Malaysian Journal of Chemical Engineering & Technology 4 (1) (2021) 39–49

Malaysian Journal of Chemical Engineering & Technology

Journal Homepage: http://myjms.mohe.gov.my/index.php/mjcet

Review on landfill gas formation from leachate biodegradation

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Abstract

Landfill waste management is a very crucial procedure in handling Municipal Solid Waste (MSW) because it may create significant environmental issues if it is not managed properly. Landfill leachate and landfill gas (LFG) is part of the landfill waste management which triggered lot of researchers especially in terms of the environmental implications associated with the movement of the gasses during the waste constituents’ processes. Hence, this paper review is aiming to understand the behaviour of leachate itself as a decomposition agent in producing landfill gas (biogas). Biogas is naturally produced by anaerobic bacteria through anaerobic digestion which is affected by operating parameters and substrate characteristic. The results indicate that temperature, pH, and C/N ratio of leachate are the important factors that could increase the production of biogas with high content of methane. Furthermore, in terms of microbial activity during anaerobic digestion process, hydrogenotrophic and acetoclastic methanogen are the dominant substrate that contribute in producing methane gas as the final product. Firmicutes and Bacteroidetes are the common fermentative bacteria that had been found during fermentation process in hydrolysis and acidogenic phases. While, methanobacterial, methanococcal, methanomicrobial, methanosarcinal, and methanopyral are being classified as orders among 65 types of methanogenic archaea during methanogenesis stage. Overall, the relationships between operating parameters and microbial structure are important aspects that need to be considered in order to optimise the production of methane gas.

Article Info

https://doi.org/10.24191/mjcet.v4i1.12719

Article history:

Received date: 18 March 2021
Accepted date: 23 April 2021
Published date: 30 April 2021

Keywords:

Anaerobic Digestion
Landfill Leachate
Landfill Gas
Microbial Community
Methane Gas

1.0 Introduction

The capacity for leachate and municipal solid waste (MSW) landfill gas output has received significant attention over the last decade, especially in terms of the environmental implications associated with the movement of leachate and MSW landfill gas during the processing of waste constituents. The leachate is a high intensity drainage rich in hazardous chemicals which possesses high content of ammonia and organic pollutant, halogenated hydrocarbons and heavy metals (Tadda et. al, 2016). Landfill gases are comprising of CH_4 and CO_2 in which both are among the major contributions to the greenhouse gases. Those gases are the by-products from decomposition process of Anaerobic Digestion (AD) of organic waste (Olisa et. al, 2015).

During anaerobic digestion, microorganisms’ activities are the main causes of the process. The microorganism continues to survive by utilising the organic waste and generating nutrition for themselves through metabolism reaction. Catabolism is the decomposition of complex organic matter into basic and energy-releasing materials. The energy produced is then absorbed by microorganisms in oxidation and is stored in cells in the form of ATP (Andesine Troposphere) through fermentation process in which fermentative bacteria hydrolyse primary substrate polymers and produce acetate, saturated fatty acids, CO_2 and CH_4 (Kamalan, 2015).

Over the 20th century, greenhouse gas (GHG) levels have risen and culminated in a significant environmental issue—global warming, that impacts citizens worldwide (Zhang et. al, 2018). Based on analysis made by The World Bank Group in 2019, with fast population development and urbanisation, annual waste production is projected to rise to 3.40 billion tons in 2050 or by 70 % from 2016 rates around the world.

With those strong proven data, one of the main issues confronting metropolises and towns is the solid waste disposal. Waste disposal could bring negative impact towards environment for example global warming due to Greenhouse Gas (GHG) effect (Zhang et. al, 2018). The primary greenhouse gases in Earth's atmosphere are water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3).

Therefore, this research aims to determine how leachate acts as a decomposing agent to produce methane gas. The study has the following objectives in particular: a) To explore and identify the underlying operational factors that caused the methane gas production from leachate, and b) To describe microbial community involved during anaerobic digestion process.

2.0 An Overview of Landfill Gas Produced from Landfill Leachate

2.1 Landfill

Generally, landfill is one of the conventional ways to bury trash. Landfill is structurally designed in which the waste is isolated from the exposed area such as rain, air, etc. The isolation is done by using the regular soil cover. Usually, a sanitary landfill is isolated from the expose environment by using a clay liner. Landfill sites are often used for purposes of waste control such as cleaning and recycling.

In Malaysia, there are 230 landfills site which are mostly uncontrolled and old landfills with different sizes operated without appropriate bottom liners and leachate collection system. Due to lack of leachate collection and treatment facilities with no landfill gas capture infrastructure, most of the landfill sites are not categorised as sanitary landfills. Only few landfills in Malaysia have such facilities (Hussein et. al, 2019).

