors is the pH value of the material. Acidic bacteria are immune to methanogenic bacteria. This acidic state could adversely affect bacterial growth and methane production (Arsova, 2011). At different stages of the AD cycle various optimum pH values are reached. These changes occur during biological transformation which occurs during the various stages of the AD cycle. The pH level during organic acid production which occurs during the acetogenesis stage may be below 5 (Arsova, 2011). According to Liu et al., (2008), the optimal pH range for obtaining maximum biogas yield in AD is 6.5–7.5, and this pH range in the plants is relatively wide. Several factors, such as the substratum used and the digestion technique, could vary the optimal pH value. Therefore, a constant pH level is of great importance and equilibrium buffers such as calcium carbonate or lime have to be added to the system to maintain a constant pH level. In short, pH is a vital measure for anaerobic processes. This gives a good indicator of the system efficiency including digestion stability. A lower pH suggests system failure or low buffering ability, and can inhibit digestion. High pH, too, can restrict the process of methanogenesis. The pH value depends on the following factors: concentration of VFA, concentration of bicarbonate, alkalinity of the system and fraction of CO_2 in the digester water. According to Liu et al., (2008), the relationship between the VFA and the concentration of bicarbonate is important in order to maintain a constant pH value within the system.

2.6.2 Temperature

As reviewed by Davidsson et al., (2008), AD is normally maintained within two distinct temperature ranges, one at 35 ° C (mesophilic) optimum and the other at 55 ° C (thermophilic) optimum. While thermophilic digestion may give some advantages over mesophilic digestion, such as improved reaction rate and pathogen reduction, mesophilic digestion microorganisms have less nutrient demand (Takashima et al . , 2011), and mesophilic digestion may work as thermophilic digestion (Nges et al., 2012). Temperature refers to biological reaction temperature. It is a sensitive parameter which must be regularly monitored, particularly when the weather changes. The temperature option (mesophilic or thermophilic) will depend on what type of outcome is predicted. Temperature should however be appropriate for the type of microorganisms used in waste treatment.

2.6.3 Retention Time

Retention time is one of the major parameters, which needs to be repeatedly observed in the anaerobic digesters. Retention time is the time needed for the complete degradation of organic matter or the average time organic matter remains in a digester (Deepanraj et al., 2014; Mao et al., 2015). There are two important types of retention times involved in the AD system. First one is solid retention time (SRT) and the second one is hydraulic retention time (HRT). SRT is the average time that the bacteria spend in the digester, whereas HRT is the average time that the liquid sludge spends in the digester (Deepanraj et al., 2014). According to Mao et al. (2015), bacterial development rate related to retention time depends on process temperature, substrate composition, and organic loading rate; the shorter the HRT, the higher the value of organic loading rate. A retention time of 10–40 days is necessary to treat organic waste in mesophilic temperature, while a lesser retention time could be used in thermophilic temperature (Kothari et al., 2014). Yadvika et al. (2004) described that high capital cost and large reactor volume are the main requirements for a longer HRT. However, shorter HRT offers insufficient time for the optimal degradation of the substrate. Yadvika et al. (2004) noted that HRT varies with climate change. For example, for tropical countries and in cold weather, HRT fluctuates from 30 to 50 days and 100 days, respectively.SRT maintains the bacterial population in the reactor, which could result in waste stabilisation (Dobre et al., 2014).

2.6.4 Mixing

In a conventional anaerobic digester, mixing has been observed to generally increase CH_4 yields and to render the digester more stable (Forday and Greenfield, 1983). Mixing has the effect of bringing a homogeneous environment and an effective use of the entire digester volume. This is achieved by minimizing hydraulic dead zones in the digester and preventing build-up of large pockets of unfavourable environmental conditions (low pH and high VFA). Consequently, the concentration of toxic agents throughout the reactor is diluted. Mixing also assists in the removal of excess CO_2 which has inhibitory effects at partial pressures larger than 0.2 atmospheres (Pulles et al., 2001).

