DRY- DIGESTION TECHNOLOGY USING KITCHEN, AGRICULTURAL AND MARKET WASTE FOR CONTINUOUS BIOGAS GENERATION AND ITS EFFECTIVENESS

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CERTIFICATE

*This is to certify that the thesis entitled “**DRY- DIGESTION TECHNOLOGY USING KITCHEN, AGRICULTURAL AND MARKET WASTE FOR CONTINUOUS BIOGAS GENERATION AND ITS EFFECTIVENESS’’** submitted to the Department of Animal Production & Management, Faculty of Animal Science & Veterinary Medicine, Sher-e-Bangla Agricultural University, Dhaka-1207, as partial fulfillment for the requirements of the degree of **MASTER OF SCIENCE (MS) in ANIMAL SCIENCE**, embodies the result of a piece of bona fide research work carried out by **AFSANA AKTER**, **Registration No.: 19-10062**, Semester: **JANUARY- JUNE/2021** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma in any other institution.*

I further certify that any help or source of information, received during the course of this investigation has been duly acknowledged.

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DEDICATED TO MY BELOVED PARENTS

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The Author

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LIST OF ACRONYMS & ABBREVIATION

ABBEREVIATION	FULL WORD
AD	Anaerobic digestion
Avg	Average
AW	Agriculture waste
C/N	Carbon nitrogen ratio
CD	Cow dung
DAD	Dry Anaerobic Digestion
DF	Dry Fermentation
DM	Dry Matter
e.g.	For example
et al	And others/Associates
FAO	Food and Agricultural Organization
G	Gram
HRT	Hydraulic Retention Time
i.e.	That Is
Kg	Kilogram
KW	Kitchen waste
LCFAs	Long chain fatty acids
LSAF	Liquid-State Anaerobic Fermentation
SD	Standard Deviation
MC	Moisture Content
MJ	Mega Joule
MW	Market waste
OLR	Organic loading rate
SRT	Solid retention time

LIST OF SYMBOLES

SYMBOLES	**FULL MEANING**
ºC	Degree Celsius
@	At the rate of
:	Ratio
*****	5% level of significance
&	And
/	Per
±	Plus-minus
%	Percentage

DRY- DIGESTION TECHNOLOGY USING KITCHEN, AGRICULTURAL AND MARKET WASTE FOR CONTINUOUS BIOGAS GENERATION AND ITS EFFECTIVENESS

ABSTRACT

For securing the clean energy demand along with the safety of the environment, a feasible renewable energy source could be biogas. Dry anaerobic digestion needs less water, lower logistic costs for fertilizers these factors generate interest in using it for treatment of even high-nitrogen substrates for biogas production. The purpose of this work was to study different type of wastes biogas generation by dry anaerobic digestion technology. This study was carried out for ten weeks in batch type digestion by dry anaerobic digestion of kitchen waste (KW), agricultural waste (AW) and market waste (MW) co digestion with cow dung and urine at 33.3 % of total waste. A total 300 kg of waste for each three treatment group was digested for 49 days. Three digester were operated under each treatment group. Total solid percentage in Treatment 1 (KW, Cow dung, urine), Treatment 2 (AW, Cow dung, urine) and Treatment 3 (MW, Cow dung, urine) 17.34±0.39 %, 19.70±0.44 % and 18.52±0.73% respectively. C/N ratio of KW, AW, MW, CD and urine (28.82 ±1.52, 32.72± 0.28, 30.30 ± 1.03, 24.75 ±0.30, 4.36± 4.55 respectively) highest in AW. Significant variation ($p<0.05$) were observed among T1, T2 and T3, in gas production, highest gas production was recorded at 40-49 days. Because dry digestion process require high retention period. The temperature ranged from 20ºC to 36ºC during ten weeks. The results indicated that biogas production was 1.48±0.28, 1.30 ± 0.06 and 1.29± 0.07 m^3 from T1, T2 and T3 respectively at 1st week. After a batch study, at 7th week cumulative biogas production was 50.78±0.48 m^3 observed in digester containing MW with cattle dung which was significant ($p<0.05$) as compared to other reactor. Methane content was recorded for all the digester between 60-65%. As digestion period increases the biogas production was also increased because wastes used in this research work contain more lignin, cellulose and silica therefore it takes more time for digestion. A lot of variation in daily biogas production was also recorded due to fluctuating pH, mixing and other environmental condition. The digestate remaining after biogas production need no further treatment for using as fertilizer, pH and total carbon has no significant variable, total nitrogen content (7.18, 6.74, 7.96 mg/g) was significant among T1, T2 and T3. So, it can be concluded that the treatment of (T3) MW with cow dung and urine considered as the best compared to other treatment and it can be suggested as field level application.

Key words: Biogas, dry fermentation, waste, digestate

CHAPTER-1

INTRODUCTION

CHAPTER 1

INTRODUCTION

Biogas is a naturally occurring gas that is generated by the breakdown of organic matter by anaerobic bacteria and is used in energy production. Biogas differs from natural gas in that it is a renewable energy source produced biologically through anaerobic digestion rather than a fossil fuel produced by geological processes. Biogas is primarily composed of methane gas, carbon dioxide, and trace amounts of nitrogen, hydrogen, and carbon monoxide. The average concentration of methane and carbon dioxide are in the order of 65% and 34% respectively. It occurs naturally in compost heaps, as swamp gas, and as a result of enteric fermentation in cattle and other ruminants. Biogas can also be produced in anaerobic digesters from plant or animal waste or collected from landfills. The overdependence on fossil fuels as primary energy source has led to global climate change, environmental pollution and degradation, thus leading to human health problems. According to current research and future predictions, the crude oil will run out within 40 to 70 years, and natural gas will be finished within 50 years (Courtney and Dorman, 2003). At this critical stage of energy and fertilizer crises, this process has been and will be the most practical and economical means for treating and managing the large volume of wastes. Large scale adaptation of this technology can result in several additional benefits like a general improvement in hygiene and health, reduction of human drudgery, creation of local employment, and above all an improvement in the quality of life. World population is growing rapidly, and this explosion has led to rapid consumption of oil resources and a tremendous increase in the volume of wastes generated. Globally, about 17 billion tones of total solid wastes are generated per year (Chattopadhyay *et al.*, 2009), and the amount is estimated to reach 27 billion tones in 2050 (Karak *et al.,* 2009). Continuous emissions of carbon dioxide, methane, and other greenhouse gases from these waste streams and the burning of fossil fuels has led to a global environmental crisis. The intensive agriculture practice to produce food also damages the environment through the use of chemical fertilizer.

Bangladesh situated in the north-eastern part of south Asia is among the world most densely populated nations with a population of 163 million in 2019. Bangladesh produces huge amount of municipal solid waste i.e. kitchen waste, poultry waste, sewage sludge, cow manure, agriculture residues, food scrap, etc. The municipal solid generation capacity of Bangladesh on daily basis was 0.5 Kg/capita/day (Zurbrugg, 2006). In Bangladesh, disposal of municipal solid waste (MSW) is a major concern in large cities from the management perspective. These wastes are always damped in the open land field and river which pollutes environment seriously and causes the public health disease like malaria, cholera, typhoid etc. Industrial production in Bangladesh is based on natural gas. Since 2005, the increased gas demand outpaced gas supply resulting a gas shortage. As major power stations here are run by natural gas; as a result the gas reserve has fallen to such an alarming level and it is assumed that very early the supply of the nature gas will start to decline (Hasan and Khan, 2012). Biogas production also becomes a human rights issue when it destroys ecosystems and natural resources that are critical to the health and subsistence of people (Nuffield Councilon Bioethics, 2017), hence, the residue remaining after biogas production must be free of pathogens, viruses, and toxic compounds that could contaminate soil, air, or water. Biogas production through anaerobic digestion is a resource effective way of managing the large volume of organic waste generated. Biogas production from organic waste has dual functions; it produces energy and organic fertilizer and at the same time reduces waste volume. Biogas technology has an important role to play in meeting the present and future energy needs in both rural and urban areas (Abila, 2012). Anaerobic digestion is a naturally process that allows the growing of microbial communities in the absence of oxygen to accelerate the biological pretreatment of organic substrates. In addition, it is an effective and environmental-friendly treatment of organic wastes and their valorization in the form of several products (Abdelsalam *et al.*, 2018; Xu *et al*., 2019; Hijazi *et al*., 2020).

Anaerobic digestion of organic wastes for biogas production is generally done through both wet and dry digestion processes. In industry, biogas production from wastes with high water content is most common process; however the utilization of solid wastes from agricultural, municipal, and industrial activities, including forest and crop residues, is becoming more and more important as well. Solid wastes usually have a solid content of between 15 % and 50 %; hence conventional wet anaerobic digestion treatment of these kinds of wastes requires a lot of water. Therefore, processing these waste streams for biogas production using dry-AD technology is a better option making it possible to manage waste streams with low moisture content.

The dry anaerobic digestion is assessed as a new technology and a promising approach for small-scale biogas production from solid waste in the agriculture sector (Bayrakdar *et a*l., 2017). The most important features of this technology are the small size, easy maintenance and simplicity of the digester process; it doesn't occasion any troubles for foam, surface crust and sedimentation furthermore. Also, it doesn't require any additional energy for stirring (Alper *et al*., 2017; Xu *et al*., 2019).

Bio-slurry from the biogas plants was used in horticulture, pisciculture, and agriculture. The average saving per plant amounted to Taka 759 per month (BCSIR, June 2001).

Biogas production through dry digestion technology is popular and available many country in the world, and many research also conducted on this technology. But in Bangladesh this dry fermentation technology for biogas production from kitchen waste, agricultural waste and market waste is not practice yet. Biogas production sometimes requires a lot of water, and this use of water should be reduced if possible because access to water is an essential human right. Biogas production for the generation of energy should not be at the expense of this essential right. Therefore, this research was focused on dry anaerobic digestion, in which a reduced amount of water is used. With this background, the work was planned to explore the possibilities of dry fermentation method for production of biogas with the following specific objectives:

- To promote the biogas production from kitchen, agricultural and market waste by anaerobic dry- digestion process.
- To ensure waste management economically viable and environment friendly.
- To replace of industrially produced chemical fertilizers by dried bio-fertilizer or without any treatment.

CHAPTER-2

REVIEW OF LETERATURE

CHAPTER 2

REVIEW OF LITERATURE

Performing any type of survey or experiment review of literature is important which are linked to the proposed study for the convenient of research work. The past research works related to the experimented has been reviewed to conduct the experiment properly. In recent years, across Bangladesh the demands of agricultural waste for cattle feed and industrial purpose has increased due to excessive in-situ burning of it. Thus, it is imperative to set up appropriate policies that promote multiple use of agricultural waste in the context of conservation agriculture and to prevent their on-farm burning. Kitchen waste, agricultural waste and market waste can be useful by conversion as a biogas, and this can be done by dry fermentation. Many research work has been done in Bangladesh on Biogas production but those has been limited on wet fermentation. In view of the foregoing, the purpose of this study was examining the production of biogas using the dry fermentation technology through kitchen waste (KW), agricultural waste (AW), market waste, co-digestion with manure. In addition, this paper aims at reducing the knowledge gaps in the dry anaerobic co-digestion process.

2.1 An overview of biogas production

Biogas is produced from organic wastes through anaerobic digestion processes. This reduces the effect of feedstock costs on biogas production and makes biogas production and utilization a good solution for addressing both waste and energy challenges (Curry and Pillay, 2012).

Kumar et al., (2004) investigated the reactivity of methane. They concluded that it has more than 20 times the global warming potential of carbon dioxide and that the concentration of it in the atmosphere is increasing with one to two per cent per year. The article continues by highlighting that about 3 to 19% of anthropogenic sources of methane originate from landfills.

Singh *et al.* (2000) studied the increased biogas production using microbial stimulants. They studied the effect of microbial stimulant aquasan and teresan on biogas yield from cattle dung and combined residue of cattle dung and kitchen waste respectively. The result shows that dual addition of aquasan to cattle dung on day 1 and day 15 increased the gas production by 55% over unamended cattle dung and addition of teresan to cattel dung : kitchen waste (1:1) mixed residue 15% increased gas production.

2.1.1 Biogas

Biogas is a gaseous mixture generated during anaerobic digestion processes using waste water, solid waste (e.g. at landfills), organic waste, and other sources of biomass. Biogas can be upgraded to a level compatible with natural gas ('green gas') by cleaning (removal of H2S, ammonia and some hydrocarbons from the biogas) and by increasing its methane share (by removing the CO_2). The resulting green gas can subsequently be delivered to the natural gas distribution grids. In developing countries, biogas could be an interesting energy option, in particular for those countries that rely heavily on traditional biomass for their energy needs. (Abdulkarim and Maikano, 2008; Bras and Zootec, 2012).

Composition of biogas depends upon feed material. Biogas is about 20% lighter than air, has an ignition temperature in range of 650- 750 °C. Colorless gas that burns with blue flame similar to LPG gas. Its caloric value is 20 Mega Joules (MJ)/m^3 and it usually burns with 60% efficiency in a conventional biogas stove. (Suyog VIJ , 2011).

Table 1 Typical composition of biogas

Constituents	% Composition
Methane, (CH_4)	55 – 65
Carbon dioxide, (CO_2)	35-45
Hydrogen sulphide, (H_2S)	0-2
Nitrogen, (N_2)	0-1
Hydrogen, (H_2)	0-1
Carbon monoxide (CO)	0-3
Oxygen, (O_2)	0-2

Source: Suyog V. (2011).

2.1.2 Anaerobic digestion

Anaerobic digestion is a naturally process that allows the growing of microbial communitiesin the absence of oxygen to accelerate the biological pretreatment of organic substrates. In addition, it is an effective and environmental-friendly treatment of organic wastes and their valorization in the form of several products (Abdelsalam *et al*. 2018; Xu *et al*. 2019; Hijazi *et al*. 2020).

Schnurer, (2009) and Jarvis, (2010) published a paper titled Microbiological Handbook for Biogas Plants, in this paper they pointed out that, the process of biogas production includes preparation of the feedstock for digestion and the anaerobic digestion process, which consists of four basic steps, hydrolysis, fermentation, acetogenesis, and methanogenesis, as explained in Table 2. In this process, the first stage is very essential because microorganisms cannot use large molecules directly unless they are disintegrated into smaller molecules; the rate of disintegration during this stage depends on the nature of the substrate. During fermentation, the products from the previous stage are used as substrates except fatty acids released during the decomposition of fats and aromatic structures. The third stage is very complex because it requires interaction between the acetogens and the methanogens; the process is closely linked to the concentration of hydrogen gas and will stop if the hydrogen produced is not continuously consumed. (Schnurer and Jarvis, 2010)

Ferry, (2012) stated that ,the most important substrates for methane formation are H_2, CO_2 and acetate but some methanogens can also use methanol, formate and methylamines. Additionally, optimal conditions such as neutral pH, constant temperature, balanced nutrient composition, and consistent feed rate are required for effective conversion of organic wastes to biogas.

Table 2: Steps related to fermentation process

Steps	Function	Microbiomes
Hydrolysis	Conversion of suspended organic matter, proteins, carbohydrates, and lipids to amino acids, sugars, and fatty acid	Fermentative bacteria (Bacillaceae, Lactobacillaceae, Enterobacteriaceae, etc.)
Acidogenesis	Conversion of amino acids, sugars, and fatty acid to intermediate products, C_3, or higher organic acids like propionate and butyrate	Clostridia
Acetogenesis	Conversion of intermediate products, propionate, and butyrate to acetate, hydrogen, and CO2	Acetogenic bacteria
Methanogenesis	Conversion of acetate and hydrogen to methane	Acetotrophic methanogen, hydrogenotrophic methanogen

2.1.3 Fermentative Microbes

All the microbes involved in biogas fermentation are generally called biogas microbes, which include non-methane producing bacteria and methane producing bacteria .The non-methane producing bacteria can be divided into two groups, fermentative bacteria and hydrogen producing acetogenic bacteria (Figure 1). In the process of biogas fermentation, these microbes, according to their nutrient requirements, play different roles in the conversion of substances. A result of their joint action is the degradation of complex organic substances into methane (APH,1989).