Municipal Solid Waste (MSW) in Malaysia requires the processing of nearly 98 % of the overall waste in landfills. The production of MSW depends on the size of the township and the degree of economic norm, with in Kluang (a small town in the southern part of the Peninsular Malaysia) generates as little as 45 tons of MSW, whereas up to 3,000 tons in Kuala Lumpur (Malaysia 's capital) (Agumuthu et al., 2004).

To ensure effective management of solid waste especially in Malaysia, the National Solid Waste Management Department under the Ministry of Housing and Local Government plays a vital role in providing sustainable policies and enforcement.

The department is responsible to come out with significant policy and framework which serve as guidelines for solid waste management in protecting the communities and achieve a developed country status.

2.2 Landfill Leachate

The liquid that drains or 'leaches' from a waste dump is leachate. The composition varies widely with respect to the age of the landfill and the type of waste it contains. It usually contains both dissolved and suspended of organic matter, ammonia, inorganic salts and heavy metal (Donneys-Victoria et al., 2018). Leachate also is one of the rainwater percolation's result through the waste, extracting and bringing with the several pollutant materials (Fernandes et al., 2015). From here, we know that climate is also one of the factors in producing a leachate from landfill site. Moreover, the compaction of the landfill sites plays role in leachate production. The lower compaction of the landfill sites contributes in high production of landfill leachate due to reduces in filtration rate.

2.2.1 Phases of Biodegradation of Landfill Leachate

Phase I is known as Initial Adjustment phase. During this phase, the waste is initially placed or buried in the landfill site. Accumulation of water or moisture will occur preliminary. As we can see the dominant gases at this phase is O_2 (20 % by volume) and N_2 (80 % by volume). Changes are initially detected in the

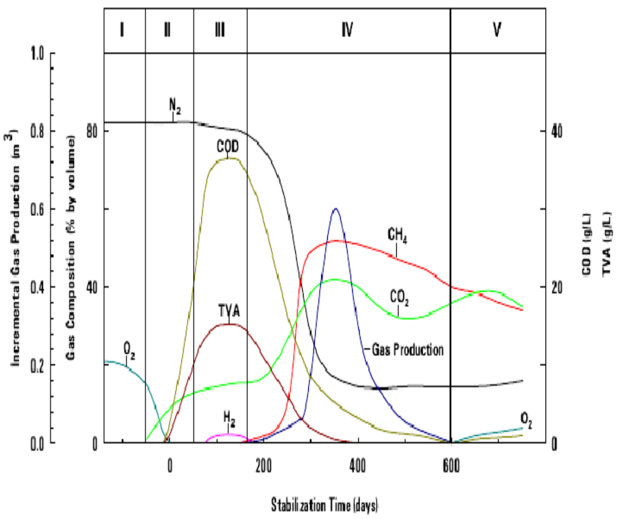

Fig. 1: Schematic diagram of waste stabilisation in a landfill (Pohland and Harper, 1985).

environmental parameters to reflect the onset of logically-trending stabilisation processes.

Phase II, known as Transition phase. Leachate begin to form where a transition or shifting from initial aerobic to anaerobic microbial stabilisation occurs. In principle, aerobics consume confined oxygen and infiltrating water quickly with respiration by the microorganism. End products including total volatile acids (TVA and CO_2) are the consequences of anaerobic environments. Due to the presence of TVA and CO_2 solutions, the pH of the leachate declines. The low pH mobilises heavy metals into the leachate from the waste.

Phase III, known as Acid Formation phase. From the figure it shows that during this phase amount of TVA dominated with continuing fermentation and hydrolysis of leachate and waste constituent which result in high BOD, COD and ammonia-nitrogen concentration. Nutrients like phosphorous and nitrogen are released and used for the growth of biomass in line with the prevailing conversion rate of the substrates. There also will be small amount of hydrogen that might be detected, and it will affect the products that being formed soon.

Phase IV, Methane Formation phase. As the landfill begins to mature, the methanogenic phase occurs by developing the methanogenic microorganism in the waste. Nutrients continue to be consumed by the microorganism. As shown in the figure, there is a drastic decrease in TVA which it is converted to methane, CH_4 and carbon dioxide, CO_2. The values of BOD and COD are at its lowest values. High pH value, resulting in complexion, precipitation and transition to the solid phase, tends to decrease in heavy metals leachate. The organic strength of leachate decreases with increasing in gas production.

Phase V, Final Maturation phase. Most of the biodegradable compounds have been decomposed hence waste stabilisation takes place (Fig. 1). Physically, natural environment become reinstated. As the COD and BOD decrease alongside with TVA, recalcitrant such as humid substances dominate the organic fraction in the leachate.