2.6.5 Oxygen

Oxygen is harmful to most microorganisms of anaerobic origin. This presence in an anaerobic reactor can lead to a substantial decrease in digestion levels. However, facultative anaerobes may metabolize the dissolved oxygen before noticeable toxic effects occur (Sawyerr et al., 2019).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter presents the methodology used to achieve the objectives of the study which is to check the performance the biomethane production from fruit and pseudo stem banana waste in the anaerobic digestion reactor. This chapter discussed the parameters and analyses used in this study, including the water displacement method, pH, and temperature. For the water displacement method, after the gas has occupied the measuring cylinder, water will flow out of it. The pH and temperature were recorded within 28 days using the pH meter. The potential gas volumes from bio methane resources depend on many factors that affect anaerobic digestion. For GC-TCD, the collected gas in the gas bag produced during the anaerobic digestion process was subjected to analysis testing to determine the concentration of gas and the type of gases produced. This chapter also discussed the different kinds of waste pre-treatment. Physical treatment was used in this study to treat the wastes before isolating them in the reactor.

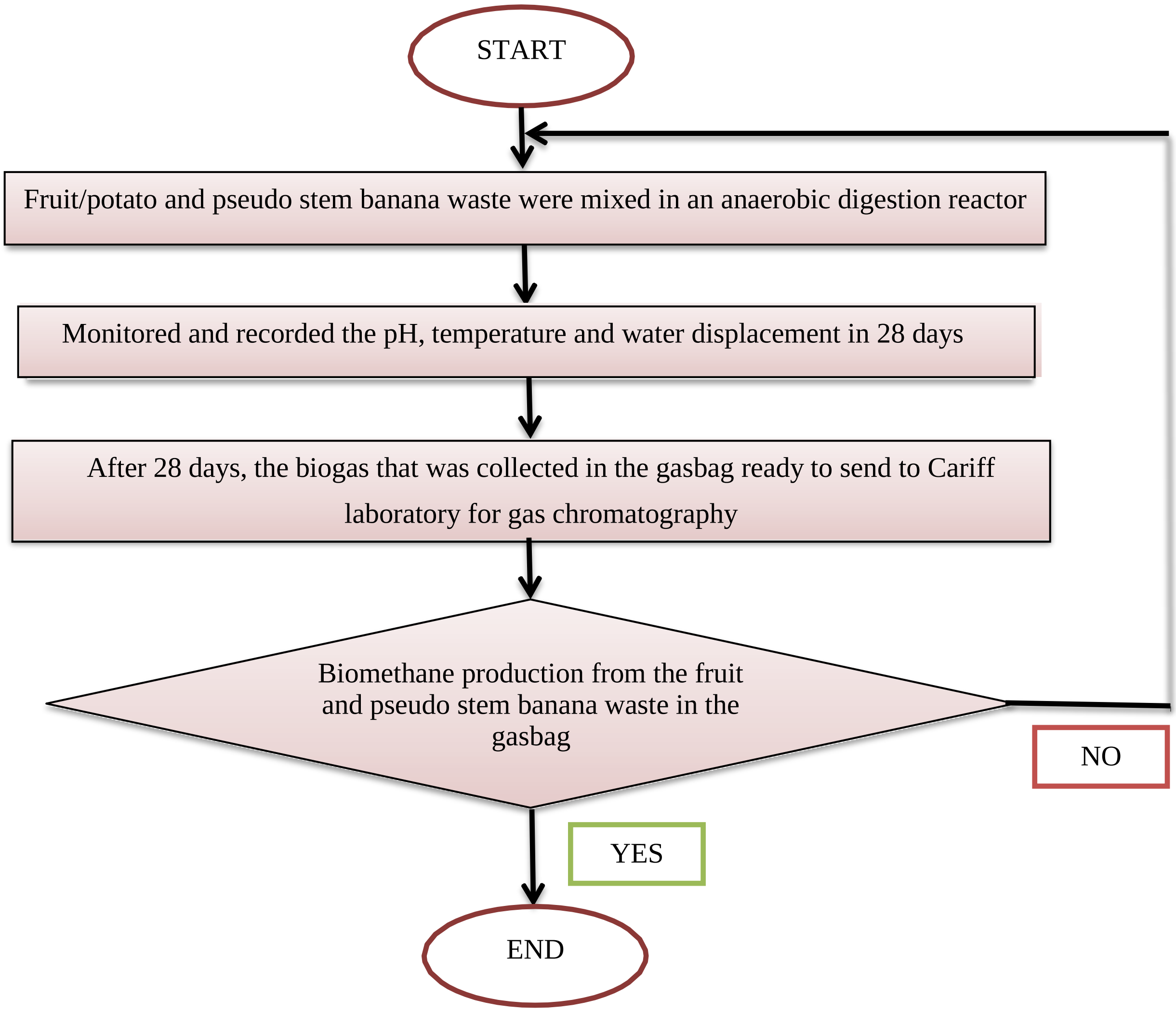

Figure 3.1 Summarized flowchart of the methodology

3.2 Materials and Equipment

This section provided information on the materials and equipment used in the study and reactor setup.