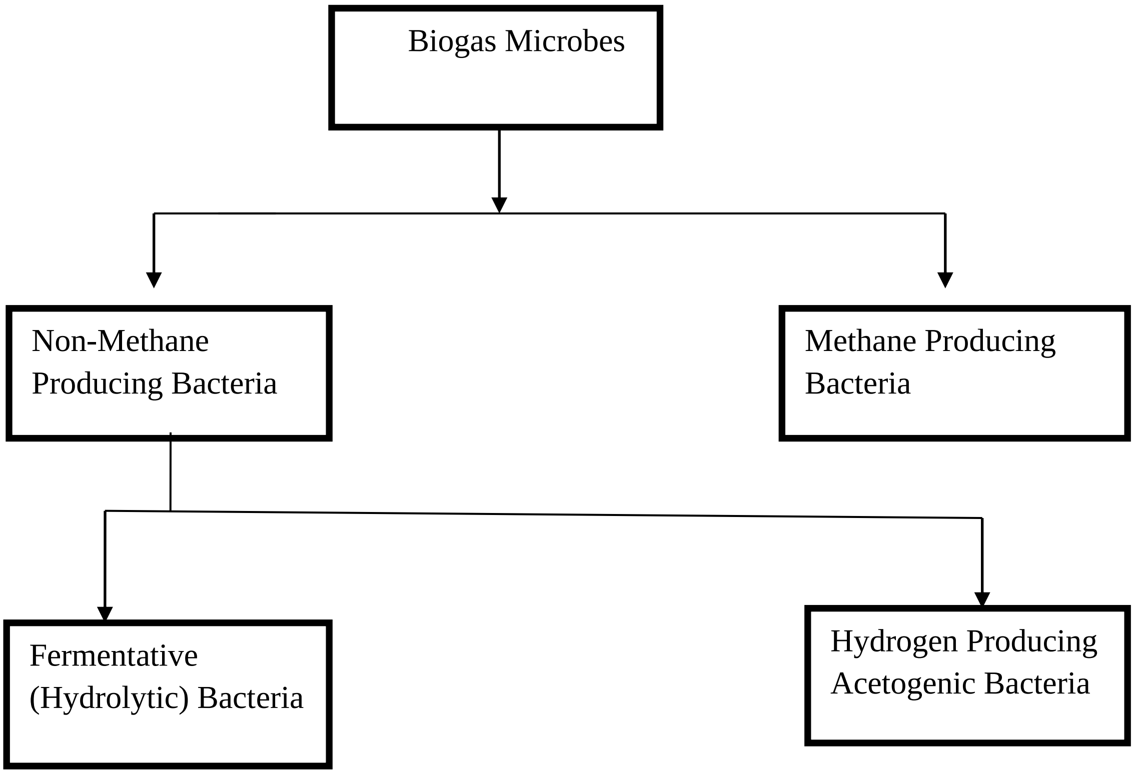

Figure1: Groups of Biogas Microbes

There are three stages in the conversion of organic substances into methane by biogas microbes (Figure 2).The function and characteristics of each group involved in a certain stages (APH,1989) is described in the following section.

2.1.3.1 Fermentative bacteria

Fermentative bacteria are complicated and mixed group of bacteria. They are involved in the first stage of biogas production. Their main function is to hydrolyse various complex organic substances and then ferment them into various volatile acids, hydrogen, and carbon dioxide. According to different substrate requirements, fermentative bacteria can be subdivided into cellulose decomposing bacteria, protein decomposing bacteria, and fat decomposing bacteria etc.

2.1.3.2 Hydrogen producing acetogenic bacteria

This type of bacteria act in the second stage of biogas production. Their function is to decompose further substances produced in the first stage (such as volatile acid, propionic acids, aromatic acids, and alcohols etc which cannot be utilized directly by the methane producing bacteria) into acetic acid, hydrogen and carbon dioxide etc.

The variety and quantity of fermentative and hydrogen producing acetogenic bacteria vary with the fermentation material . Judging from their reaction to oxygen, they are mostly anaerobes and facultative anaerobes, including butyric clostridia and other kinds of clostridia, lactobacilli, and gram positive micrococci.

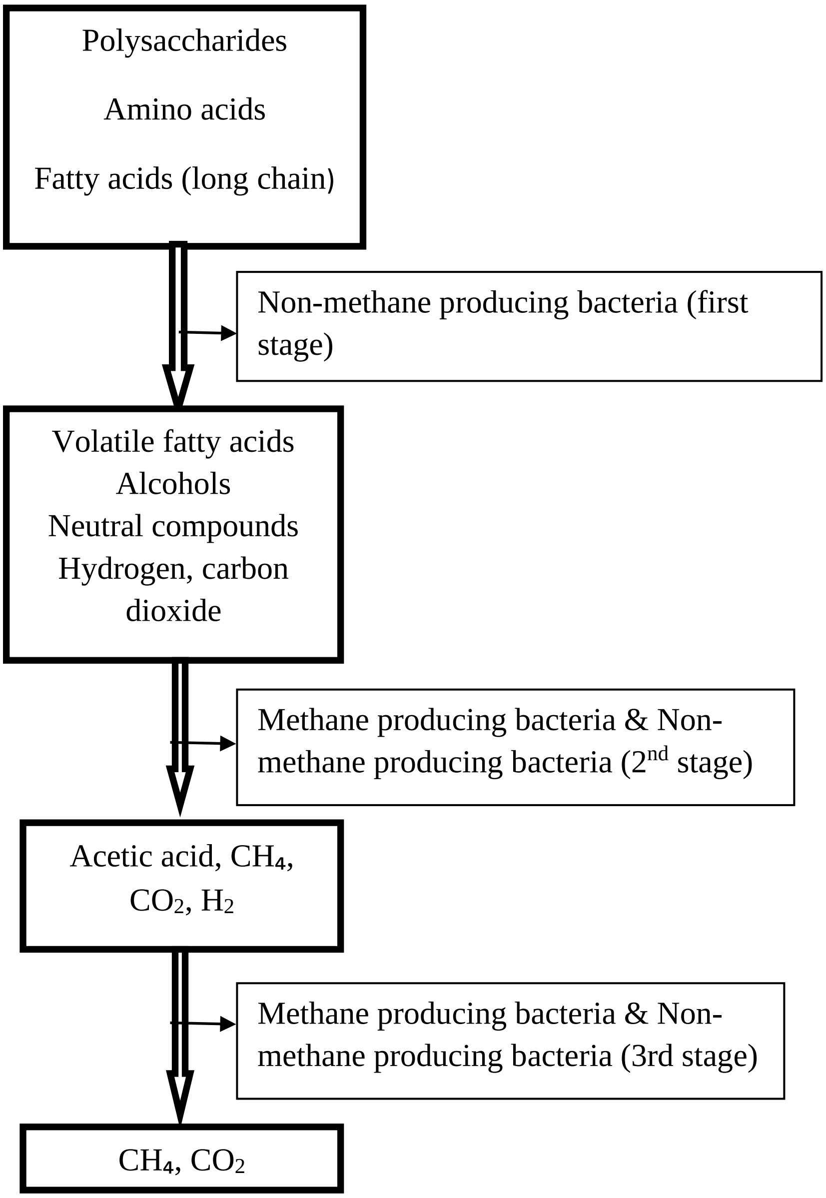

Figure 2: Groups of Microbes Involved in the Three Stages of Biogas Production

2.1.3.3 Methane producing bacteria

This kind of bacteria active in the third stage of biogas fermentation. Their function is to convert the acetic acid, hydrogen, carbon dioxide and thus bring biogas fermentation to an end.

Methane producing bacteria are group of extraordinary microbes. They are anaerobes in the strict sense, very sensitive to oxygen and oxidizers. Their growth is slow. Studies show that most methane producing bacteria can use hydrogen carbon dioxide, and formic acid as substrates to yield methane through metabolism.

2.1.4 Basic reactions involved in the anaerobic digestion process for biogas production

Themelis and Kim explained in their studies that the mixture of organic wastes can be approximated by the chemical formula $C_6H_{10}O_4$, excluding nitrogen and sulphur because they are relatively minor and occur principally in mixed food wastes. The hydrolysis reaction can then be written as shown in equation 1.

$C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + H_2$ ……………………………………….(1)

Madigan, M., *et al* showed that the hydrolysed organic compounds (sugars and amino acids) are converted to alcohols andorganic acids by fermentative bacteria, as written in equations 2 and 3.

$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2$ …………………………………………(2)

$C_6H_{12}O_6 + 2H2 \rightarrow 2CH_3CH2COOH + 2H2$ …………………………………(3)

Kothari, R., *et al.* studied that all of the organic acids, except the acetic acids, are consumed by the acetogenic bacteria and then converted to acetic acid and hydrogen, as written in equation 4 (Madigan, M., 2015)

$CH_3CH_2COOH + 2H_2O \rightarrow CH_3COOH + CO_2 + 3H_2$ ………………………(4)

The last step is the formation of methane, in which, methanogens which carry out the terminal reaction in the anaerobic process are the most important in anaerobic digester systems. The methane is produced from a number of simple substances: acetic acid, methanol or carbon dioxide and hydrogen. Among these, acetic acid and the closely related acetate are the most important, since around 75% of the methane produced is derived from acetate (Evans, 2001). It has been estimated from stoichio metric relations that about 70% of the methane is produced via the acetate pathway (Madigan *et al.*, 2003).

The basic reactions involved in methane formation are written in equations 5, 6, 7, and 8 showed by Madigan, (2015).

$CO_2+4H_2 \rightarrow CH_4+2H_2O$ ……………………………………………… (5)

$CH_3COOH+CO_2 \rightarrow CH_4+2CO_2$ ………………………..…………….(6)

$CH_3OH+H_2 \rightarrow CH_4+H_2$…………………………………………………….(7)

$2CH_3CH_2OH+CO_2 \rightarrow 2CH_3COOH+CH_4$………………………………….(8)

2.2 Types of fermentation process

A wide variety of systems have been developed to anaerobically treat kitchen waste, agricultural waste market waste and MSW. For convenience, researchers usually divide biogas fermentation process into different types according to different standards. The characteristics of different fermentation process are described in the following sections.

Classification according to the way of deposit of substrates in plants:

2.2.1 Batch fed fermentation

Batch fermentation is a discontinuous process and the fermenter has to be cleaned after each process and a fresh batch started. This is a single step process where all the steps of methane production occur in the same digester. Substrate is added at once to the digester together with the inoculum and it is left to digest till the end of HRT. This technique is employed when the TS of substrate is high (Bioenergy via Dry Fermentation, 2008)

The main characteristic feature of this fermentation process is that a whole batch of material is put into the digester at a time after fermentation is completed, all the residue is taken out and then the digester is fed with another batch of materials so as to start the next fermentation period. This fermentation process is mostly adopted for the small-sized dry fermentation apparatus in the rural areas of China (APH, 1989). It is also used to treat urban refuse in other countries, and known as ‘land filling’ method. This fermentation process is rather simple, and it needs no control so long as the start up is successful. Its disadvantage is that the speed of biogas production varies with time, in this process, the production of biogas is non-continuous. Gas production will peak at the middle of the process and will be low at the beginning and at the end of the process. In order to ensure a more steady supply of biogas, a number of batch digesters with substrates at different stages of anaerobic digestion are operated in parallel. Fermentation period refers to the retention time of material, the material concentration at the start-up is indicated by the total solid content of fermentative fluid. The length of a fermentation period and the time for the change of fermentation material should be decided according to the sources of materials, the temperature, and the seasons associated with the use of manure (Bioenergy via Dry Fermentation, 2008).

2.2.2 Semi-batch-fed fermentation

The characteristic of this fermentation process is that the digester is fed with a considerable amount of material during the start-up of fermentation; later on some fresh material is added to the fermentative fluid and some fermented material is taken out of the digester the amount of the additional or discharged material is determined in the light of specific conditions after a certain period of time the fermented material is entirely discharged and the digester is replenished again so as to start another fermentation period. Its advantage is that biogas production can be carried out a steady speed and it is easy to plan the use of biogas produced; moreover, the discharged material can meet needs of agricultural production for manure. It is an effective fermentation process for treating the mixture of stalks, excrement and urine. But this is labor intensive process to start up of fermentation and to discharge the material.

2.2.3 Continuous fermentation

In a continuous fermentation process, the substrate is added to and removed from the digester continuously. Since fresh substrate is added continuously, all reactions involved in biogas generation will occur at a fairly constant rate. This results in a fairly constant biogas production rate. The feature of this fermentation process is that after the start-up of fermentation, material is fed in the digester continuously or in regular quantity each day according to the process design, and mean while the same amount of fermented material is discharged from the digester so that biogas fermentation can proceed continuously. The reactors were filled with the inoculums and then operated under mesophilic (37**ºC**) condition until the residual biogas production dropped to zero. So long as there is nothing wrong in fermentation process and there is no need to overhaul it, there is no need for a complete change of material. With this fermentation process, fermentative fluid remains stable in terms of its quantity as well as its quality; consequently, the yield of biogas is also stable. This fermentation process is suitable for both the medium and large scale biogas projects.(Mottalib, 1996)

2.3 Dry anaerobic digestion (dry-AD)

Kothari, R. et al., (2014) together worked on Different Aspects of Dry Anaerobic Digestion for Bio-Energy: An Overview they stated that AD can be performed as dry AD and wet AD, i.e., at different moisture content values, because under a specific content of total solids (TS), the substrate loses its fluidity. There is no generally accepted distribution limit of moisture content for dry and wet fermentation. Some authors have defined this limit to be equal to 15% (Li, 2011).

According to Li and Zhu, (2011) total solid contents for wet digestion between 0.5 % and 15 % and total solid contents for dry digestion greater than 20 %. In industries, wet anaerobic digestion processes are most common, but recently there has been great concern about the large amount of water used while treating organic solid wastes for biogas production and the huge water content of the digestate residue. In addition, the use of solid wastes (total solid content between 15 % and 50 %) from agricultural, municipal, and industrial activities, including forest and crop residue, is becoming more attractive. Therefore, the impetus for developing dry anaerobic digestion processes is increasing in both research and industry. (Bolzonella *et al.*, 2003 and Yi *et al*., 2014).

2.3.1 General Aspects of Dry fermentation

Pandey, (2003) studied on Solid-state fermentation, he defined Dry fermentation (DF) as a fermentation process in which digestion occurs in the absence of water while the substrate possesses enough moisture content to support the growth as well as the metabolism of microbes.

Dry AD, also referred to as high-solids or solid-state digestion, is one of the possible modes of operation of the AD process, the other being wet digestion. Dry AD is typically used to treat organic materials with high solids content, between 20% and

40%, making it particularly attractive for treatment of the organic fraction of municipal solid waste (OFMSW) and agricultural wastes (AW) (Guendouz et al., 2010)

Dry Anaerobic digestion using input material that has moisture content less than 75%. The usage of dry anaerobic fermentation has been increasing since 2005 as the technique gives both economic and environmental benefits compared to other solid waste treatment techniques such as incineration, composting, and land filling. The DAD technique is considered as superior to typical liquid-state anaerobic fermentation (LSAF) or wet fermentation because it requires a comparatively smaller volume of digester in the absence of water, does not require mechanical stirring, dewatering, or drying of the effluent, shows a higher solid loading capacity with TS contents of between 20%and 50%, high yields, better energy recovery, less wastewater generation with lesser risk of bacterial contamination, less material management, and less loss of total parasitic energy (Guendouz *et al*., 2008, Guelfo, 2010,Yabu, 2011, Kafle , 2013 and Zhou, 2017)

Dry fermentation systems require no movement of organic matter or addition of liquid. No pre-treatment of biomass or organic waste is required. Dry anaerobic digestion (DAD) is an attractive method for the stabilization of solid organic waste with high solid concentration (22–40%).