Table 1: Standard of acceptable conditions for the leachate to be discharge.

Parameter	Unit	Standard
Age of deposited wastes	year	
pH		6.0 - 9.0
Temperature	°C	40
Biochemical Oxygen Demand (BOD)	mg/l	20
Chemical Oxygen Demand (COD)	mg/l	400
Iron	mg/l	5
Manganese	mg/l	0.2
Zinc	mg/l	2

2.2.2 Composition and Characteristic of Landfill Leachate

With different physicochemical environment and microbial activities, it could affect the composition and mineralisation of the leachate (Naveen et al., 2017). By referring to Table 1, the Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfills) Regulations 2009, several standards of acceptable concentration and conditions of the leachate to be discharged. Those standards have been written off and compared between its leachate composition to other closed and active landfill sites in Malaysia as shown in Table 2 and Table 3.

Table 2: Characteristic of leachate at several active landfills in Malaysia (Hussein et al., 2019).

Parameter	Ulu Maasop Landfil	Kg. Keru Landfill	Bukit Beruntung Landfill
Age of deposited wastes	36	20	14
pH	7.76	8.59	7.09
Temperature (°C)	33.9	29.9	
Biochemical Oxygen Demand (BOD) (mg/l)	614	610	259
Chemical Oxygen Demand (COD) (mg/l)	7624	5082	985
Calcium(mg/l)	67.78	127.1	91.2
Magnesium(mg/l)	42.17	30.85	96.6
Iron(mg/l)	14.56	16.594	60
Manganese(mg/l)	0.312	0.304	5.1
Zinc(mg/l)	0.652	0.656	236

Table 3: Characteristic of leachate at several closed landfills in Malaysia (Hussein et al., 2019).

Parameter	Air Hitam Landfill	Ampar Tenang Landfill	Taman Beringin Landfill
Age of deposited wastes	11	12	24
pH	6.96–8.49	8.10–8.24	7.57
Temperature (°C)	26.44–26.68	28.44–29.40	-
Biochemical Oxygen Demand (BOD) (mg/l)	–	256–288	127
Chemical Oxygen Demand (COD) (mg/l)	1239–3607	3187–3222	482
Calcium(mg/l)	0.949–1.059	9.1–9.9	242.1
Magnesium(mg/l)	0.314–0.416	52.23–53.19	52.2
Iron(mg/l)	0.080–0.159	2.180–2.910	134.6
Manganese(mg/l)	0.005–0.011	0.080–0.100	3.1
Zinc(mg/l)	0.013–0.032	0.642–0.666	24.3

2.2.3 Migration of Landfill Leachate

The movement of leachates is often calculated by the disposal of waste. Compacted waste decreases their permeability; however, waste layers and topsoil may build high porosity to allow leachate to flow across the ground. This is reflected in Leachate's transitory nature, which may occur in wet seasons but disappear in dry seasons, leaving soil stained. Leachate migration can occur in two ways, advection and hydrodynamic dispersion (Milad, 2014).

Advection is the mass of dissolved contaminant carried by groundwater flow. So, understanding of the groundwater stream directs the advection, which depends on topography, geography, wells, porosity and conductivity-driven pressure. The Darcy law can describe average linear migration rate (Milad, 2014).

The process of mechanical mixing and atomic dispersion that affects physical parametric is known as hydrodynamic dispersion. This process also describes the penetrability of the soil or medium which could affect the migration rate. For example, is sorption (adsorption or desorption), may happen through particle trade. Sorption cannot be happened if the contaminants flow onto or out of solid particles such as residue (Milad, 2014).

2.2.4 Treatment of Landfill Leachate

Treatment for leachate can be done using conventional method such as physicochemical treatment and biological treatment. Physicochemical treatment is advisable to treat the leachate with low BOD/COD ratios (<0.1) compared to biological treatment process which is only suitable for biodegradable organic materials that found in leachate (Hussein et al., 2019).

Physicochemical treatment requires the usage of substances that may change the physical condition of colloidal particles and serve to render them more stable and coagulable for further application and filtration process. It consists of a set of processes such as coagulation, flocculation and sedimentation which can be performed in single unit or separate unit. Example of this treatment is adsorption, reverse osmosis and chemically-aided post-treatment system (Hussein et al., 2019). On other hand, biological treatment is a system that usually uses bacteria, protozoa and another special microbe to treat the leachate. Those microorganisms need food to survive, so they will stay at the leachate that have organic matter and undergo aerobic (microorganisms use oxygen), anaerobic (microorganisms do not use oxygen) and anoxic (microorganisms use other than oxygen) to breakdown the organic matter (Naveen et al., 2017).