3.2.1 Equipment and Material

The thermometer was used to monitor the performance of the waste. The temperature of the fermentation process needed to be checked daily. Besides that, the temperature above 45°C should be prevented because sensitive microorganisms may be killed. The reassuring value of pH must be within 6.5 to 7.5, and the reactor was placed under partial sun exposure to keep the reactor warm. The extreme temperatures would kill the beneficial microorganism in the reactor. A pH meter was used to test temperature and pH in this fermentation. The equipment that was used in this experiment was shown in table 3.1.

Table 3.1 The equipment used and its parameter

Equipment	Parameter	Descriptions
pH and temperature meter 	To monitor the performances of the Wastes.	To monitor the temperature and pH value of the mixture.
Gas bag 	To collect the methane that were produced from the mixture.	The methane gas that were produced from the wastes was collected from the gas bag sampling.

3.2.2 Reactor Setup

The reactor was placed in a secure place to avoid rain and help maintain the temperature inside. It was also used to keep bad odors and keep other animals from disturbing the fermentation process. The container was vertically positioned for the fermentation process at temperatures ranging from 20°C to 40°C. Figure 3.2 depicts the reactor setup for biomethane production from fruit and pseudo stem banana waste.

The rubber tube was placed on the top of the reactor so that the biogas that was formed during the anaerobic digestion process will flow through it. The first pathway was going to the gasbag. The gasbag tube was used to collect the biogas that was produced in the reactor.

Figure 3.2 The set-up of production of methane from fruit and pseudo stem banana wastes

3.3 Analytical Method

This section discussed regarding the parameters that analysed in this study of the production of biomethane from fruit and pseudo stem banana waste to

3.3.1 The Parameters of the Mixture

The parameters of the mixture were temperature, pH, and water displacement. Every parameter was checked daily. The fermentation process occurs primarily in mesophilic (25°C to 45°C) temperature ranges. These temperatures allow adequate to produce biogas. The pH must be between 6.5 and 7.5 to be considered satisfactory.

3.3.2 Water displacement Method

The water displacement method is to get the amount of gas produced in the reactor. This method involved gas and liquid matter. The gas came out from the reactor while the water was used to displace the gas. In this method, the gas will flow into the water. In the measuring cylinder as the gas is occupied in the measuring cylinder, the water will flow. The volume was calculated based on the amount of water flow out of the measuring cylinder.

3.3.4 pH

pH is a way to express the concentration of hydrogen ions in a solution. Since solution acids and bases dissociate to yield hydrogen ions [H+] and hydroxyl ions [OH-] respectively, pH is used to indicate the intensity of a solution's acid or alkaline state. Alkalinity is a measure of dissolved substances' acid-neutralizing potential in water which compares the amount of strong acid needed to reduce the solution from the original pH to around 4.5. Many of the materials may contribute to water alkalinity. It is primarily attributed to the presence of salts with low acids (primarily bicarbonate and carbonate) and hydroxide (at high pH) for most practical purposes.

3.3.4 Temperature

Temperature has a significant impact on enzyme production, microbial development, methane output, and fertilizer efficiency. In anaerobic digestion, there are three major operating conditions: psychrophilic (10-30 °C), mesophilic (30-40°C), and thermophilic (50-60°C). Raising the temperature in the reactor would increase the output of methane gas up to around 60 degrees Celsius (Labatut and Pronto 2018). Most digesters, however, function in the mesophilic range. Methanogens that thrive in the mesophilic spectrum are more resistant to temperature fluctuations, lowering the chance of the reactor sour. Thermophilic environments can also reduce food waste solubilization (Labatut and Pronto 2018). Psychrophilic environments are often seen only in small anaerobic digesters, which are commonly used in homes and small farms. This range is not recommended for large- scale applications due to the high expense of larger reactors needed for psychrophilic environments, which is not always commercially feasible or sustainable at industrial scales. The operation of two-phase anaerobic digestion, where the first phase operates in thermophilic conditions with a shorter retention period and the second phase operates in mesophilic conditions with a longer retention time, is one method for achieving the advantages of both mesophilic and thermophilic digesters. This study used mesophilic temperature where the reactor was placed in the room temperature.