Weiland (2006) pointed out that, for dry fermentation, several batch processes with percolation and without mechanical mixing are applied mainly for mono fermentation of energy crops. The solid substrate is loaded batch wise in a gas tight fermenter box by a wheel loader and mixed with inoculum from a previous batch digestion. The necessary share of solid inoculum has to be determined individually for each substrates. While yard manure from cows requires only small ratios of solid inoculum, up to 70% of the input is necessary for energy crops (Kusch et al. 2005).

2.3.2 Comparison between dry and wet anaerobic digestion

Lissens *et al*.,2001. pointed out that wet AD occurred at a TS concentration between 10 and 15%, and dry AD occurred at a TS concentration between 25 and 40%. However, there was another opinion that dry AD reactors (ADR) were intended for digestion of substrates with a TS concentration between 20 and 40% (Rapport et al.2008; Satoto *et al*., 2009).

The dry digestion systems digest waste as received, while the wet digestion systems need to slurry the waste with water to about 12 % TS (Vandevivere *et al.,* 2002). However, from a technical point of view, the dry digestion systems appear more robust as regular technical failures are reported with wet systems due to sand, plastics, wood, and stones. Many researchers have already reported various studies on laboratory scale, pilot-scale, and full scale anaerobic digestion for the treatment of organic solid waste.

Watkins *et al.,* (2006) noted that in his research wet anaerobic digestion of solid wastes requires a lot of water, which is a challenge for countries with water shortage. Presently, there is global water scarcity; about 1.4 billion people live in river basins in which water use rates exceed recharge rates.

It is obvious that there will be competition for water as population increases and industrial development progresses. Also, the digestate residue remaining after biogas production through the wet process contains a lot of water, and dewatering of the digestate requires high energy consumption and results in loss of nutrients. Therefore, dry anaerobic digestion is a promising technology to avert these problems. Compared with the wet anaerobic digestion processes, dry-AD provides better economic feasibility because reactor volume is minimized due to the reduced volume of water (Karthikeyan *et al*., 2013; Rapport *et al*., 2008).

According to Rapport *et al*., (2008) DF is also beneficial because it is more robust, flexible in its acceptance of feed stocks which requires less pre-treatment.

Luning *et al*., (2003) conducted a research on Comparison of Dry and Wet Digestion for Solid Waste in this paper they found that, Dry AD technologies require from four to ten times (Baeten, D.*et a*l .1993) less water for dilution than wet AD technologies.

Thus, advantages for dry AD include reduced reactor volume (Li *et al.,* 2011), higher volumetric methane yields (Li *et al*., 2013), lower energy consumption for heating (Rapport, J.*et al*.,1997), a positive energy balance(Guendouz, 2010), less waste water and, consequently, lower logistics costs for fertilizers (Schäfer et al.2003 ; Baeten et al.1993), and only very dry substrates with a TS content of more than 50% require dilution (Oleszkiewicz *et al.*,1997). One of the specific advantages of dry AD is the lack of foam (Mata-Alvarez *et al.,* 2003). Using dry ADR also guarantees decontamination of the effluent. Similar to wet AD, about 30% of energy is consumed for bioreactors heating (Baeten et al., 1993).

Li, Chu, *et al*. (2013) reported that Anaerococcus species are abundant in solid-state anaerobic digestion (dry-AD) and that these species are responsible for improved degradation efficiency and methane yield.

Reduced costs for dry AD are a consequence of lower reactor volumes and savings on sorting equipment, as dry AD technologies are more stable and resistant to stones, glass, metals, plastics, and wood. The process of fermentation requires removal of only very coarse particles with a size of more than 5 cm, which reduces the costs of sorting equipment (Rapport *et al*., 1997). The main problem of dry AD systems of municipal solid waste, agricultural waste, and food waste are mixing and transportation, but not biochemical constraints. Equipment for shipping of solids, as a rule, is more expensive than that for liquids. Shipping is carried out using conveyor belts, augers, and powerful pumps, especially designed for high-viscosity flows (Mata-Alvarez et al., 2003). Perfect contact of biomass and a substrate may not be achieved due to a lack of mixing (Farrow *et al*., 2016).

According to Abbassi-Guendouz *et al*., (2012), mixing was complicated when the TS content was more than 30%. In addition, during dry anaerobic digestion, percolation was observed, and it was possible to intensify the process by adding straw and wood chips to save water, which could have led to an increase of the specific methane yield by 6% and 11%, respectively (Wedwitschka et al., 2020). Different kinds of dry fermenters are available for biogas production. Dry anaerobic digestion includes batch and continuous processes, and the applied option is determined by the actual situation.

2.3.3 Factors affecting dry anaerobic digestion system

Anaerobic digestion is a biological process. DAD depends on a wide variety of factors related to the environmental conditions and the physical characteristics of the organic matter. The rate at which the microorganisms grow is of vital importance in the DAD process. The operating parameters of the digester must be controlled so as to enhance the microbial activity and thus increase the dry anaerobic degradation efficiency of the system. Some of these parameters are discussed in the following section.

2.3.3.1 Bacteria

Methane bacteria are the key bacteria in anaerobic digestion, they are more sensitive to environmental conditions than the acid former and possess slow growth rate (Mc Carty, 1964). The classification of methanogenic bacteria according to their morphology viz. Methanobacterium, Methanococcus, Methanosarcina and Methanospirillum(Bryant 1974). The main type of acidogenic bacteria that converts protein to amino acids is the clostridium sp. (Siebelt and Toerien, 1969)

2.3.3.2 Feedstock composition

The biogas yield from anaerobic digestion of organic solid wastes depends on factors such as, the organic and nutrient contents, impurities in the feedstock, the presence of possible inhibitors (e.g. antibiotics, disinfectants, solvents, herbicides, salts, and heavy metals) , the total solids content as well as the long chain fatty acids content (Friehen et al., 2010).

2.3.3.3 Waste composition/volatile solids (VS)

It is a crucial criteria of material for biogas generation, generally 7-9 % concentration of the feed slurry is considered to be optimal for gas production. The wastes treated by AD may comprise a biodegradable organic fraction, a combustible and an inert fraction. The biodegradable organic fraction includes kitchen scraps, food residue, agricultural wastes, livestock wastes and grass and tree cuttings. The combustible fraction includes slowly degrade inorganic matter containing coarser wood, paper, and cardboard. As these organic materials do not readily degrade under anaerobic conditions, they are better suited for waste-to-energy plants. Finally, the inert fraction contains stones, glass, sand, metal, etc. This fraction ideally should be removed, recycled or used as landfill. The removal of inert fraction prior to digestion is important as otherwise it increases digester volume and wear of equipment. The volatile solids comprise the Biodegradable Volatile Solids (BVS) fraction and the Refractory Volatile Solids (RVS).

Kayhanian and Rich, (1995) reported that knowledge of the BVS fraction of waste helps in better estimation of the biodegradability of waste, of biogas generation, organic loading rate and C/N ratio. VS are an important parameter for measuring biodegradation, which directly indicates the metabolic status of some of the most delicate microbial groups in the anaerobic system. The VS reduction is measured for the continuous addition of MW and domestic sewage of high strength effluent. Elango *et al*. (2007) reported that the initial range of VS reduction is 73% only. After the continuous feeding of substrate, the VS (87%) reduce gradually.

2.3.3.4 Total solids content

Motte *et al*.,(2013) stated that the total solids content of the feedstock can affect gas yield because there is limited mass transfer if the total solids content is high and, as a result, the microorganisms are only able to decompose the substrate in their immediate environment. At very high contents ≥ 40 %, digestion can come to a complete halt as there is insufficient water available for the growth of the microorganisms. Additionally, a high content of total solids can cause problems if inhibitors are present in the feedstocks as these are present in concentrated forms because of the low water content (Friehe *et al.,* 2010).

2.3.3.5 Alkalinity and pH

Sufficient alkalinity is essential for pH control. Alkalinity serves as a buffer that prevents rapid change in pH. The alkalinity is the result of the release of amino groups and production of ammonia as the proteinaeceous wastes are degraded. Anaerobic bacteria, specially the methanogens, are sensitive to the acid concentration within the digester and their growth can be inhibited by acidic conditions. It has been determined that an optimum pH value for AD lies between 5.5 and 8.5 (RISE-AT, 1998).

As digestion reaches the methanogenesis stage, the concentration of ammonia increases and the pH value can increase to above 8. Once methane production is stabilized, the pH level stays between 7.2 and 8.2.

2.3.3.6 Volatile fatty acids concentration

VFA is important intermediate compounds in the metabolic pathway of methane fermentation and cause microbial stress if present in high concentrations. The intermediates produced during the anaerobic bio-degradation of an organic compound are mainly acetic acid, propionic acid, butyric acid, and valeric acid (Buyukkamaci & Filibeli, 2004). Amongst these, acetic and propionic acids are the major VFAs present during anaerobic bio-degradation and their concentrations provide a useful measure of digester performance.

Acetate yield is increased slightly with increasing pH, whereas butyrate yield is increased with decreasing pH. Propionate yield was found to be unrelated to pH (Hu &Yu, 2006).

2.3.3.7 Temperature

Due to the strong dependence of temperature on digestion rate, temperature is the most critical parameter to maintain in a desired range. A wide range of temperature is possible for anaerobic fermentation, usually between 3°C and 70°C. In general, three temperature ranges is common, the psychrophilic (below 20°C), the mesophilic (between 20°C and 45°C) and the thermophilic (above 45°C) ranges.

There are two temperature ranges that provide optimum digestion conditions for the production of methane i.e. the mesophilic and thermophilic ranges. The optimum temperature for mesophilic digestion is 35°C and a digester must be maintained between 30°C and 35°C for most favorable functioning. The thermophilic temperature range is between 50°C-65°C (RISE AT, 1998). A thermophilic 21°C temperature reduces the required retention time. The microbial growth, digestion capacity and biogas production could be enhanced by thermophilic digestion, since the specific growth rate of thermophilic bacteria is higher than that of mesophilic bacteria (Kim & Speece, 2002).

Usama, *et al*., (2007) studied that the rate of methane production increases with increased temperature. On the other hand, the increased temperature in turn will also increase the concentration of free ammonia. As a consequence, the process will be inhibited and the production will be reduced.

The methane formation process is extremely sensitive to temperature alternation. In general three changes in temperature ranges are accepted as still un-inhibitory effects concerning the process. The limits for fluctuation should not exceed the given ranges; there are ± 2°C/h for the psychrophiles, ± 1°C/h for the mesophiles, and ± 0, 5°C/h for the thermopiles.

2.3.3.8 C/N ratio

The relationship between the amount of carbon and nitrogen present in organic materials is represented by the C/N ratio. Microorganisms need nitrogen for the production of new cell mass. A nutrient ratio of the elements C:N:P:S at 600:15:5:3 is sufficient for methanisation. Optimum C/N ratios in anaerobic digesters should be between 20–30 in order to ensure sufficient nitrogen supply for cell production and the degradation of the carbon present in the wastes (Fricke *et al*., 2007).

Table 3. Typical C/N ratio for various materials

Raw material	C/N Ratio
Cow Dung	24
Municipal Solid Waste	40
Maize Straw	60
Rice Straw	70
Chicken Dung	10
Goat Dung	12
Water Hyacinth	25

Source: RISE-AT, 1998

2.3.3.9 Retention Time (RT)

Shefali. (2002) published a research paper onanaerobic digestion ofbiodegradable organics in municipal solid wastes, where she mentioned that the required retention time for completion of the AD reactions varies with differing technologies, process temperature, and waste composition. The retention time for wastes treated in mesophilic digester range from 10 to 40 days. Lower retention times are required in digesters operated in the thermophilc range. The RT is the ratio of the digester volume to the influent substrate flow rate. The Eq. 2.1 gives the time of substrate to be inside the digester.

$RT = V/Q$

Where,

V = digester volume (m3)

Q = flow rate (m3/d)

RT = retention time (d)

2.3.3.10. Organic Loading Rate (OLR)

Low solids AD systems contain less than 4 - 8 % Total Solids (TS) and High Solids (HS) processes range about 22% or higher TS (Tchobanoglous, 1993). An increase in TS in the reactor results in a corresponding decrease in reactor volume. The OLR is a measure of the biological conversion capacity of the AD system. Feeding the system above its sustainable OLR results in low biogas yield due to accumulation of inhibiting substances such as fatty acids in the digester slurry. In such a case, the feeding rate to the system must be reduced. OLR is a particularly important control parameter in continuous systems. Many plants have reported system failures due to overloading (RISE-AT, 1998). However, underfeeding the plant would lead to low gas production and economically ineffective process as well. Vandevivere (1999) reported that OLR is twice in HS in comparison to low solid (LS).

2.3.3.11 Solid Retention Time (SRT)

The SRT is the most important factor controlling the conversion of solids to gas. It is also the vital factor in maintaining digester stability. The solids retention time is defined by Eq.2.2.

SRT= [(V) (Cd)] / [(Qw)(Cw)]

Where,

V = digester volume (m3)

Cd = solids concentration in digester (kg/m3)

Qw = volume wasted each day (m3/d)

Cw = solids concentration of waste (kg/m3)

2.3.3.12 Mixing

Mixing, or lack of, becomes more critical in dry AD due to the high TS content (Singh *et al*., 2019). Karim *et al*. (2005) reported the necessity of mixing when TS are more than 5%, showing increases in methane production of around 20% when any form of mixing was used in 4 L lab scale reactors using cow manure slurry with a10 % TS content.

Proper mixing is one of the important guide lines for start up of the digester (Fulbert, 1967). The purpose of mixing inside the digester is to homogenize the material.

Furthermore, mixing prevents scum formation and avoids temperature gradients within the digester. However excessive mixing can disrupt the microbes so slow mixing is preferred. The kind of mixing equipment and amount of mixing varies with the type of reactor and the solids content in the digester. Complete fermentation of organic cannot occurs without actual contact of the bacteria with the feedstock (Dague, 1968). In this regards, adequate mixing is desirable for digester run to its maximum efficiency. The importance of adequate mixing is considered to encourage distribution of enzymes and microorganisms throughout the digester where MSW decomposition is carried out. Furthermore, agitation aids in particle size reduction as digestion progresses and in removal of gas from the mixture. (“Biogas technology-A training manual for extension”, FAO,1996).

2.3.3.13 Hydraulic Retention Time (HRT)

HRT is the average time spent by the input slurry inside the digester before it comes out. In tropical countries like India, HRT varies from 30~50 days while in countries with colder climate it may go up to 100 days. Shorter retention time is likely to face the risk of washout of active bacterial population while longer retention time requires a large volume of the digester and hence more capital cost. Hence there is a need to reduce HRT for domestic biogas plants based on solid substrates. It is possible to carry out methanogenic fermentation at low HRT’s without stressing the fermentation process at mesophilic and thermophilic temperature ranges. (Alemayehu, 2014).

2.4 Inhibitors or challenges of biogas production by dry fermentation

Biogas production sometimes become challenging or complete failure by different factors or inhibitors. Inhibitory problems are common to both dry and wet AD, with dry AD systems more prone to inhibitors accumulation. This is linked to the high OLR and TS content and the low or null mixing, which result in poor homogenisation (Abbassi-Guendouz *et al.*, 2012) and facilitate accumulation of inhibitors like fatty acids and ammonia (Ajay *et al.*, 2011; Chen et al., 2008; Fernandez-Rodriguez *et al.*, 2014).

At the same time, dry AD has higher tolerance to inhibitors (Dong et al., 2010; Fagbohungbe *et al.*, 2015; Nagao *et al.*, 2012), and can operate at higher concentrations of VFA or ammonia, as the inhibitors are localized due the poor diffusion in the ADs and frequently do not affect the entire reactor volume. The major challenge or inhibitors are discussed in the following subsection.