However, due to change in quality and the lifetime amount of leachate, these conventional treatments could become ineffective throughout the treatment plant (Fernandes et al., 2015). Recently, there are lot of studies upon treatment of leachate using electrochemical treatment. Electrocoagulation (EC),

Electro-Fenton (EF) and Electrochemical oxidation (EO) are the most electrochemical processes used for the treatment of sanitary waste disposal leachate (Fernandes et al., 2015).

Electrochemical oxidation method (EO) is an evolving process for the degradation of organic contaminants in which oxidation agents are generated directly and indirectly at high voltage anodes with oxygen and chlorine evolution. Due to the presence of chloride ion in leachate, the EO process is justifiable in which reactive chlorine species oxidise organic compounds and remove ammonia (Ghanbari et al., 2020).

Electrocoagulation (EC) is a flexible method in the treatment of wastewater with electrochemical coagulation reactions (Fig. 2). The iron and aluminium electrodes are used in this treatment and produce coagulant (Ghanbari et al., 2020). The coagulated particles will be attached to the H_2 bubbles, developed at the cathode and carried to the top of the solution, can be separated by sedimentation or electro flotation of the liquid phase (Fernandes et al., 2015).

Electro-Fenton treatment is applying the concept that was observed by Fenton in 1984. Based on Fig. 3, the Fenton reactions based on the transfer of electrons between H2O2 and Fe2+ or also known as Fenton reagents (H2O2 and an Fe(II) salt). Result from the process hydroxyl radicals such as iron sludge in form of iron oxyhydroxides will produce which are very strong oxidising species. Hence, organic compound oxidation occurs by indirect electrochemical oxidation by hydroxyl radical, produced by a Fenton reaction (Fernandes et al., 2015).

2.3 Landfill Gas (LFG)

Landfill gas (LFG) is a natural by-product of the decomposition of organic materials in landfills. It usually contains 50-70 % of CH_4, 30-50 % of CO_2 and other components (Angelidaki et al., 2018). There are

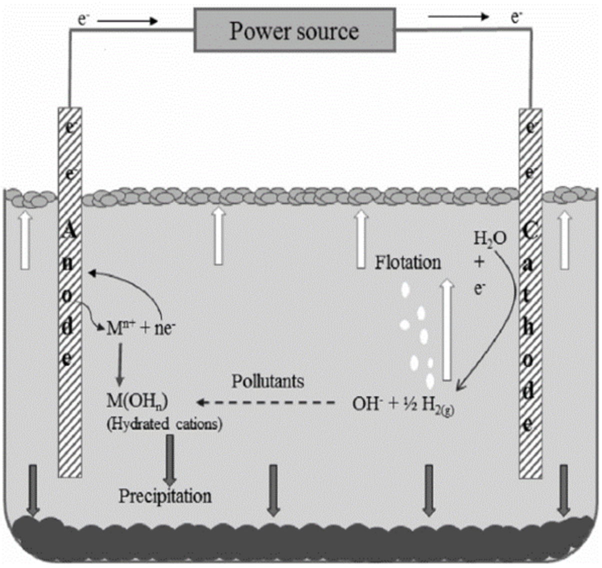

Fig 2: Schematic diagram of Electrocoagulation (EC) treatment method (Fernandes et al., 2015).

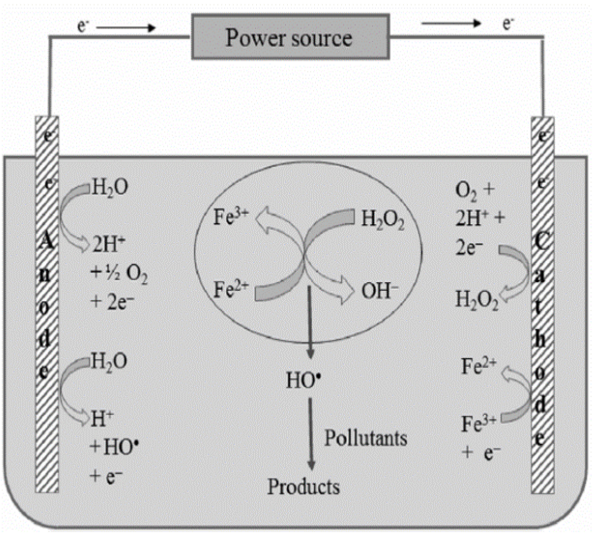

Fig 3: Schematic diagram of Electro-Fenton (EF) treatment method (Fernandes et al., 2015)

three ways how the landfill gas can be generated, which includes bacterial decomposition, volatilisations, and reactions of chemicals present in waste. Bacterial composition refers to the breakdown of the organic matter meanwhile volatilisations is the process where certain organic compound changes from liquid to vapor.