3.3.5 Gas chromatography (GC-TCD)

Gas chromatography (GC or GLC) is a standard analytic method used in many research and commercial facilities for quality control and identifying and quantifying substances in a mixture. GC is also a popular method in many environmental and forensic laboratories because it detects tiny amounts. A wide range of samples can be examined as long as the chemicals are sufficiently thermally stable and volatile.

3.4 Physical pre-treatment

Physical pre-treatment was used on the wastes, in which the fruit and pseudo stem banana wastes were chopped and ground using a knife and an electronic blender. First, the food waste was chopped and then weighted with a ratio of 3:1, where the three ratios were a fruit weighing 600 grams, and the one ratio was a pseudo stem banana weighing 200 grams. The waste was then ground in a blender with water to facilitate the grinding process. Then dilute with water with a 1:1 ratio and sampling for further analysis and feeding inside the reactor. The brown sugar is added to the waste because it contains glucose from food resource microorganisms.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This research was about biomethane production from fruit waste and pseudo stem bananas within 28 days through the water displacement method and the changes of pH value in the fermentation process. Biomethane production is optimum because the anaerobic fermentation process is without oxygen. The pH of mixed wastes ranged from 6.5 to 7.5, comparable with the optimum range of pH for biogas production. The temperature ranges from 30˚C to 45˚C, allowing for biomethane production. This decomposition happens in an anaerobic environment. The process of producing biomethane is also known as anaerobic digestion. Anaerobic digestion is a natural form of waste-to-energy that uses the process of fermentation to break down organic matter.

4.2 pH

The reading for pH started to analyze after the fruit waste, and pseudo stem bananas were mixed in the anaerobic digestion reactor. It is essential to maintain the pH of an anaerobic digester between 6-8; otherwise, methanogen growth would be seriously inhibited (Gerardi, 2003).

Table 4.1 The pH value for week 1

DAY	pH
1	6.4
2	6.5
3	6.4
4	6.5
5	6.6
6	6.6
7	6.7

Table 4.2 The pH value for week 2

DAY	pH
8	6.8
9	6.9
10	6.9
11	7.0
12	7.0
13	7.0
14	7.0

Table 4.3 The pH value for week 3

DAY	pH
15	7.0
16	7.0
17	7.1
18	7.3
19	7.4
20	7.5
21	7.5

Table 4.4 The pH value for week 4

DAY	pH
22	7.4
23	7.3
24	7.2
25	7.3
26	7.1
27	7.0
28	7.3

All of the pH readings of the anaerobic digestion reactor for the fruit waste mixture and pseudo stem banana ranged from 6.4 to 7.5, which was comparable to the optimum pH for biomethane production. Table 4.1 shows that the pH was slightly lower than in previous weeks. Because it tends to form acid, the pH can drop significantly early in producing biogas. Low pH can render biogas microorganisms, such as methanogenesis bacteria, inactive. It also demonstrates how a system failure or a lack of buffering ability can impair digestion. A pH greater than 7.5 can also stifle the process of methanogenesis. In week 2, the pH reading was approaching the optimum pH for biogas production. For the following weeks, pH was getting the optimum pH for biogas production. The pH did not change abruptly. This clearly shows the anaerobic digestion process stability. When the pH ranged from 6.5 to 7.5, the AD process was complete, and the final product, biomethane, was released and collected in the anaerobic digestion reactor.

4.3 Temperature

Although there are no standard rules for optimum process stability, the temperature should be regulated within a narrow operating temperature range. With a mesophilic, digestion proceeds best at 30˚C-40˚C. Climatic considerations influence the choice of temperature to be used. The reading for the temperature was recorded at 34˚C on Day 1.