2.4.1 Ammonia Concentration

Fricke *et al*., (2007) pointed that a high concentration of ammonia may inhibit the biological process, and concentrations of this nitrogenous compound higher than 100ml inhibit methanogenesis. A wide range of inhibiting ammonia concentrations has been reported in the literature, with the inhibitory TAN concentration that caused a 50% reduction in methane production ranging from 1.7~14 g/L. The significant difference in inhibiting ammonia concentration can be attributed to the differences in substrates and inoculum, environmental conditions (temperature, pH), and acclimation periods. (Alemayehu, 2014). Therefore, methanogenic bacteria are particularly sensitive to ammonia inhibition. In order to prevent the ammonia inhibitory effect, its concentration should be kept lower than 80 mg/l (Al *et al*., 2008). Methanogens are the most prone archaea to ammonia inhibition, and their inhibition may cause a pH drop due to VFA accumulation in the ADs. Mechanisms on how ammonia toxicity occurs were explained by Kayhanian (1999), who identified two potential inhibition mechanisms. One is the inhibition of the methane synthesizing enzyme directly by the ammonium ion, and the second is the diffusion of the hydrophobic FA molecule passively into the cell causing proton imbalance or potassium deficiency.

2.4.2 Toxic Compounds

Another factor influencing the activity of anaerobic microorganisms is the presence of toxic compounds. They can be transferred to the bioreactor together with the feedstock, or generated during the AD process (Al *et al*., 2008).

Some of the toxic materials that might inhibit the normal growth of pathogens in the digester include mineral ions, heavy metals and detergents. However, low concentrations of the mineral ions, such as sodium, potassium, calcium, magnesium, ammonium and sulphur, are needed for stimulation of bacterial growth. At the same time, if the concentration of these ions were too high, it would lead to toxification. Addition of substances including soap, antibiotics, organic solvents, etc should be avoided, since this would lead to inhibition of the activity of methane producing bacteria (Usama *et al*., 2007).

2.4.3 Intermediate Products

The stability of the AD process is proved by the concentration of intermediate products, like volatile fatty acids (acetate, propionate, butyrate, lactate), produced during acidogenesis. For example, animal manure has a surplus of alkalinity, which means that the accumulation of volatile fatty acids should exceed a certain level before this can be detected, due to a significant decrease of pH (Al Seadi *et a*l., 2008). Short chain fatty acids, also known as VFA, are intermediate compounds produced in the hydrolysis step, consequence of the breaking down of more complex structures like long chain fatty acids. The main VFA present in the media during the AD process are acetic, butyric and propionic acids, which are commonly accumulated at the start up period in the ADs (Massaccesi *et al.*, 2013).

Inhibition of the AD process occurs when VFA are produced in the hydrolysis step at a faster rate than they are assimilated by acetogenesis or methanogenesis, which results in a pH drop and inhibition of the methanogenic archaea (Guendouz *et al.*, 2010). Generally, the inhibitory effect of VFA starts at levels of more than 2000 mg/l for acetic acid or 8000 mg/l for total VFA (TVFA) (Karthikeyan and Visvanathan, 2013).

Kusch et al. (2012) reported a drop in pH when VFA production peaked at the beginning of the run when digesting MSW in dry batch ADs with different percolate reticulation strategies, only observing an increase to a stable pH value of 7.5 when the VFA concentration in the different ADs dropped below 2000 mg/l (Fagbohungbe *et al.*, 2015).

The low or null mixing conditions at which dry ADs are operated and the high TS content, can frequently lead to poor solid liquid mass transfer and accumulation of VFA in some localized areas, not affecting the totality of the methanogenic archaea but producing localized inhibition (Dong *et al.*, 2010). This lack of diffusion and contact often contributes to the instability of the process, and contributes to the longer reaction times required in dry AD, but some authors (Fagbohungbe et al., 2015) reported some benefits. The poor diffusion through the media can in practice mean that dry AD can be operated at higher VFA concentrations than in wet AD, as VFA are getting in contact with methanogens in a steady and slow flux, avoiding the pH shock and inhibition.

2.4.4 Temperature fluctuations

Temperature fluctuations affect the performance of a biogas process adversely because the activity of the microorganism is reduced if temperature is above or below their optimum range. A decrease in temperature may result in a reduced volatile fatty acid production rate, substrate decomposition rate, and metabolic rate of the microorganism (Bowen *et al*., 2014).

Navickas *et al*., (2013) investigated the influence of temperature variations on the performance of anaerobic digestion of industrial wastes and observed that a change in temperature from 52 °C to 57 °C (at constant total solids concentration, organic load, and pH) resulted in a 24 % reduction in biogas yield. The degradation rate is higher thermophilic processes, however they are more sensitive to changes in temperature (Song, Y.-C.,2004) and moreover, they require increased energy input to maintain a stable temperature.

2.4.5 Organic content and nutrients

The organic content and the nutrients present in the feedstock affect the rate of growth and the activity of microorganisms. Microorganisms are dependent on macro and micro nutrients, trace elements, and vitamins for their growth, and these are vital for effective conversion of organic matter to methane (Angelidaki *et al.*,2009).

Friehe *et al*., (2010); Bachmann *et al*., (2015) reported that excess availability of nitrogen during the degradation leads to the formation of NH3, which inhibits microbial growth at higher concentrations, and its deficiency causes the biogas process to fail.

2.4.6 Impurities in the feedstock

Barjenbruch *et al*., (2000) reported that clean feedstock is important among others for the quality of the digestate residue and for the overall efficiency of the anaerobic digestion process. Inadequate preparation of feedstock before feeding can lead to blockage of gas pipes and the formation of foam in the reactors, thereby causing a significant reduction in biogas yield and a great effect on the overall digestion process. Additionally, inhibitors (e.g. antibiotics, disinfectants, solvents, herbicides, salts, and heavy metals) that enter the reactor through the feedstock can slow the process, or the accumulation of inhibitors in the reactor can lead to the death of the microorganisms at high concentrations.

2.4.7 Long chain fatty acid content

Lipid-rich wastes such as wastes from slaughterhouses, oil processing industry, dairy product industry, and wool scouring contain high methane content compared to carbohydrates and proteins-rich wastes (Hanaki *et al*., 1981). These waste streams are easily degraded to glycerol and LCFAs; excessive amount of LCFAs could inhibit the activity of the microorganisms thereby resulting into low biogas yield or failure of the process. Angelidaki *et al*.(1992) investigated the effect of long chain fatty acids in cattle manure under a thermophilic biogas process and observed that low concentrations of oleate and stearate acid inhibited all steps of the anaerobic digestion. Dasa, Westman *et al*.,(2016) also reported that palmitic and oleic acids with concentrations of 3.0 and 4.0 g/l, respectively, resulted in > 50 % inhibition of biogas production and that stearate acids had an even greater inhibitory effect.

2.4.8 Foam formation

Foam is a dispersion of gas in liquid consisting of a large proportion of gas, and its formation in anaerobic digestion processes is a major challenge for plant operators (Vardar *et al.,* 1998). The presence of surface active substances such as volatile fatty acids, oil, grease, detergents, proteins, particulate matter (grit, metals, sand, etc.) (Ganidi *et al.* 2009; Brown *et al.,*2002) is the major cause of foam formation. Reactors operated with a high organic loading rate are more prone to foaming because at higher loading rate the organic compounds are not fully degraded (Moen et al., 2003). Excessive mechanical mixing also increases the amount of bubbles in the bulk phase, enhancing the attachment of surface active and hydrophobic compounds and thereby causing foaming (Scardina *et al.,* 2006).

2.4.9 Reactor design

Anaerobic reactors for biogas production also pose some challenges to the effectiveness of the biogas process depending on the process configurations and operating conditions of the reactors. A reactor may be suitable and economical for a particular type of feedstock or co-substrate but may not be suitable for another. Therefore, for overall effectiveness of the biogas production process, reactors must be selected with consideration of the feedstock composition, amount of feedstock to be treated, desired product, and process economy (Patinvoh *et al.,* 2017).

Tale 4: Co-digestion of solid wastes for improved biogas production (modified from Luque, R., *et al*., 2016)

Feedstocks	Effect of co-digestion	Influencing factor	Reference
Food, vegetable, fruit, leaf and paper wastes	Reduced ammonia-nitrogen inhibition	C/N ratio	Zeshan *et al*., 2012
Crops (grass silage, oat straw, and sugar beet tops) and cow manure	Increased methane yield Increased VS removal	Mixing ratio	Lehtomäki *et a*l., 2007
Solid energy crops and pig manure	Enhanced process performance Increased plant capacity	High buffering capacity	Lindorfer *et al*.,2008
Fresh vegetable and precooked food wastes	Increased methane production yield and rate	Dilution to non-inhibiting initial concentration Synergetic effect	Carucci *et al*.,2005
Cattle manure with wheat straw	Increased methane yield	C/N ratio	Patinvoh *et al*.,2017
MSW, manure, crop residues, and slaughterhouse wastes	Increased methane yield	High buffering capacity (synergetic effect	Pagés *et al*.,2011
Yard and food wastes	Increased methane yield and volumetric productivity Increased VS reduction	Mixing ratio (C/N ratio)	Brown *et al*., 2013

Paper tube residues and nitrogen-rich substrate mixture	Stabilized the process Reduced HRT Reduced VFA accumulation	High buffering capacity	Teghammar *et al*.,2013
Crop silage and cow manure	Increased methane yield Allowed higher organic loading rate	Mixing ratio	Comino *et al.*, 2010

2.6 Biogas from different waste

In most of cities and places, kitchen waste, market waste agricultural waste is disposed in landfill or discarded which causes the public health hazards and diseases like malaria, cholera, typhoid. Inadequate management of wastes like uncontrolled dumping bears several adverse consequences: It not only leads to polluting surface and groundwater through leachate and further promotes the breeding of flies, mosquitoes, rats and other disease bearing vectors. Also, it emits unpleasant odour & methane which is a major greenhouse gas contributing to global warming, so by using this waste with measured chemical we can produce gas from this (Suni *et al.,*2013).

Table 5: Biogas production rate and methane yield of the anaerobic co-digestion of different types of organic waste

Substratum	**Co-Substrata**	**Biogas production rate [l d-1]**	**Methane yield [l kg-1 VS]**	**Comments**	**References**
Cattle excreta	Olive mill waste	1.10	179	Co-digestion produced 337% higher biogas than excreta.	Goberna *et al.,* (2010)
Cattle manure	Crop waste and energy crops	2.70	620	A significantly increased biogas production from co-digestion was observed.	Cavinato *et al.,* (2010)

Fruit and vegetable waste	Abattoir wastewater	2.53	611	The addition of abattoir wastewater to the feedstock increased biogas yield up to 51.5%	Bouallagui *et al.*,(2009a)
Fish and biodiesel waste	Pig manure	16.4	620	A higher biogas production rate was obtained from co-digestion.	Alvarez *et al.*,(2010)
Potato waste	Sugar beet waste	1.63	680	Co-digestion increased methane yield up to 62%, compared with the digestion of potato waste.	Parawira *et al.* (2004)

2.8 Digestate as bio-fertilizer

Digestate is the residue remaining after biogas production by anaerobic digestion of organic wastes. The organic wastes used as feedstock for biogas production contain some macronutrients (nitrogen, phosphorus, potassium, calcium, sulphur, and magnesium) and micronutrients (boron, chlorine, manganese, iron, zinc, copper, molybdenum, and nickel), and additional nutrients/trace elements are sometimes added to enhance the digestion process. As these feedstock degrade during the digestion process, the nutrients are released and concentrated in the residue (Schnürer, A., *et al.*,2010); therefore, the digestate residue is a valuable fertilizer which contains most of the macronutrients and minor nutrients in plant-available form. This residue after biogas production can result in similar or even better crop yields than obtained by using commercial fertilizers (Debosz, K., *et al.*,2002).

2.8.1 Composition and quality of digestate

The composition of the digestate or slurry determines its quality, and this varies from one biogas reactor to another. The nutrients content of the digested i.e. its composition depends on the composition and nature of the feedstock, TS content of the feedstock, process conditions, and pre-treatment methods.

Debosz *et al*., (2002) pointed out in his research that most of the nutrients in the feedstock end up in the digestate. The nutrients content of the digestate can be controlled by regulating the composition of the feedstock and as such the feedstock should be free of heavy metals (Cadmium, Lead and Mercury) which in higher concentration are toxic to plant growth (Kupper *et al.*, 2014; Govasmark *et al*., 2011).

Risberg, (2015) in his study observed that the most suitable feedstock for biogas production with digestate used as fertilizer are animal manure, crops, the organic fraction of MSW, vegetable by-products and residues, and wastes from agriculture, horticulture, and forestry. Furthermore, during co-digestion of different feedstocks, there may be variations in the digestate nutrients compared to those of mono-digestion

2.8.1.1 TS content of the feedstock

The higher the TS in the feedstock, the higher the TS in the digestate residue. Digestate with higher TS contains larger amounts of carbon and nitrogen that can be broken downfurther in the soil, which in the long-run results in the release of more nutrients (Risberg et al 2015) .

2.8.1.2 Process conditions

The retention time for the feedstock inside the reactor, at constant process temperature, influences the digestate quality (Al *et al.*, 2012). If the organic loading rate of the anaerobic digestion process is high and the retention time is short, the digestate might contain a large amount of undigested organic matter, which is not economical (Makádi *et al.*, 2012). The waste may sometimes be heated at a lower temperature but for a longer time prior to mesophilic or thermophilic digestion aiming to achieve similar effects (Bendixen, 1999).

2.8.1.3 Pre-treatment methods

After anaerobic digestion, the material usually requires refining before it can be used for fertilizer or soil amendment. If the MSW is treated in a dry process, the digested material is usually dewatered and matured to compost. Recalcitrant feedstocks are often pretreated to enhance digestibility and thereby improve AD performance. However, the pretreatment method should be mild and must not generate inhibitors or retain chemicals that can have a negative effect on the quality of the digestate.

2.8.2 Benefits of digested as fertilizer

Improved quality of soil: Digestate has some active microorganisms which increase the biological activity of the soil and enhance the formation of microscopic biofilms within the soil. The microorganisms in soil are mostly heterotrophic (use organic carbon as a source of carbon and energy), and the use of digestate stimulates the growth of these microorganisms in soil, thereby facilitating nutrient mineralisation for plant uptake and protection of plants against disease (Odlare *et al*., 2008). Digestate increases the buffering capacity of soil and enhances retention of water and air in the soil profile (Schnürer *et al*.,2010).

During anaerobic digestion of organic wastes, organic nitrogen is converted to ammonium nitrogen, so the digestate residue contains a high proportion of mineralised nitrogen, especially in the form of ammonium, which is available for plants. It also contains other macro- and micro-elements essential for plant growth (Makádi *et al*., 2012; Möller *et al*., 2012).

Properly applied, organic fertilizers can improve the health and productivity of soil and plants, as they provide essential nutrients to encourage plant growth. Organic nutrients increase the abundance of soil organisms by providing organic matter and micronutrients for organisms, such as fungal mycorrhiza, which aid plants in absorbing nutrients. The organic matter benefits crop production via increases in soil water-holding capacity, water infiltration rates, cation exchange capacity, structural stability, and soil tilth. They can drastically reduce external inputs of pesticides, energy and fertilizer, at the cost of decreased yield (“Biogas technology-A training manual for extension”(FAO, 1996).

2.9 Potentials of Biogas Production from Organic Waste

According to a biogas producing company (Home undated), 1 kilogram of food waste can produce an average of about 200 liters (7 cubic feet or 0.2 cubic meter) of gas, which can fuel an hour's worth of cooking over a high flame, so with a full daily input of 6 liters of organic waste, the company's units can produce several hours of cooking gas each day, and can help homes eliminate one ton of organic waste each year, and avoid generating the equivalent of 6 tons of CO2 annually.