2.3.1 Factor Effecting Production of LFG

There are several factors that need to foresee affecting the production of LFG. The first factor is moisture content in which microbial population will increase due to high content of moisture in range of 60 % to 80 % (Varma et al., 2014). Hence, due to its high population of microorganisms, the organic matter will easily breakdown via bacterial decomposition and produce high amount of LFG.

With high amount of moisture content, it will also affect the second factor which is nutrients by enhancing the transportation (Olisa et al., 2015). Those nutrients come from landfilling organic waste (Sara, 2017). The nutrients are very important for the microorganisms to undergo the anaerobic digestion. Therefore, high nutrients will enhance the microorganism's activities in order to produce high amount of landfill gas.

The third factor is temperature. During the methanogenic phase or also known as methane formation phase, there is several sub phases that depend on the temperature ranges of methane production which are Psychrophilic (0 °C – 15 °C), Mesophilic (15 °C – 45 °C) and Thermophilic (45 °C – 60 °C) (Noraini et al., 2017). The thermophilic activity in compost systems shall be considered to be highest at a temperature from 52 °C to 60 °C (Varma et al., 2014). It has been found out that increase in temperature will increase the LFG production rate through volatilisations and reaction rates over short period of time.

Next factor that affecting the production of LFG is pH value. The optimum pH range for production of LFG is between 5.5 to 8.0 (Pohland and Harper, 1985). At lower pH value, it will be toxic and only happen at the early stage of leachate generation in order to increase the solubility of heavy metals into leachate.

The fifth factor would be the composition of waste (carbon and nitrogen) that would affect the rate and maximum yield of LFG. High C/N ratio indicates low in nitrogen and high in carbon content in the organic waste where the microorganisms will consume during the anaerobic digestion process. Consumption of nitrogen by the microorganisms will lead to the building the cell structure while carbon will be used as source of energy (Noraini et al., 2017). Hence, high C/N ratio will cause the slow-down of the process due to lack in nitrogen and excessive amount of carbon. Thus, the optimal C/N ratio in generating the methane gas were 20 to 30 (Wang et al., 2014).

2.3.2 Theoretical Maximum Yield of LFG

As we know LFG is a product from decomposition of waste. This reaction will occur in phase IV known as methane formation phase (Pohland and Harper, 1985; Kamalan, 2015). High value of initial stochastic will yield high amount of methane and carbon dioxide.

Below show the stoichiometric of waste decomposition theoretically by Eq. (1):

$$C_aH_bO_cN_d + \frac{(4a-b-2c+3d)}{4} H_2O \longrightarrow \frac{(4a-b-2c+3d)}{8} CH_4 + \frac{(4a-b-2c+3d)}{8} CO_2 + dNH3 \quad (1)$$

where*: a,b,c,d* = initial stochastic values of the waste

The second method of predicting the LFG is by using the EPA's Landfill Gas Emission Model (LandGem). U.S. Environmental Protection Agency (EPA) has developed the software and being widely used by other country in order to determine the LFG generating in landfill sites. The crucial component in these models, and particularly in LandGem are the first-order decay rate (k) and the potential of LFG generation (L_0) from MSW (Rasapoor et al., 2020). The LandGem model will calculate the generation of LFGs as per Eq. (2) (Alexander et al., 2005)as follows:

$$Q = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL0 \frac{Mi}{10} \exp(-kt\text{ij}) \quad (2)$$

where: Q_{CH4} = annual methane generation in the year (m^3/year), *i* = 1 year time increment, *n* = (year of the calculation) – (initial year of waste accepter), j = *0-1* year time increment.

3.0 Microbial Community Involved in Anaerobic Digestion Process

3.1 Fundamental of Anaerobic Digestion Process in Producing Methane Gas

Anaerobic Digestion (AD) is a mechanism or process that transforms and breaks down complex organic matter into biogas (CH_4 and CO_2) and some co-products (solid and liquid co-products) containing oxygen and bacteria. The process will be carried out in four separate phases in total, including hydrolysis, acidogenesis, acetogenesis and methanogenesis (Dussadee et al., 2016).