Table 4.5 The temperature reading for week 1

DAY	TEMPERATURE (˚C)
1	34
2	41
3	43
4	42
5	41
6	39
7	36

Table 4.6 The temperature reading for week 2

DAY	TEMPERATURE (˚C)
8	35
9	34
10	33
11	31
12	32
13	31
14	33

Table 4.7 The temperature reading for week 3

DAY	TEMPERATURE (˚C)
15	34
16	33
17	34
18	33
19	30
20	31
21	30

Table 4.8 The temperature reading for week 4

DAY	TEMPERATURE (˚C)
22	31
23	33
24	34
25	35
26	32
27	31
28	30

Temperature, which affects bacterial performance in anaerobic digestion, significantly impacted biomethane production. The temperature affected both methanogenic and volatile acid-forming microorganisms. Temperature fluctuations have a significant impact on the performance of methanogenic microorganisms. Temperature refers to the temperature of a biological reaction. It was a sensitive parameter that needed to be monitored regularly, significantly when the weather changed. According to the results, the temperature in the anaerobic digestion reactor ranged from 29 C to 42 C, which was in the mesophilic range, and 25 C to 45 C, which was allowed for biogas production. Mesophilic digestion required less nutrient demand and was easier to maintain with the temperature conditions in Malaysia.

4.4 Water Displacement

The first reading that were conducted to identify the production of biogas from mixture that it will received. The mixture needs to receive partial sunlight so that it will not kill the microorganism inside the mixture. This result depends on the weather of each day.

Table 4.9 The Volume of Biogas for week 1

DAY	VOLUME OF BIOGAS (ml)
1	0.00
2	0.00
3	0.00
4	13.00
5	25.00
6	28.00
7	32.00

Table 4.10 The Volume of Biogas for week 2

DAY	VOLUME OF BIOGAS (ml)
8	44.00
9	61.00
10	64.00
11	63.00
12	66.00
13	68.00
14	72.00

Table 4.11 The Volume of Biogas for week 3

DAY	VOLUME OF BIOGAS (ml)
15	72.00
16	77.00
17	54.00
18	44.00
19	48.00
20	33.00
21	32.00

Table 4.12 The Volume of Biogas for week 4

DAY	VOLUME OF BIOGAS (ml)
22	34.00
23	23.00
24	25.00
25	22.00
26	19.00
27	18.03
28	16.00

The volume of biogas produced by fruit and pseudo stem banana wastes from day 1 to day 28 is shown in the results. The importance of biogas was calculated using the water displacement method. According to the findings, the biogas produced increased significantly from day 1 to day 16. The volume of biogas then began to decrease until day 28. This occurred due to the reduction in carbon dioxide levels on day 16. During the experiment, anaerobic digestion took place in the reactor. The volume of every gas can be calculated with the concentration of gas from GC-TCD data with volume of biogas:

$$\text{Volume of CO2} = \text{volume of biogas (ml)}\ x\ \frac{39.388\%}{100}$$

$$\text{Volume of O2} = \text{volume of biogas (ml)}\ x\ \frac{34.852\%}{100}$$

CHAPTER 5

CONCLUSION

5.1 Introduction

This study aims to check the methane production performance from fruit and pseudo stem banana waste within 28 days and identify the methane production from fruit and pseudo stem banana waste in an anaerobic digestion reactor. All the objectives are analyzed by using an anaerobic digestion. The parameters are pH, temperature, water displacement, and gas chromatography

5.2 Conclusion

For the conclusion, the retention time for reducing carbon dioxide and oxygen gas was much longer, and the removal began on day 16. The mesophilic process has a maximum retention time of 40 days. If more than that, methane production will happen. Pretreatment for waste should be improved to avoid the late show of methane gases, particularly for hemicellulose waste, which has a double bond structure. Low pH, or acid, can break down the double bond structure. The acid can dissolve the double bond structure into a single bond, and the extra single bond can react with the other charge to form glucose. This chemical pretreatment process can shorten the retention time and increase methane production. The temperature of the pretreatment should be raised by removing the moisture content. In this study, the method of removing moisture content was only dried at outside temperatures of 30 degrees Celsius or less, and it was also only left for two months.

5.3 Recommendation

This experiment produced biomethane from banana fruit and pseudostem wastes. In the future, this experiment could be conducted in greater detail by providing more visible support, such as creating biomethane from food waste and calculating how much volume of gas was harnessed from a specific volume orweight of waste.

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Appendix A:

Pseudo stem banana waste from agricultural farm

Appendix B:

Chopping process at Environmental laboratory

Appendix C:

Grinding process at Environmental laboratory.

Appendix D:

Weighing the food waste using analytical balance

Appendix E:

Preservation of the food waste in the anaerobic digestion reactor

Appendix F:

Water displacement method

Appendix G:

pH and temperature monitoring of the food waste mixture in the reactor

Appendix H:

Expanded of the gas bag after 28 days