Ogur and Mbatia, (2013), stated that, One kg of kitchen waste in 24 hours can produce the same amount of biogas as 40 kg of cow dung in 40 days. That means more than 400 times efficiency can be achieved by using kitchen waste as compared to cow dung.

Ngumah. *et al*., (2013) elucidates the potential benefits of organic waste generated as a renewable source of biofuel and bio-fertilizer.The selected organic wastes studied in this work are livestock wastes (cattle manure, sheep and goat manure, pig manure, poultry manure; and abattoir waste), human manure, crop residue, and municipal solid waste (MSW). They explained that this potential biogas yield will be able to completely replace the use of kerosene and coal for domestic cooking, and reduce the consumption of wood fuel by 66%. It was recommended that an effective biogas program in Nigeria will also remarkably reduce environmental and public health concerns, deforestation, and greenhouse gas (GHG) emissions.

Sambo. *et al.,* (2015) carried out experiment on biogas production from co-digestion of selected agricultural wastes. Using a slurry of 1 kg mixture of agro-waste feed stocks (plantain peel/rice husk, PP/RH; banana peel/plantain peel, BP/PP; and banana peel/rice husk, BP/RH) in 1:1 ratio was co-digested in locally fabricated digesters (10 L capacity). The experiment was run for 50 days and assessed for proximate content, biogas generation, organic matter, and mineral content in the digested and undigested agro-waste materials. The proximate composition showed that while banana peel had the highest moisture (56%), rice husk was highest in the content of ash (64%), crude protein (6.94%), and volatile solids (20%). The weekly cumulative biogas generation increased from 852.6 cm3 for BP/PP sample to 1049.7cm3 for PP/RH sample for the 7 weeks at the experimental room temperature range of 29 ^{o}C to 35 ^{o}C. Sample PP/RH generated the highest volume of gas (biogas, methane, and others) compared to BP/RH and BP/PP samples. In each case the volume of gas production decreased in week 7 from 271.4 cm3 to 152.0 cm3 (for biogas), 161.4 cm3 to 97.1 cm3 (for methane), and 110.0 cm3 to 54.9 cm3 (for other gases). The nutritional concentrations of the digested and undigested mixture of the waste samples after Atomic Absorption Spectrophotometer (AAS) and Flame Photometry showed that the digested samples had higher contents of the nutritional elements than the undigested samples. The mineral elements ranged from 0.554 mg in the undigested rice husk to 18.155 mg/g in the digested banana peel samples. They concluded that fermentation of agricultural wastes to generate biogas and sludge with agricultural value offers an alternative and efficient method of agricultural wastes and energy management.

2.10 Biogas potential in Bangladesh

Bangladesh produces huge amount of municipal solid waste i.e. kitchen waste, poultry waste, sewage sludge, cow manure, agriculture residues, food scrap, etc. The municipal solid generation capacity of Bangladesh on daily basis was 0.5 Kg/capita/day (Zurbrügg *et al.,* 2006). In Bangladesh, disposal of municipal solid waste (MSW) is a major concern in large cities from the management perspective. These wastes are always damped in the open land field and river which pollutes environment seriously and causes the public health disease like malaria, cholera, typhoid etc. Biogas mainly from animal and MSW may be one of the promising renewable energy resources for Bangladesh. MSW contains an easily biodegradable organic fraction (OF) of up to 40%. It is a potential source to harness basic biogas technology for cooking, rural and peri-urban electrification to provide electricity during periods of power shortfalls. On feasibility study prepared for the Danish investors about the market potential of Bangladesh it has been indicated up to 800 MW of electricity could be produced in Bangladesh using organic city waste and poultry litter. 12 gasification-based biogas plants equivalent to 5 MW capacities are now being considered by donor-financed IDCOL. As on 2012, only a fraction of the total of 15,000 tons of waste is being recycled annually. About 80% of produced waste is organic which have a high potential for biogas production. The amount is expected to rise up to 47,000 tons in 2025 (Bhowmik *et al.,*2013).

Bangladesh is predominantly an agrarian economy. Agricultural sector still dominates the economy accommodating major rural labor force. As an agricultural country, Bangladesh has embedded with plenty of renewable sources of energy and has huge potentials for utilizing biogas technologies. During winter seasons, huge amounts of vegetables are cultivated in our country which will be a potential source of kitchen waste (KW). Due to lack of efficient transportation and preservation, huge amounts of vegetables are wasted, which may be a source of biogas (Islam et al., 2009).

2.11 Economic, and social benefits of biogas production

Taleghani and Kia, (2005) outlined the economic, and social benefits of biogas production. The economic benefits were as follows:

- Treatment of solid waste without long-term follow-up costs usually due to soil and water pollution

- Decreased local distribution of fertilizer, chemical herbicides, and pesticide demand
- Generation of income through compost and energy sales (biogas/electricity/heat) to the public grid
- Improved soil/agriculture productivity through long-term effects on soil structure and fertility through compost use
- Reduction of landfill space and consequently land costs
- The social and health effects associated with biogas include:
- Creation of employment in biogas sector
- Improvement of the general condition of farmers due to the local availability of soil-improving fertilizer
- Decreased smell and scavenger rodents and birds.

2.11.1 Environmental Sustainability of Biogas Production Organic Waste

The use of organic wastes to produce biogas enhances environmental sustainability. Biogas production from organic wastes reduces the need for fuel wood and fossil fuel for cooking thereby improve energy efficiency and environmental performance in place of conventional raw materials (Martin and Eklund, 2011). Through the production of biogas, industrial by-products, agricultural and household wastes are given added value rather than been disposed to the landfill.

2.11.2 Economic Sustainability of Biogas Production Organic Waste

Economic sustainability "concerns the specification of a set of actions to be taken by present persons that will not diminish the prospects of future persons to enjoy levels of consumption, wealth, utility, or welfare comparable to those enjoyed by present persons" (Bromley, 2008). Sustainability interfaces with economics through the social and ecological consequences of economic activity (Costanza and Patten, 1995). Economic sustainability of biogas production from organic waste is in its ability to: Provides cheaper energy and fertilizer; provision of additional income to farmers; creation of job opportunities; decentralization of energy generation and environmental protection and others.

2.11.3 Social Sustainability of Biogas Production Organic Waste

The general definition of social sustainability is the ability of a social system, such as a country, to function at a defined level of social wellbeing indefinitely. That level should be defined in relation to the goal of *Homo sapiens*, which is (or should be) to optimize quality of life for those living and their descendents. Social sustainability of biogas production from organic waste is that it create time for social activities by reducing time spent on waste disposal and fetching of fuel wood mostly by women and children. It is also smoke-free and ash-free kitchen, so women and their children are no longer prone to respiratory infections which is capable of eliminating the affected person(s).(http.thwink.org/sustain/glossary/SocialSustainability.htm).

Sustainability issues are generally expressed in scientific and environmental terms, as well as in ethical terms of stewardship, but implementing change is a social challenge that entails, among other things, international and national law, urban planning and transport, local and individual lifestyles and ethical consumerism (Billon, 2005). Broad-based strategies for more sustainable social systems include: improved education and the political empowerment of women, especially in developing countries; greater regard for social justice, notably equity between rich and poor both within and between countries; and intergenerational equity. Depletion of natural resources including fresh water increases the likelihood of “resource wars” (Kobtzeff, 2000).

CHAPTER-3

MATERIALS & METHODS

CHAPTER 3

MATERIALS AND METHODS

3.1 Experimental site

The Experiment was conducted at SAU Animal farm, and at the laboratory of the Department of Animal Production and Management (Animal Science), Faculty of Animal Science and Veterinary Medicine at Sher-e-Bangla Agricultural University, Sher-e Bangla Nagar, Dhaka-1207, Bangladesh, during the period August 2020 to December 2020.

3.2 Experimental materials

3.2.1 Plant description

Horizontal reactors for batch dry anaerobic digester process were used in this study. The reactor was operated under mesophilic conditions.

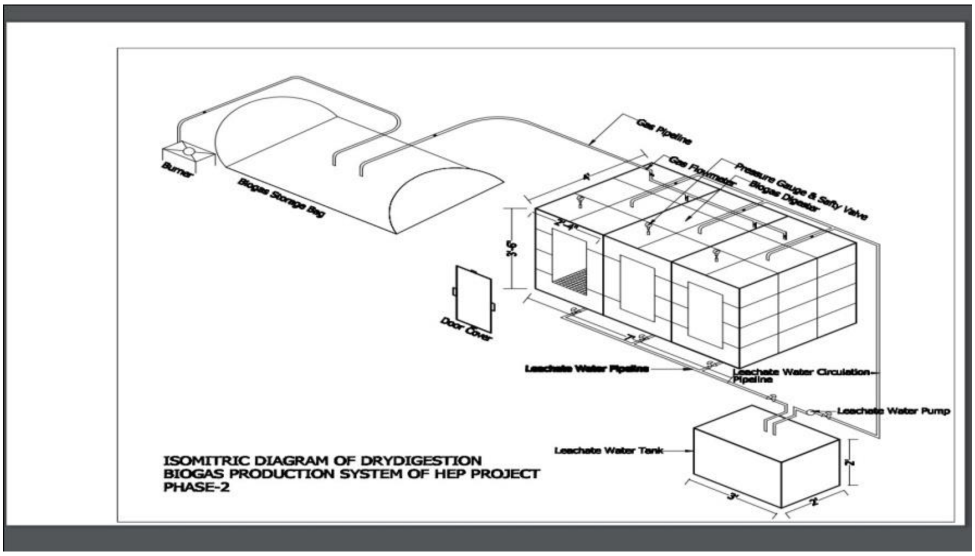

Figure 3: Isometric diagram of dry digestion Biogas Production System

☐	Length	7.5ft
☐	Breadth	3.5 ft
☐	Height	4 ft
☐	Mouth/gate	2 ft x 2ft
☐	Plant weight	450kg

In this research, the biogas plant was built in Sher-e-Bangla Agricultural University, Sher-e Bangla Nagar, Dhaka. The local agricultural waste, kitchen waste and market waste were used as fermentation raw material.

This biogas production system consists of the following features:

a) Digester

This is the reservoir of organic wastes in which the substrate is acted on by anaerobic micro organisms to produce biogas.

b) Pipe

PVC pipe for connection with digester and gas storage bag. The connection between the pipe and the digester must be air tight.

c) Gas Storage

Depending on the proposed design, this is a large leak proof plastic bag. Gas holding capacity around 3m3

d) Gas Burner

This is a regular burner for cooking.

e) Exhaust outlet

This consists of a pipe of similar size to the gas pipe connected to the under the digester to facilitate outflow of exhausted leachate into container.

3.2.2 Experimental Equipment

- pH meter
- Stress tape
- Drum / container
- Balance
- Petridish
- Oven
- Water bottle
- Measuring cylinder
- Beaker
- Small leak proof plastic bag for gas testing
- Polythene

- Hand gloves
- Thermometer
- Bucket

3.2.3 Experimental Chemicals

- Lime
- Sodium bicarbonate ($NaHCO_3$)

3.3 Experimental design

A 3-chamber dry anaerobic digester made of mild steel is fabricated in Advance Engineering work shop at Dhaka Uddayan. Leak- proof test has been done using vacuum system and found to be leak- proof. The digester has been shifted from Dhaka Uddayan to Sher-e-Bangla Agriculture University.

Experimental method includes the collection and preparation of kitchen waste, agriculture waste, market waste, cow dung (CD) and determination of the initial properties of collected raw materials, preparation of slurry with desire concentration, charging of digesters and recording of the experimental data.

Table 6: Experimental Setup

Treatment	**Kg of feedstock (digester – wise)**		
	D_1	**D_2**	**D_3**
T_1	300	300	300
T_2	300	300	300
T_3	300	300	300

Note: **D_1**=Digester 1, **D_2**=Digester 2, **D_3**=Digester 3, **T_1**= Treatment 1 (Kitchen waste + Cow dung + Urine), **T_2**= Treatment 2(Agricultural waste + Cow dung + Urine), **T_3**= Treatment 3(Market waste + Cow dung + Urine)

Table 7: Each experimental setup amount of feedstock

Treatment 1	Amount (kg)	Treatment 2	Amount (kg)	Treatment 3	Amount (kg)
KW	200	**AW**	200	**MW**	200
Cow Dung	65	**Cow Dung**	65	**Cow Dung**	65
Urine	35	**Urine**	35	**Urine**	35
Total	**300**		**300**		**300**

Note: **KW**= Kitchen waste, **AW** = Agricultural waste, **MW**= Market waste

3.3.1 Designing and fabrication of digester

The study was carried out in a compact biogas plant of storage tank for digester where its upper part was slightly perforate to place the gasholder. The gas pipe, which is a bit longer fitted with digester tank by gas holder and connected with gas storage bag. Exhaust outlet pipe was fitted into the bottom of digester tank to drainage.

3.4 Collection, segregation, and chopping of solid wastes

The four different waste (kitchen waste, agricultural waste, Market waste and cow dung) used, was collected from their different waste generation. The cow dung used throughout this project was collected from the Animal farm at Sher-E-Bangla Agricultural University, Sher-E Bangle Nagar, Dhaka cow's corral while the kitchen waste market waste was collected from different staff quarter within and around the university campus. We provide two polythene bags, so that they can kept separately perishable and non perishable wastes. The fruit waste was gotten from fruit selling areas around university, it comprises of orange, banana, and pineapple peels. The agricultural waste was collected from the SAU agriculture field. In the course of the collection of the waste, necessary health precaution was taken by wearing hand gloves and nose cover. All types of biodegradable solid wastes except very acidic and hardly decomposed were collected from household. They were sorted out, weighed and chopped into smaller ones of size 10-20 mm to allow ease of bio- degradation.

3.4.1 Collection of kitchen waste:

Kitchen waste collected from twenty flats of chameli building in sher-e bangle agricultural university campus to determine the quantity of wastes per flat and the percentage of perishable and non-perishable wastes. 40 (Forty buckets) were supplied to 20(Twenty) flats, each flat having two buckets; one for perishable wastes another one for non- perishable wastes. Perishable wastes were collected for biogas generation and non- perishable wastes were kept in city corporation waste collection station.

Table 8: Types of kitchen waste

Fruit waste	Vegetable waste	Cooked waste	Other perishable uncooked waste
Water melon waste, banana peel, orange peel, musk melon waste, apple	Cucumber, carrot, papaya, sojina leaf, different vegetable leaf, tomato, cabbage.	Discard rice, bread, fish, chicken and beef	Entrails and unwanted portion of fish , egg, chicken and beef etc.

3.4.1.1 Composition of collected kitchen waste

Total composition of kitchen waste was analyzed on various occasions are added on Appendix 1. Appendix1. Show that in kitchen waste 200 kg perishable waste and 19.20 kg non perishable waste was found. In 200 kg perishable waste over 25 % of waste was composed of uncooked waste (eggs, raw meat, raw fish waste, paper the main source of pathogens), vegetable wastes 17%, fruit waste around 29%, 30% of cooked waste (cooked meat, leftover rice, bread, cheese, discard food tea bag) was there.

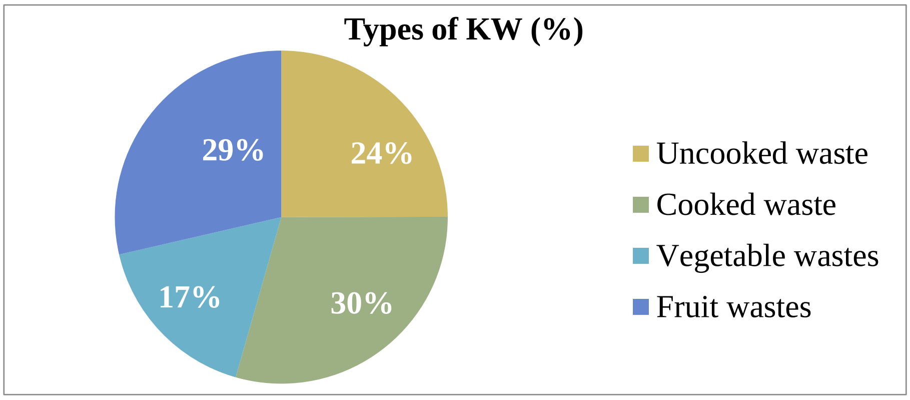

Figure 1: Types of collected kitchen waste (%)

3.4.2 Collection of agricultural waste

Agriculture waste was collected from the SAU, agricultural land. Different types of agricultural waste were collected for biogas production.