Anaerobic digestion is a promising green energy technique that allows for a reduction in waste when providing renewable energy and a high nutrient digestive content such as nitrogen and phosphorus. Consequently, anaerobic digestion has environmental advantages, such as decreasing the size of waste products, decreasing the emission of harmful greenhouse gases, generating organic fertilizers, eliminating the odour of waste materials in response to the implementation of production methane gas (Usman and Kiaer, 2020)

Through those four stages, organic compound is broken down into methane production (Fig. 4). In the first-stage hydrolysis, the complex macromolecules such as carbohydrates, lipids and proteins present in organic matter are converted into micro-molecules of sugars, long-chain fatty acids, and amino acids. Then in the second stage (acidogenesis), these soluble micro molecules are converted into VFA, acetic acids, CO_2 and H_2. The reactive fatty acids are converted to more acetic acid, CO_2, and H_2S gas by the third stage of acetogenesis. At final stage of methanogenesis, methane gas is being produced by using CO_2 and H_2S gas (Letinga et al., 1997; Dussadee et al., 2016).

In this microbial process, fermentative bacteria play an important role in converting the complex organic waste to organic acids, hydrogen and Carbon Dioxide during fermentation and hydrolysis. Finally, as terminal functional microorganisms in the AD, methanogens are responsible for producing biogas. An effective and optimal performance of AD is highly depending on healthy metabolic cooperation between microorganisms participating in the bio methanation of organic matter (Pasalari et al., 2020).

3.2 Microbial Community in Hydrolysis Stage

Fermenting bacteria catalyze the degradation of complex organic matter, including carbohydrates, proteins, lipids into soluble and biodegradable organic compounds, such as monosaccharides, amino acids,

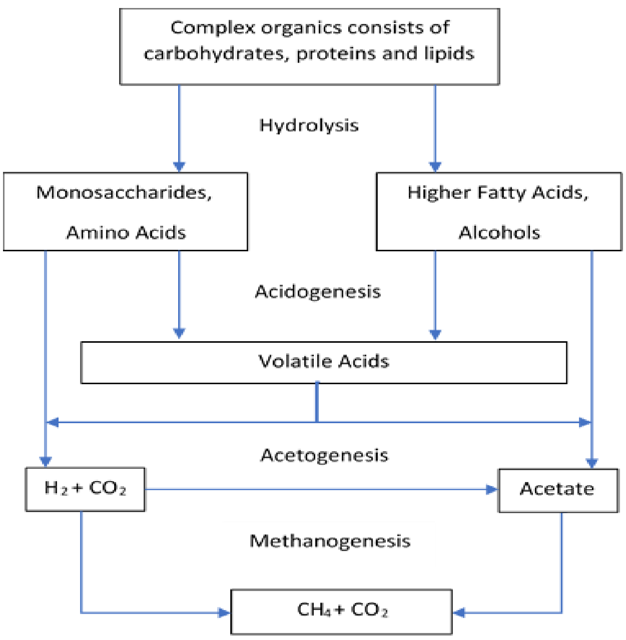

Fig 4: Flow diagram of Anaerobic Digestion process (Letinga et al., 1997).

higher fatty acids, and alcohols in hydrolysis, as a first step of AD. The fermentative bacteria initiate the degradation process and speed up the bioavailability of intracellular organic matter through the development of extracellular enzymes (such as cellulase, lipase, and protease) bound to their walls of their cells (Westerholm and Schnürer, 2019).

Fermentative bacteria that involved during hydrolysis stages are Firmicutes, Bacteroidetes, *Fibrobacter, Spirochaetes*, and *Thermotogae (Luo et al., 2018)*. Those bacteria will involve during the fermentative and metabolised processes during hydrolysis stages by the action of its various hydrolytic enzymes to breakdown the macromolecular organic structure into simpler soluble monomers such as sugar, amino acids and long chain fatty acids (LFAs) (Pasalari et al., 2020).

The degradability of the different polymers depends on the shape, composition and complexity of the polymers; for example, carbohydrate hydrolysis takes place within a few hours, whereas protein and lipid hydrolysis can take a few days. Similarly, lignocellulose and lignin degradation are both inefficient and incomplete. It has also been identified that hydrolytic bacteria cannot generate enzymes without a cellulosome (Ur Rehman et al., 2019).

The fermentative bacteria, or also known as hydrolytic bacterial operation, mainly rely on the type of inoculum, operating temperature, cell retention time (CRT) and substrate. Other parameters such as high concentrations of VFAs, LCFAs, elevated H_2 partial pressure, and humic acid have also inhibited the activity of hydrolytic bacteria. Such inhibition causes either permanent deformation of enzymes complexes leading to changes in the chemical structure of enzymes) or partial reduction of hydrolysis due to binding of receptors to active enzymes or substrate-enzyme complexes (Ur Rehman et al., 2019).