Types of agricultural waste:

-Cabbage and Broccoli waste

-Maize leaf,

-Tomato,

-Paddy straw,

- Leafs of different types of vegetable & plants etc.

3.4.2.1 Composition of collected agricultural waste

From the Appendix 2 calculated that agricultural waste collected from farm land around 56% was maize leaf, 19% paddy straw, 13% cabbage and broccoli waste, 6% tomato waste and 6 % vegetables.

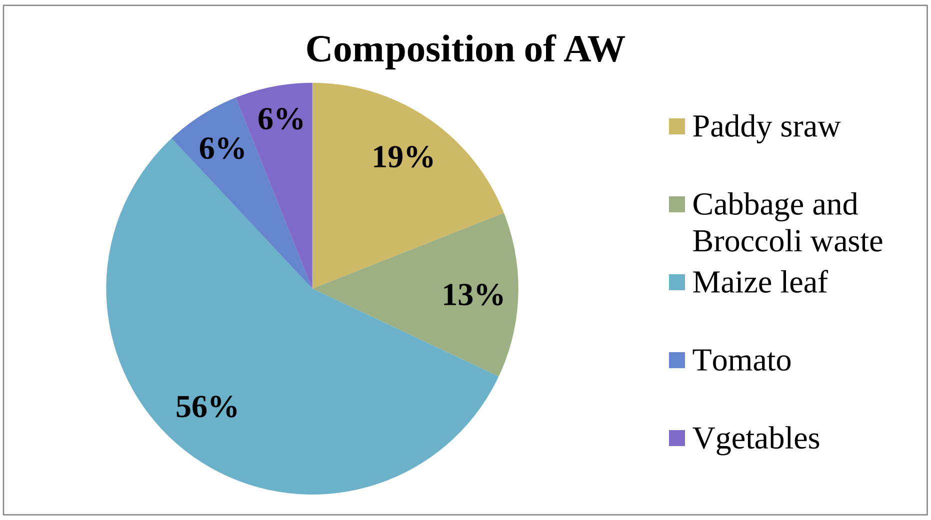

Figure 5: Types of collected agricultural waste (%)

3.4.3 Collection of market waste

Market waste was collected from nearer market area of university. Market waste was comprised of-

-rotten tomato, pumpkin, cucumber, rotten potato, onion waste,

-different types of vegetables (banana waste, steam amaranth leaf, bottle gourd red spinach etc)

-fish waste, rotten egg

-Livestock waste (faeces, feathers, feed waste)

-Hotel and restaurant waste. After collection of market waste were sorted out different waste, chopped and then taken weight. Market waste mixed together and kept for further treatment.

3.4.3.1 Composition of collected market waste

Market waste was collected from the local market comprised of around 55% different vegetable waste, potato waste 22%, rotten egg 2%, fish waste 2%, livestock waste 3%, pumpkin 6%, discard cucumber 2%,onion peel 2% and 12% hotel and restaurant waste calculated from Appendix 3.

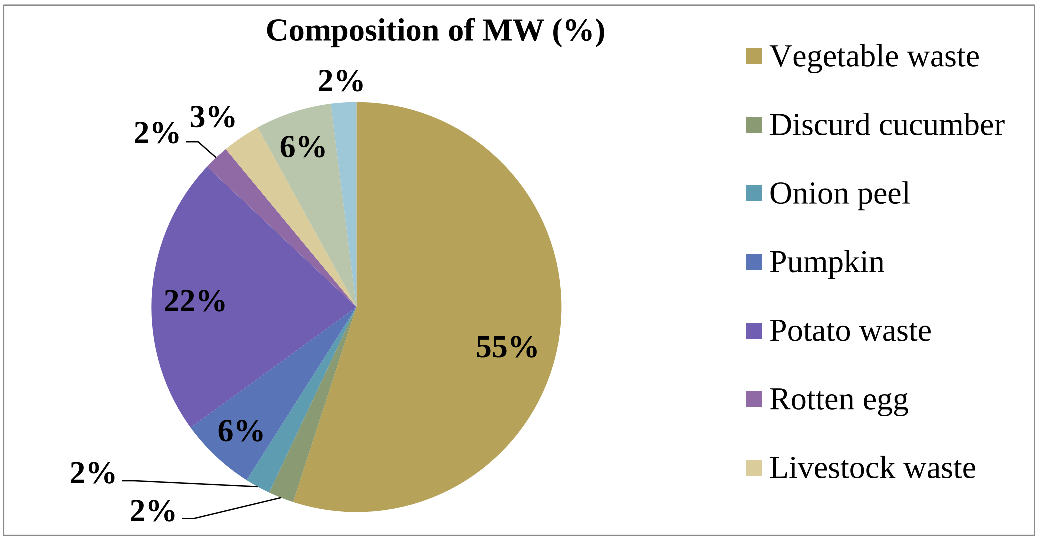

Figure 6: Types of collected market waste (%)

3.5 Pretreatment of collected raw materials

Pretreatment of the substrate is needed either for making it easier to handle at the biogas plant or for altering its structure for easy degradation, hence enhancing its methane production potential. The most suitable pretreatment methods for agricultural, kitchen wastes and MW are reduction (10-20mm) of particle size and mixing of the feedstock. It can also reduce viscosity in biogas reactors making mixing easier. Pretreated the chopped waste particle with (5-10) % inoculum (cow dung, urine), then mixed properly those wastes with cow dung and then kept the wastes for

7 days for aerobic digestion. Those 7 days acts as a pre-digestion time because in this time microorganism inside the cow dung help to digestion and enhance methane production.

3.6 Preparation of digestion chamber or digester

The digestion chamber or digester was air tight. The leak was checked properly.

3.6.1 Digester start-up phase

The digester was initiated with the 200 kg of waste for each of the treatment group. The total capacity of digester was 400kg of waste and the total weight of the waste fed including inoculums was 300 kg per digester and requisite amount of inoculum. The reactor was operated in batch mode for 7 weeks for gas production. The inoculum was comprised of cow dung, urine of cow. Homogenization of fresh wastes with inoculums was done properly before feeding into the system. To avoid the risk of thermal shock inside the reactor, the reactor was started with mesophilic temperature 30-38°C. The main feature of this system was to avoid the use of leachate for the mixing. To enhance the biodegradability of the substrates, the mixing was performed by circulating the waste inside the reactor.

3.7 Parameter studies

The day to day work schedule and data observations were as follows:

- Regular loading of feedstock
- Gas generation volume
- Total solids
- Volatile solids
- pH

3.7.1 Gas volume

The daily evolved gas was collected in the large plastic bag. The gas bag raised up due to the pressure developed by gas. The daily raise of the gas bag was measured. The gas accumulated daily in the bag was released after recording.

3.7.2 pH

The pH of the sample was measured by the digital pH meter (Model H12211pH/ORP Meter). It displayed the pH in digits directly.

3.7.3 Laboratory Analysis

The chemical parameters such as pH, total solid, volatile solid both fresh waste and slurry were subjected to solid analysis. Solid waste analysis was conducted before feeding into the digester and after withdrawing the digestate from digester.

3.7.3.1 Determination of Moisture content (MC %)

At first washed a petridish and then dried it an oven at 105°C after that petridish was cool down in desicator and weighted in a Balance. The percent moisture of the samples was determined by weighing 10 g of the samples and grinding at 1-2 mm into a pre-weighed dish and drying the samples in an oven at 105 °C for 24 hours to a constant weight. The percent MC were calculated using following equation. The analysis was conducted in duplicates.

% MC = [(Initial Weight – Final Weight)/ Initial Weight] x 100%

3.7.3.2 Total Solids (TS %)

After determining the moisture content, the samples were further tested for Total Solid content (%) as explained in the section that follows. The percent TS were calculated by using following equation.

%TS = 100% - %MC

3.7.3.3 Volatile Solid (VS %)

The volatile solid content was determined by the method of ignition of the sample at 550 °C for 1 hour. The same sample as was determined for moisture content and total solid (%) was used for determining volatile solids. The dried samples were pulverized into fine solids and were mixed properly to ensure homogeneity. After that the pulverized sample were weighed for 2 grams and were placed on several evaporating dishes. Then the sample was evaporated for at least 1 hour at 550°C in the muffle furnace. After drying the sample was placed into desiccator for cooling and was weighed immediately by using analytical balance. Thus volatile solid was calculated using following equation.

$\% \text{ VS} = W_1 - W_f / W_1 - W_e \times 100\%$

Where,

W_1 = weight of sample and evaporating dish after 105 °C

W_f = weight of sample and evaporating dish after 550 °C

We = weight of empty dish

3.7.3.4 Ash and fixed Carbon content

Ash content of the samples waste was determined by heating the samples in an oven at 750 °C (ASTM 3174). The residue left after combustion represents the ash content (%). Fixed carbon was determined by the following (Eq 3.4):

Fixed Carbon (% weight) = 100 – weight (% moisture content + % Ash +% volatile matter)

3.7.3.5 Macro Nutrient analysis

The nitrogen and phosphorus contained in the kitchen waste, agricultural waste and mixed waste are sufficient to satisfy the cell growth requirements during biogas production (Elango et al, 2007). The others elements, such as sodium, potassium, calcium, magnesium and iron are present in low concentrations. However, they may exhibit inhibitory effects at higher concentrations. Nutrient concentrations vary in most organic wastes. So its analysis is essential to provide proper environmental conditions for microbes inside the reactor. Both fresh wastes and digestate were analyzed for nitrogen (N), phosphorus (P), and potash (K) as they are major nutrient constituents in waste.

3.8 Leachate characteristics analysis

To measure the performance of the feedstock pH and Alaklinity was tested regularly. Checking those parameters is very important for biogas production because pH and alkalinity affect the microbial growth of methane producing bacteria.

3.9 Biogas analysis

Gas sample was collected to determine the composition of gas from each three setup nine times. Gas samples were collected by gas sampling injectors in plastic air tight bag and a sample of 2000ml was used for each run. The biogas composition (CH_4+ CO_2 and other gas) was determined by Institute of Fuel Research and Development (IFRD) at Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhaka, Bangladesh.

3.10 Bio-slurry or bio fertilizer

Bio-slurry or digestate is the solid remains of the original input material to the digesters that the microbes cannot use. It also consists of the mineralized remains of the dead bacteria from within the digesters. Digestate can come in three forms: fibrous, liquor, or a sludge-based combination of the two fractions.

3.10.1 Digestate from dry digestion process

In this study, the digestate residue remaining after dry anaerobic digestion of three experimental group T_1 (KW+CD+Urine), T_2 (AW+CD+Urine), T_3 (MW+CD+Urine) was analyzed for its suitability as a bio fertilizer. The digestate residue was tested to quantify the available macro and minor nutrients, heavy metals. For analyzing the chemical composition of remaining digested 50 g of digested from each digester was kept, and then send for further test.

3.11Statistical analysis

Each treatment was launched in triplicates to conduct the statistical analysis study for assessing production of biogas production and concentration of methane concentration by using dry anaerobic co-digestion, and the obtained data statistically assessed by the analysis of variance (ANOVA) using STATISTICS 10 computer package program. All pair wise comparison test was used to test the significance of difference between means by considering the differences significant at $P < 0.05$. Data was analyzed in Completely Randomized Design (CRD). Excel program was used for preliminary data collection.

CHAPTER-4

RESULTS & DISCUSSION

CHAPTER 4

RESULTS AND DISCUSSION

The experiments were conducted in batch type loading. The results of the test are also illustrated to compare the performance of the system in terms of biogas production and volatile solids reduction. The experiments were conducted with three different loadings for constant retention time. The analyses and evaluation are described to examine the performance of several strategies particularly in experiment to achieve the objectives of this study.

4.1 Waste generation

Under this program, we were emphasizing on door-to-door waste collection, local market, agricultural field and segregation of waste. After continuous efforts, the door-to-door waste collection system had started with 20 households and other potential sources. The amount of organic wastes was collected from different sources are presents in Appendix 1, Appendix 2 and Appendix 3. Before initiating the project, no such system of waste management existed in SAU and people were not aware about the segregation of organic and inorganic materials.

4.2 Feedstock preparation and analysis

The KW, AW and MW used for this study were obtained as source-separated food waste from market, field and selected households that covered 20 households. The waste was kept in room at a temperature of 20-25°C to avoid the degradation of waste. Before being loaded to the reactor, food wastes must undergo some pretreatments (Bouallagui *et al.,* 2005).

Dry Anaerobic digestion of agricultural, kitchen wastes and market wastes often results in low biogas yields and slow degradation rates because some of these wastes have recalcitrant molecular structures that make them difficult to degrade by microorganisms and some contain chemicals/substances that can inhibit microbial growth. Pretreatment is the most suitable way to overcome the challenges associated with these wastes. They were shredded to small particles with average size of 10 mm and homogenized to facilitate digestion. The sub-samples were dried and milled to the millimeter size and analyzed for moisture content (MC), total solids (TS) and volatile solids (VS) using standard methods (APHA, 1998).

The chemical characteristics of the wastes used in this experiment for biogas production systems are shown below in Table 9.

Table 9 Chemical parameters of raw shredded wastes during loadings

Treatment	Name of Components			
	Moisture content (%)	Total solid (%)	Volatile solid (%TS)	Ash content (%)
KW	79.88 ^{a} ±0.68	17.34 ^{c} ±0.39	89.16 ^{b} ±0.36	8.11 ^{b} ±0.19
AW	78.09 ^{b} ±0.54	19.71 ^{a} ±0.44	80.33 ^{c} ±1.23	9.14 ^{a} ±0.32
MW	81.24 ^{a} ±1.11	18.52 ^{b} ±0.73	91.30 ^{a} ±0.53	8.69 ^{ab} ±0.55
Level of Significance	*	*	*	*

Here, KW =Kitchen waste, AW= Agricultural waste, MW = Market waste.

** In a column, means having similar letter (s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability*

Table 9 shows that chemical parameters of wastes during loadings of three treatment group. There was a significant difference ($p < 0.05$) in chemical components of wastes. The percentage of moisture content (81.24±1.11%) was higher in the market waste due to presence of high fraction of fruit waste and vegetables and lower in agricultural waste (78.09±0.54 %). Total solid percentage was high in agricultural waste (19.71±0.44%) and low in kitchen waste (17.34±0.39%), VS content percentage 91.30±0.53 %, 89.16±0.36% and 80.33 ±1.23% to market waste, kitchen waste and agriculture waste respectively. Lastly ash content percentage higher in agricultural waste around 9.14±0.32 %. For the anaerobic digestion process the nutrients proportion should be suitable for the microbial growth.

Essam. *et al*., (2020) conducted a research on Biogas production using dry fermentation technology through co-digestion of manure and agricultural wastes in this research they found TS% of manure 22.9% and VS% 65.2%. Co- digested with manure and agriculture wastes they found TS and VS 21.8% and 74.2%.

Previous research has studied industrial wastes, agricultural wastes, energy crops, and a variety of biomass feedstocks as energy sources (Garcia *et al.* 2012; Kok and Emre, 2013; Braz et al., (2014) however, this study is novel in its efforts to characterize common household food wastes discarded into waste streams including fruits, vegetables, carbohydrates, and meats.

Borowski and Weatherley, (2013) stated that in their research higher volatile solid generally means higher amount of organic materials that are convertible to biogas. Also higher volatile solid/total solids increased the amount of biodegradable materials and it would cause the increase of the microbial activities, thereby increasing volatile solid removal rate.

Carbohydrate samples contained the highest average ash content indicating potential for the recovery of the ash as use for landfill fly ash and cement (Adrian et al. 2010).

Garcia *et al.*, (2012) found that the energy crop Miscanthus had about 7.53% moisture, 79% volatile matter, 11.4% fixed carbon, and 9.6% ash. The high number of volatiles and low moisture correlate with the high amount of energy of 18.57 MJ/kg found in Miscanthus.

Table 10: C/N ratio of wastes used for biogas production

C/N ratio of wastes	
Type of waste	**Mean ±SD**
Kitchen waste	28.82 ±1.52
Agricultural waste	32.72± 0.28
Market waste	30.30 ± 1.03
Cow dung	24.75 ±0.30
Urine	4.36± 4.55

According to Stroot *et al.*, (2001), the suggested optimum C/N ratio for anaerobic digestion is in the range of 20:1 to 30:1, which supports the results obtained from the current study. Table 10 show the C/N ratio of the kitchen waste was found to be 28.82±1.52 and market waste was found 30.30±1.03 and higher C/N ratio obtained from agricultural waste 32.72±0.28 which were suitable for the AD process. The feedstock was prepared with the mixture of food wastes, fruit waste and boiled rice in order to obtain the desired loading rate and optimum C/N ratio. Cow dung and urine of cow used as inoculum was collected from SAU Animal farm.

Digester with cow dung and food waste produced biogas much faster, followed by the digestion of cow dung single and fruit and vegetable waste single digestion of the three waste, which is in line with the work of Aragaw *et al.*,(2013). This might be due to the attribution of the positive synergetic effect of the co-digestion of cow dung and food waste in providing more balanced nutrients, increased buffering capacity, and decreased effect of toxic compounds (Aragaw *et al.,* 2013).

Cow urine contains 95% water, 2.5% urea, 2.5% minerals, salts, hormones and enzymes. It contains iron, calcium, phosphorus, salts, carbonic acid potash, nitrogen, ammonia, manganese, sulphur, phosphate, potassium, urea, uric acid, cytokines, lactose etc. Urine has also been shown to improve biogas production when added with cow manure and water; this is due to the nitrogen-rich urine reducing the carbon: nitrogen ratio of the slurry, which also improves the quality organic fertilizer output from the digester (Haque and Haque, 2006). Cattle urine was observed to increase gas production by 30% at a proportion by volume of 50 cattle dung: 35 urine: 15 water (Haque and Haque, 2006). During the digestion process, much of the organic matter in waste is converted to volatile fatty acids by acidogenic bacteria, and these VFAs are then consumed by methanogenic bacteria to produce methane, carbon dioxide and other few gases. Nitrogen, phosphorus and potassium are transformed by these microbial processes, but these nutrients are not destroyed.

4.3 Comparison of biogas generation and quality

Digestion during start-up ran for a total of 49 days (7th week), during that period start-up reached methanogenesis, characterized by high methane composition (60-65%).

Table 11: Weekly cumulative biogas production from 3 different experimental group

Digestion period (Week)	**Gas generation(Cubic meter) ± SD**			**Level of Significance**
	T_1	**T_2**	**T_3**	
1st	1.48 ±0.28	1.30 ± 0.06	1.29± 0.07	NS
2nd	4.88 ±0.77	4.73 ±0.25	4.95 ±0.17	NS
3rd	9.84^{b} ± 0.56	7.77^{c} ±0.09	10.95^{a} ±0.13	*
4th	16.45^{b} ±0.89	13.92^{c} ±0.14	18.95^{a} ±0.25	*
5th	24.63^{b} ±1.065	21.71^{c} ±0.38	26.76^{a} ±0.61	*
6th	35.40^{b} ±1.27	33.20^{c} ±0.84	37.59^{a} ±0.52	*
7th	48.19^{b} ±1.20	43.87^{c} ±0.32	50.78^{a} ±0.48	*

Here T_1=Treatment 1 (Kitchen waste + Cow dung + Urine), T_2= Treatment 2 (Agricultural waste + Cow dung + Urine), T_3= Treatment 3 (Markrt waste + Cow dung + Urine). NS =Not Significant, SD= Standard deviation

**In a row, means having similar letter (s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.*

Table 11 indicates every week cumulative biogas production where the biogas production was high in the beginning which was due to the entrapped air (CO_2) inside the reactor and the waste itself because the methane composition during that period was almost zero. High biogas production and methane yield was obtained during circulation of the wastes inside the reactor. From Table 11, it is clear that the biogas production rate was lower between 2nd and 3rd week and at this time methane production also lower because there was no circulation of the waste and these components were increased on initiating the circulation of the waste. Table 11 shows the cumulative gas production of different waste samples. There was a no significant variation ($p > 0.05$) in gas production among three treatment groups at 1st and 2nd week. At first week cumulative gas production was 1.48 ±0.28, 1.30 ± 0.06 and 1.29± 0.07m^3 for T_1, T_2 and T_3 respectively. Gas production significantly varied ($p < 0.05$) at 3rd week (9.84 ± 0.56, 7.77 ± 0.09 and 10.95 ± 0.13 m^3 respectively) among Treatment 1, Treatment 2 and Treatment 3. Highest cumulative gas production was obtained at 7th week from Treatment 1 (48.19 ±1.20 m^3), Treatment 2 (43.87 ±0.32 m^3) and Treatment 3(50.78 ±0.48m^3).

Table 12: Weekly average volume of biogas produced from different substrates

Treatment	Gas production(Cubic meter)
T_1	$6.88^{b} \pm 1.55$
T_2	$6.26^{c} \pm 0.32$
T_3	$7.25^{a} \pm 0.48$

**In a row, means having similar letter (s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.*

Average gas produced from T_1 = 6.88 ± 1.55m^3, from T_2 = 6.26 ± 0.32m^3 and T_3 =7.25 ± 0.48 m^3 per week (Table 12). Treatment 3 containing market waste with cow dung and urine highest gas produced.

According to Dubin., *et a*l., (2008) One kilogram of kitchen waste, if well digested, yields 0.3 m3 of biogas, this findings is comparable to the current study. The low production of biogas in this study may be because of the improper digestion of the waste, and the shade of the roof on the biogas plant preventing the direct sun rays to the bio-digester. Similarly, the data collection period was 49 days.

Li et.al.,(2020), conducted a study using food waste (FW), kitchen waste (KW), and fruit/vegetable waste (FVW) as substrates, the biogas production and performance of anaerobic mono-, co-, and tridigestion systems were evaluated. The results showed that the highest biogas and methane yields were 614.8 and 354.51 mL/gVS respectively. This result supported the current study.

Ziauddin and Rajesh, (2015) performed a study to compare the amount of biogas derived from kitchen waste and cow dung. Two sets of samples were collected, set-1 contained cow dung and set-2 contained kitchen waste, where AD experiments were conducted on both samples for 8 days. The study revealed that kitchen waste produced more gas than cow dung during eight days with average values of 89.37 and 23.75 ml, respectively, findings of this experiment supports the current study.

Sapkota et al. (2012) obtained 32.12 l/kg of biogas from kitchen waste. According to Zupancic and Grilc (2012), municipal organic waste contains 0.5-0.8 m3/kg of Volatile Solid (VS). Kukkonen, T.(2014) mixed kitchen waste with chicken manure at 4:1 ratio, found TS % 26.5 and methane produced 230 ml/g VS.

Another research was conducted by Chibueze *et al.*, (2017) to evaluate the efficiency of biogas production from cow dung versus food waste and the same conclusion was obtained. The AD experiment was performed for 15 days on 150 g of two samples (cow dung and food waste feedstock). The results showed that after 15 days, 19.2 mL of biogas was produced from cow dung, however, 30.58 ml was produced from food waste digestion. The result was predicted due to two factors: firstly, the nutrients contained in food waste are greater than those in cow dung. As per proximate analysis results, the cow dung contains less carbohydrate than that of food waste with values of 20 wt% and 61.9 wt%, respectively.

According to the results obtained from Essam, *et.al.*, (2020) , it was found that the co-digestion of the manure and AW at the ratio of 2:1 enhanced the anaerobic digestion process. In addition, the highest amount of methane (6610.2 ml) and biogas (12756.7 ml) was produced from manure with lettuce leaves compared to the control (manure) which yielded 4689.9 ml and 11606.7 ml, respectively.

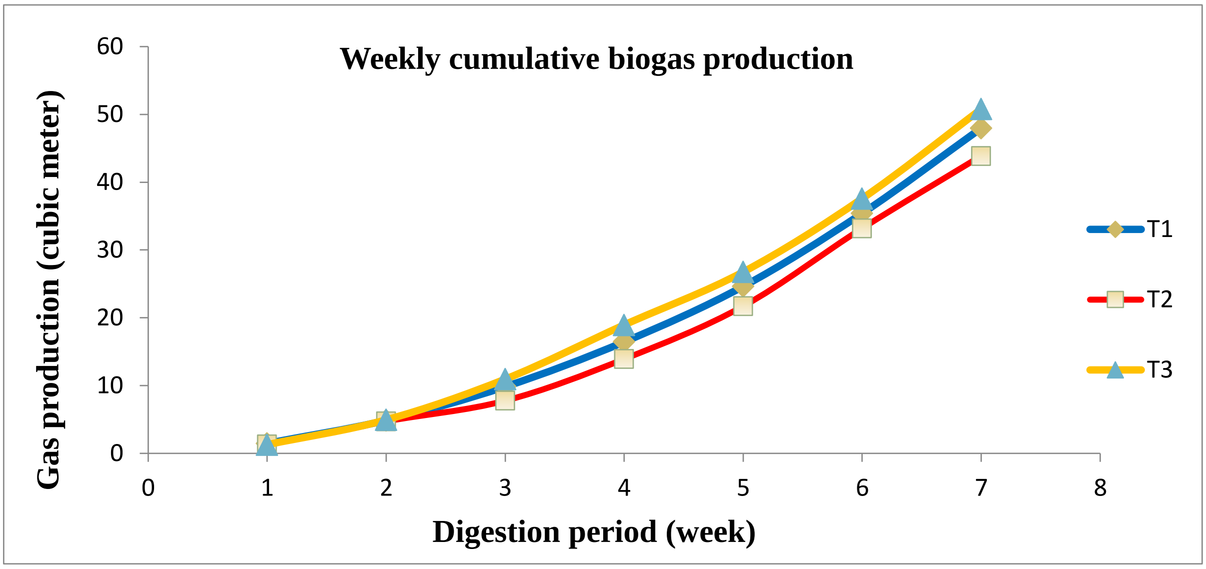

Figure 7: Weekly cumulative biogas production from T1, T2 and T3

Figure 7 and Appendix 6 shows that weekly biogas production from three treatment groups, co-digestion of T1 (kitchen waste with cow dung and urine), T2 (agricultural waste with cow dung and urine) and T3 (market waste with cow dung and urine). At the end of 49 days or 7th week retention period, the cumulative biogas produced 48.19 m^3, 43.87m^3 and 50.78 m^3 from T1, T2 and T3 respectively. At first week gas produced due to the inside air of feed stocks (From Appendix 6). At 2nd week gas production was not remarkable due to the formation of organic acids and alkaline condition and no mixing. At 3rd week gas production increased slowly. Higher amount of biogas was produced from Treatment 3 containing market waste with cow dung and urine due to high volatile solid content in market waste, and then Treatment 1 containing KW with cow dung and urine, and lowest gas produced from Treatment 3 containing AW with cow dung and urine. After that biogas production gradually slowed down due to decreasing VS content and lack of nutrient availability.

4.3.1 Composition of biogas (%)

According to Karki *et al.*, (2015), biogas consists of 50-70% of methane and 30- 40% of carbon dioxide. The obtained percentage of methane was near to the range and carbon dioxide was within the range. Lesser volume of methane may be due to presence of carbohydrates like potato peels, cooked rice in the feeding material.

Table 13: Composition of biogas of three treatment groups (Volume of components in biogas %)

Name of components	Avg. Biogas composition (%) ±SD			Level of Significance
	T_1	T_2	T_3	
CH_4	61.91 ^{b} ±0.91	61.16 ^{b} ±0.88	64.22 ^{a} ±1.01	*
CO_2	34.13 ±0.47	34.59 ±1.23	32.46 ±0.97	NS
O_2	1.13 ±0.15	1.16 ±0.32	1.14 ±0.22	NS
H_2S	0.88 ±0.16	0.83 ±0.30	0.54 ±0.03	NS

Here T_1=Treatment 1 (Kitchen waste+ Cow dung + Urine), T_2= Treatment 2 (Agricultural waste+ Cow dung + Urine), T_3= Treatment 3 (Market waste+ CD + Urine). NS =Not Significant

**In a column, means having similar letter (s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability*

The result obtained after analysis is presented in Table 13. The p-value obtained in all the data was found to be $p<0.05$, there was a significant variation ($p< 0.05$) in biogas percentage of components among three treatment groups. The average methane (CH_4) content was calculated to be 61.91±0.91, 61.16 ±0.88 and 64.22±1.01 from T_1, T_2 and T_3 respectively, methane content was higher in T_3 and almost similar in T_1 and T_2 in and that of carbon dioxide was calculated to be 34.13±0.47% for Treatment group 1, 34.59±1.23% for Treatment group 2 and 32.46±0.97% for Treatment group 3. Analyzed O_2, H_2S has no significant variation among three Treatment group. The considerable variation in gas and methane production could be partly explained by the variations in nutrient contents of was wastes.

4.4 Leachate characteristics

As pH is an important factor that affects digestion efficiency, pH values were measured throughout the process. It is important to maintain the pH of an anaerobic digester between 6 and 8; otherwise, methanogen growth would be seriously inhibited (Gerardi, 2003). The pH and alkalinity variation is illustrated in Table 14.

Table 14: pH of three experimental group at a certain period

Days	**Average value of pH**			**Level of Significance**
	T_1	**T_2**	**T_3**	
1	5.4	5.5	5.53	NS
3	5.7	5.6	5.7	NS
5	5.4^{b}	5.7^{ab}	5.9^{a}	*
7	6.2	5.8	6.0	NS
8	6.8^{a}	6.1^{c}	6.4^{b}	*
9	6.8^{a}	6.3^{b}	6.7^{a}	*
10	7.1^{a}	6.8^{b}	7.3^{a}	*
14	7.2^{b}	7.3^{ab}	7.4^{a}	*
21	7.5	7.5	7.6	NS
28	8.1^{a}	7.8^{b}	7.6^{b}	*
35	7.6^{b}	8.1^{a}	7.9^{a}	*
42	7.6	7.6	7.7	NS
49	7.9	7.8	7.8	NS

Here T_1=Treatment 1 (Kitchen waste+ Cow Dung + Urine), T_2= Treatment 2 (Agriculture Waste+ Cow Dung + Urine), T_3= Treatment 3 (Market Waste+ Cow Dung + Urine). NS =Not Significant.

*The different superscripts indicated significant difference between three values in the same row; *, $p<0.05$ (significant)*

Table 14 showed that, first 3 days there was no significant difference ($p>0.05$) of pH among three treatments. At 5 days pH varies significantly ($p<0.05$), Treatment 3 shows higher pH (5.9). Results (Table 14) showed that pH was at a lower value below 7 during first 9 days. This was due to the formation of organic acids e.g. volatile fatty acid. The alkalinity was also found low. Due to lower alkalinity and pH, the methanogenic activity was not initialized and the composition of methane was below 50%.

The pH of the leachate was monitored and an attempt was made to keep it above 6.5 by the addition of commercial CaCO3 and NaHCO3. On days 3, 5, 7, 9 and 1.5 kg of CaCO3 and NaHCO3 were added (Table 14).