3.3 Microbial Community in Acidogenesis Stage

Product of hydrolysis, such as sugar, amino acids and long chain fatty acids, serve as a substrate for acidogenic bacteria during this process. These bacteria further convert these substrates into short-chain organic acid, which primarily contains C1-C5 carbon molecules. With the release of some other chemicals, such as alcohol, hydrogen and carbon dioxide, the organic acids formed at this point are butyric acid, propionic acid, acetate and acetic acid (Ur Rehman et al., 2019).

The most common acidogenic bacteria in the acidogenic phase are Firmicutes, Bacteroidetes, Proteobacteria and Actinobacteria (Pasalari et al., 2020; Ur Rehman et al., 2019). These bacteria secrete lytic enzymes to degrade organic matter and because of their spores, they are able to live in harsh conditions and habitats. Certain fermentation-phase products, including acetic acids, H_2 and CO_2, may be specifically used by methanogens for the production of biogas (Pasalari et al., 2020).

The abundance and population of acidogenic bacteria in anaerobic digestion can be influenced by different operating parameters and factors, including digester design, temperature, cell retention and substrate existence (Ur Rehman et al., 2019). Substrate composition and concentration are considered to be the most influential of all other factors and are also documented by many researchers; a mesophilic syntrophic acetate oxidising bacterium (Syntrophaceticus schinkii spp.) was greatly enriched by acetate substrates during Anaerobic Digestion, for example (Zhang et al., 2018; Westerholm and Schnürer, 2019; Luo et al., 2018; Liu et al., 2019).

3.4 Microbial Community in Acetogenesis Stage

In acetogenesis, the soluble organic acids produced from the hydrolytic and acidogenic steps are converted into acetate, H_2 and CO_2 by acetogenic bacteria (Pasalari et al., 2020; Westerholm and Schnürer, 2019; Ur Rehman et al., 2019). Acetogens can also specifically use hydrolysis ingredients, such as sugars and amino acids, or oxidise pyruvate acetate, a common intermediate in anaerobic degradation reactions (Drake et al., 2008; Westerholm and Schnürer, 2019). During this process, various electron acceptors can be used, including CO_2, nitrate, sulfate, and protons, with the latter being the most important in the biogas process (Ragsdale et al., 2008; Westerholm and Schnürer, 2019).

The first bacteria population is commonly referred to as homoacetogenic bacteria that generate acetate from H_2 and CO_2 on an ongoing basis (Ur Rehman et al., 2019). For instance, during ethanol fermentation, carbon dioxide and hydrogen are used to manufacture acetate; if the partial pressure of H_2 increases due to the concentration of hydrogen, the activity of acetate-forming bacteria will be halted, resulting in the loss of production of acetate (Luo et al., 2018).

Many acetogenic bacteria belonging to the genus Syntrophomonas (e.g. Syntrophobacter wolinii and

Syntrophomonas wolfei) are also capable of producing acetate from various organic acids and are referred to as microorganisms that oxidise syntrophic fatty acids. The conversion of volatile fatty acids (VFAs) into acetate is often dependent on the partial pressure of hydrogen, which has to be very low to efficiently convert volatile fatty acids (VFAs) into acetate. Some bacteria called syntrophic acetate oxidising (SAO) bacteria are rarely present in the acetogenic stage; such bacteria usually stabilise the AD system, especially when there are environmental changes in the process (Ur Rehman et al., 2019). Acetogenic and SAO usually belong to the *Clostridium* and *Acetobacterium* genera (phylum: *Firmicutes*) (Westerholm and Schnürer, 2019).

3.5 Microbial Community in Methanogenesis Stage

Methanogenic archaea transform CO_2, H_2, acetate, and methylated compounds to methane in the last stage of the microbial-driven reaction. The acetate as a substrate is split by aceticlastic methanogens into the methyl group and CO_2, and hence the methyl group is transformed from methylated compounds such as methanol, methylamines, and methylsulfides to methane during the methanogenesis period. Moreover, in the presence of H_2, hydrogenotrophic methanogens create methane by the elimination of CO_2 as a source of carbon and energy (Westerholm and Schnürer, 2019; Pasalari et al., 2020).

Methanogens are slow-growing microorganisms with a strictly anaerobic nature (highly susceptible to O_2) and can only degrade minimal organic compounds as a source of carbon and energy. In the absence of O_2, the methanogenic bacteria use H_2 and CO_2 as substrates, along with the form, methanol and acetate, to generate methane as the final portion. They are typically well known for biogas production (Ur Rehman et al., 2019).

Methanosaeta, methanobacterium, and methanosarcinaceae are widely detected in the AD process (Liu et al., 2019). A number of researchers have described 65 distinct forms of methanogens, categorised into five orders: methanobacterial, methanococcal, methanomicrobial, methanosarcinal, and methanopyral (Luo et al., 2018; Wang et al., 2018; Wang et al., 2018. In particular, by substrate use, they are further classified into three distinct groups: methylotrophic methanogens, hydrogenotrophic methanogens and acetoclastic methanogens. Methanogens that use methyl and some other single carbon compounds are classified as methylotrophic methanogens. While, the species that use CO_2 and H_2 as carbon and energy sources and turn them into methane is known as hydrogenotrophic methanogens groups and acetoclastic methanogens, these methanogens convert acetate into methane (Ur Rehman et al., 2019).

4.0 Impact of Landfill to The Environment

4.1 Soil Contamination

Soil contamination results from a combination of solid or liquid hazardous materials with the soil. Contamination of leachate may have significant impacts on the behavior of the soil as a result of chemical reactions between the soil mineral and the contaminant.

Metals sometimes disturb microbial soil biomass, activity and even reduce the microbial soil community's composition and diversity. The leachate produced by waste dumping is a source of heavy metal pollution. The eventual trend for generating waste is always induced by high volumes of leachate, particularly in developing countries (Jayanthi et al., 2016).

Thus, in the presence of leachate as a soil contaminant the interactions and responses of microbes are important. Pollution reactions of microbes may vary between one environment to another or may vary between species because of the nature and the concentrations of pollutants. For example, at low copper concentrations (Cu), microbial growth can be increased. Meanwhile, at high concentrations of copper (Cu), it will be reduced. Low cadmium levels (Cd) can cause serious toxicity in the meantime (Jayanthi et al., 2016).

4.2 Ground water Contamination

Groundwater can be used in metropolitan environments as an agricultural and/or drinking water, as well as drainage into water storage areas like lakes, streams and bays to establish potential sludge channel for landfill sites. The mechanisms of toxicity to humans may involve inhalation or absorption of polluted water through toxic contaminants or dermal contact (Hepburn et al., 2019).

Ammonia, dissolved methane, sulfate, bicarbonate, heavy metals and organic compound such as phenol and aromatic hydrocarbon are the contaminant that usually linked to the contamination in groundwater (Kjeldsen et al., 2002).

A study of Leachate Pollution Index (LPI) in various landfill sites at Malaysia conducted by (Hussein et. al, 2019) indicated that LPI for Ulu Maasop Landfill and Kampung Keru Landfill were 15.28 and 13.89 respectively which are slightly higher compared to Pajam Landfills 1 and 2. This is because Kampung Keru Landfill and Ulu Maasop Landfill are one of the active landfill sites in Malaysia. The results have shown that both landfill site have high contamination such as BOD, COD and certain heavy metals (As, Cr, Fe) at particular time. The reason why active landfill sites in Malaysia have high value of LPI is due to poor waste management that includes leachate collection and treatment.

4.3 Power Generation

Despite the above, methane is known to be able to be converted into renewable energy to the industry. In the 8th Malaysia Plan, the government had introduced various policies which encouraged the 'promotion of reuse' which focus on recycling and reuse of solid waste to beneficial energy using waste to energy (WTE) technology (Yong et al., 2019).

For example, Air Hitam landfill which had been closed and currently remains as recreational park. This sanitary landfill used to generate 2 MW of electricity on monthly basis through the onsite collection of LFG. This capacity was able to accommodate 2000 of surrounding houses in the area (Yong et al., 2019).

5.0 Conclusions

Production of biogas especially methane allows renewable energy and nutrients to be recovered from various organic waste materials and therefore it is important for the transition to a more sustainable environment. Hence, lot of parameters and aspects need to be considered in order to optimise the production of methane through AD. Among all, the most important parameters are pH, Heavy Metals, COD and (C/N) Ratio.

Furthermore, the efficiency and stability of the AD process are strongly dependent on the array of various microbial groups and in turn, their networks and functions are affected by substrate characteristics and operating parameters. However, with broad consensus of the microbiology of biogas systems, it has also become clearer that the microbial involved is much more complex and difficult to envision than initially assumed.

Nonetheless, it is believed that further study on the leachate biodegradation in landfill gas formation is vital especially on methane gas utilisation for the benefit of various stakeholders such as the owners, end users and surrounding community.

It is therefore important to enhance the understanding of the microorganisms and their functions to further develop a comprehensive understanding of the relationship between microbial community structure and operating parameters in order to establish an effective operating policies and optimal performance in the production of biogas.

Acknowledgment

The authors would like to thank School of Chemical Engineering, College of Engineering, Universiti Teknologi MARA (UiTM), Malaysia for the support of research.

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