From day 10 to 21, the pH and alkalinity was almost found steady. Despite of steady pH and alkalinity, the biogas gas i.e. methane production was low during that period due to lack of mixing. So the mixing by circulation of waste inside the reactor was performed and both pH and alkalinity was found increased. The pH reached above 7.5 but not exceeded 8.5 which are inhibiting condition for methanogenesis. During that period, the biogas production as well as methane composition was reached the maximum value. AT 42 and 49 days there was no significant variation in pH reading.

This data is almost agreed with Raveena *et al.*, (2019). She worked on biogas production and stated her paper the pH of cattle dung and paddy straw were found to be 7.5 and 6.9.

In this study, some of the initial pH of cow dung, co-digestion of cow dung and fruit waste and the co-digestion of the three waste ranges between these standard pH to be maintained given by Gerardi, (2003).

4.5 Digestate physical and chemical properties

The pH of the digestate was slightly alkaline, which should increase the buffering capacity of soil because most agricultural lands are somewhat acidic. The phosphorus content was low in every fraction. Studies have shown a loss of some amount of phosphorus during anaerobic digestion processes (Masse *et al.*, 2007); (Moller *et al.*, 2012).

Phosphorus can be added as a supplement to avoid phosphorus deficiency in the soil; however, nutrient requirements vary from one soil to another, so the digestate can be supplied to soil with major deficiencies of nitrogen and potassium. Little amounts of Ca, were found in the digestate, as illustrated in Table 15.

Table 15: Nutrient content of digested from dry anaerobic digestion of three treatment groups

Parameters	Nutrient content of digestate residue of feedstock			Level of Significance
	T_1	T_2	T_3	
pH	8.2	8.1	8.3	NS
Total carbon %	33.76	34.00	35.98	NS
Total Nitrogen mg/g	7.18 $^{\mathbf{b}}$	6.74 $^{\mathbf{c}}$	7.96 $^{\mathbf{a}}$	*
Potassium g/kg	0.03 $^{\mathbf{c}}$	0.51 $^{\mathbf{a}}$	0.23$^{\mathbf{b}}$	*
Phosphorus mg/Kg	26.40 $^{\mathbf{b}}$	22.72 $^{\mathbf{c}}$	37.52 $^{\mathbf{a}}$	*
Calcium mg/Kg	54.1 $^{\mathbf{a}}$	48.37 $^{\mathbf{c}}$	51.7 $^{\mathbf{b}}$	*

Here T1=Treatment 1 (Kitchen waste+ Cow dung + Urine), T2= Treatment 2 (Agricultural waste + Cow dung + Urine), T3= Treatment 3(Market waste+ Cow dung + Urine).

NS= p>0.05 (not-significant

**In a column, means having similar letter (s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability*

Bio-slurry produced from Treatment 1, Treatment 2 and Treatment 3 was dark brown, made from biodegradable organic matter, etc, through microbial conversion process. It is free from foul smell, live weed seeds, plastics, glass, and also free as a source for spreading pests and diseases. Total nitrogen is significantly $p<0.05$ high in market waste (7.96 mg/g). Total carbon percentage is not significant among 3 treatment group (33.76, 34.00, 35.98 respectively) (Table 15). This finding is in agreement with the results of (FAO, 2007). Its moisture content is about 25% with a bulk density of 0.64 gm / c.c. Digestate typically contains elements such as lignin that cannot be broken down by the anaerobic microorganisms. Also the digested may contain ammonia that is phytotoxic and will hamper the growth of plants if it is used as a soil-improving material. For these two reasons, maturation or composting stage may be employed after digestion. Lignin and other materials are available for degradation by aerobic microorganisms such as fungi, helping reduce the overall volume of the material for transport. During this maturation, the ammonia will be broken down into nitrates, improving the fertility of the material and making it more suitable as a soil improver. Large composting stages are typically used by dry anaerobic digestion technologies.

CHAPTER-5

SUMMARY & CONCLUSION

CHAPTER 5

SUMMARY AND CONCLUSION

Anaerobic digestion of waste material is important to reduce greenhouse gas and for production of sustainable energy supply. Biogas production plays a vital role in sustainable energy supply by producing methane which can be used as replacement of fossil fuels in both heat and power generation. Bangladesh has huge source of waste material which can be used for biogas production. Bangladesh climate is also suitable for biogas production.

The present investigation was carried out in Sher- e Bangla Agricultural University, Sher- e Bangla Nagar, Dhaka, Bangladesh. Biogas production was recorded for 49 days (Seven weeks) in batch type digestion. In this paper a system was proposed for utilization of this huge waste material. In this research wastes is classified into three categories kitchen waste, agricultural waste and market waste. T_1= Treatment 1(KW+CD+Urine), T_2 = Treatment 2 (AW+CD+Urine), and T_3= Treatment 3 (MW+CD+Urine), each three treatment group replicated into three digester and this three wastes is good source of biogas production through dry digestion technology. Anaerobic digestion of fresh Kitchen waste (KW), Agricultural Waste, Market waste and co-digested with cow dung and urine used as inoculums was carried out under batch system. The cattle manure as inoculum is endowed with a considerable biogas production potential evaluated through anaerobic decomposition that offers numerous benefits of environmental, agricultural and socio-economic standards. Data on different parameters of wastes during loadings, biogas production, pH, composition of digested were recorded and statistically analyzed using STATISTICS-10 computer package program. Cow dung and urine was mixed with substrates in percentage of 33.3% in every treatment. Regarding collected composition of kitchen waste over 24% waste was uncooked waste, vegetable waste 16 %, 30% fruit waste and 28% cooked waste. AW waste composed of maize leaf (56%), paddy straw (19%), cabbage and broccoli waste (13%), tomato waste (6%), vegetables (6%) waste. MW was collected from local market composed of (55%) vegetable waste, 22 (%) potato waste, (6%) pumpkin, (2%) onion peel, rotten egg (2%), fish waste (2%), livestock waste (3%) and (12%) hotel and restaurant waste. Collected waste was shredded into small particles, homogenized and kept for 7 days for pre treatment and then loaded to the digester. In terms of chemical parameters moisture content (%) of KW (79.88±0.68), AW (78.09±0.54) and MW (81.24±1.11) was analyzed, TS (%) (17.34±0.39, 19.71±0.44, 18.52±0.73 respectively), VS (% TS) highest in MW (91.30±0.53). C/N ratio of KW, AW, MW, CD and urine (28.82 ±1.52, 32.72± 0.28, 30.30 ± 1.03, 24.75 ±0.30, 4.36± 4.55 respectively) highest in AW. Consideration of the weekly cumulative biogas production highest gas production obtained from Treatment 3 (50.78 ±0.48m^3) at 7th week and then Treatment 1 (48.19 ±1.20 m^3) and lowest from Treatment 2 (43.87±0.32m^3). Average weekly gas produced from T_1=6.88±1.55m^3, from T_2= 6.26±0.32m^3 and T_3= 7.25±0.48m^3. Methane content in all the reactors varied between 60-65%. Highest methane (%) analyzed from Treatment 3 (64.22±1.01), from Treatment 1 and Treatment 2, 61.91±0.91 and 61.16 ±0.88 respectively. At first 10 days pH was checked regularly and when pH is stabled weekly checked pH reading. From 10 to 21 day, the pH was almost found steady (7.2-7.6). The pH reached above 7.5 but not exceeded 8.5 which are inhibiting condition for methanogenesis. During that period, the biogas production as well as methane composition was reached the maximum value. At 42 and 49 days there was no significant variation in pH reading.

The study on the production of biogas from the digestion of kitchen, agricultural and market waste and from the co-digestion of cow dung and urine has shown that biogas can be produced from these wastes through dry anaerobic digestion. These wastes are always available in our environment and can be used as a source of fuel if managed properly. The study revealed further that market waste and kitchen waste has great potentials for generation of biogas if only one type of waste is to be used and co-digestion of cow dung this waste is to be used. The utilization should be encouraged due to high volume of biogas yields. Three wastes used in experiment produce high concentration of methane among them Treatment 3 (market waste with Cow dung and urine) produce around 63- 65 % methane and biogas generation around 51 m3.

Digested or bio- slurry remaining after gas generation no need further treatment. This digested act as a good source a nutrient for soil. There is no significant difference among the pH of digested, pH ranged between 8.1- 8.3. Total nitrogen component is little bit high in Treatment 3, Ca component high in Treatment 1. This organic fertilizer increase soil health, and has no residual effect on crop and vegetables. Dry fermented digested is better than wet fermented digested because it has no pretreatment cost and easy to handling. This finding is of special importance because this lowers the operating costs, decreases the capital and operating costs of the anaerobic digestion of source-separated waste, and reduces the greenhouse gas emissions of both processes.

From al the result and discussion, it can be concluded that kitchen, agriculture and market waste co-digested with cow dung and urine is a good, and easy source of biogas production through dry digestion process, among them market waste with cow dung and urine, kitchen waste with cow dung and urine, produce high amount of gas than agriculture waste with cow dung and urine. But no discouragement for agriculture waste because every single waste has energy value, and land filling of this waste has also serious environmental issue. Eventually, dry anaerobic digestion process is an effective approach to waste treatment.

There is a vast scope to convert these energy sources into biogas by dry digestion biogas production system. The dry digestion biogas production plant can be constructed as a single large unit or many smaller units. The decision can be made by comparing cost for construction, the area usage, ease of use, technical stability and skill needed for the construction. Many research can be done by large scale practicing this technology commercially biogas can be bottling like LPG.

A new concept should be envisioned that may possibly improve the process for further study. Thus, the following aspects can be taken as the recommendations for future study of such anaerobic digester; Source segregation of organic fraction of solid waste should be implemented in whole in order to have sustainable solid waste management. Temperature measurement facility should be added. Since the methane is the excellent indicator of greenhouse effect, it should be trapped and should be either used or disposed properly. Above discussion leads to conclude that Government should develop the institutional activities and NGOs would also have taken further initiatives by which potential biogas users will be motivated to invest for a biogas plant and then, that rural household would have a greater chance to serve the nation as well as global society on less CO_2 emission, increase the soil fertility, increase the income generation and improve human health.

CHAPTER-6

REFERENCES

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CHAPTER-7

APPENDICES

CHAPTER 7

APPENDICES

Appendix 1: Collected kitchen waste from 20 building (Per Day)

Day	Raw materials (kg)				
	Vegetable waste	Fruits waste	Cooked waste	Other Perishable uncooked waste	Non perishable item
1	4.4	8.5	10.6	6.8	2.76
2	5.3	10.1	4.9	6.7	3.57
3	6.4	6.2	8.4	5.0	1.55
4	4.4	8.6	10.1	6.1	2.88
5	5.7	8.9	6.5	7.2	2.35
6	3.2	6.9	8.7	8.10	2.98
7	4.6	8.1	9.3	10.56	3.10
Total	**34.0**	**57.3**	**58.5**	**50.4**	**19.20**

Appendix 2: Collected agricultural waste from field

Day	**Raw material (kg)**				
	Paddy straw	**Broccoli waste**	**Maize leaf**	**Tomato**	**Cabbage waste**
1	6.13	4.45	14.95	2.59	4.87
2	-	1.49	21.34	4.03	2.15
3	4.05	2.06	5.23	-	6.05
4	8.56	-	12.58	2.75	-
5	7.23	2.23	16.03	0.54	6.13
6	12.49	1.78	41.01	1.91	6.86
Total	**38.46**	**12.01**	**111.14**	**11.82**	**26.12**

Appendix 3: Collected market waste from local market

Day	Vegetable waste(kg)	Discard Cucumber (kg)	Onion peel (kg)	Pumpkin (kg)	Potato waste (kg)	Rotten egg (kg)	Fish waste (kg)	Livestock waste (kg)	Hotel and restaurant waste (kg)
1	22.50	1.14	-	2.00	4.80	1.50	1.12	1.00	4.75
2	16.00	-	-	1.75	12.00	-	.80	2.00	1.00
3	20.50	0.48	2.00	1.12	6.20	0.23	-	-	1.25
4	26.00	-	.50	6.2	12.00	0.67	0.25	2.00	1.00
5	11.00	2.00	.50	-	4.00	1.00	1.45	-	2.85
6	14.00	0.42	1.00	1.00	5.00	.62	0.44	1.00	1.15
Total	110.00	4.02	4.00	12.07	44.00	4.02	4.06	6.00	12.00

Appendix 4: Characteristics of wastes before loadings

Composition	**T_1**			**T_2**			**T_3**		
	D_1	**D_2**	**D_3**	**D_1**	**D_2**	**D_3**	**D_1**	**D_2**	**D_3**
Moisture content%	79.20	80.56	79.88	78.66	78.04	77.58	80.04	82.23	81.45
Total solid%	17.60	16.89	17.53	19.80	19.22	20.01	18.71	17.72	80.15
Volatile solid%	89.5	88.77	89.21	76.85	76.12	77.03	90.88	91.90	91.12
Ash content %	8.11	7.91	8.30	8.99	9.31	9.11	8.75	8.11	9.21

Appendix 5: Calculated C/N ratio of wastes used for biogas production

Types of wastes	C/N Ratio		
	D1	**D2**	**D3**
Kitchen wastes	27.13	29.22	30.1
Agriculture waste	32.5	32.63	33.05
Market waste	31.46	29.45	30.00
Cow dung	24.66	24.5	25.1
Urine	0.67	2.97	9.45

Appendix 6: Recorded weekly gas production from three treatment groups

Run Time (weeks)	**Gas Production (Cubic meter)**								
	T1			**T2**			**T3**		
	D1	**D2**	**D3**	**D1**	**D2**	**D3**	**D1**	**D2**	**D3**
1st	1.75	1.51	1.18	1.34	1.22	1.32	1.23	1.36	1.28
2nd	3.46	3.42	3.34	3.62	3.29	3.41	3.76	3.65	3.58
3rd	5.46	4.80	4.61	2.68	3.11	3.34	6.04	6.06	5.89
4th	6.64	6.79	6.40	6.16	6.28	6.01	8.02	8.07	7.92
5th	8.38	8.14	8.03	8.29	7.42	7.64	8.13	6.92	8.37
6th	11.04	10.61	10.64	11.65	10.91	11.93	11.11	13.14	11.26
7th	13.19	12.49	12.71	10.5	11.47	10.02	12.18	12.14	12.25

Appendix 7: Recorded Weekly cumulative biogas prodution from 3 treatment groups

Run time (week)	Gas generation (Cubic meter)								
	T_1			T_2			T_3		
	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3
1st	1.75	1.51	1.18	1.34	1.22	1.32	1.23	1.36	1.28
2nd	5.21	4.93	4.52	4.96	4.51	4.73	4.99	5.01	4.86
3rd	10.67	9.73	9.13	7.64	7.62	8.07	11.03	11.07	10.75
4th	17.31	16.52	15.53	13.80	13.90	14.08	19.05	19.14	18.67
5th	25.69	24.66	23.56	22.09	21.32	21.72	27.18	26.06	27.04
6th	36.73	35.27	34.2	\33.74	32.23	33.65	38.29	39.2	38.3
7th	49.92	47.76	46.91	44.24	43.70	43.67	50.47	51.34	50.55

Appendix 8: Analyzed composition in biogas of treatment group 1

(Volume of components in biogas %)

Name of components	D_1	D_2	D_3
CH_4	61.75	61.10	62.90
CO_2	34.03	34.65	33.71
O_2	1.1	1.3	0.99
H_2S	1.07	0.8	0.79

Appendix 9 : Analyzed composition in biogas of treatment group 2

(Volume of components in biogas %)

Name of components	**D_1**	**D_2**	**D_3**
CH_4	60.35	62.10	61.03
CO_2	35.30	33.17	35.3
O_2	1.40	1.30	0.80
H_2S	0.90	1.10	0.50

Appendix 10 : Analyzed composition in biogas of treatment group 3

Name of components	Volume of components in biogas (%)		
	D_1	**D_2**	**D_3**
CH_4	63.25	64.13	65.28
CO_2	33.11	32.94	31.35
O_2	1.00	1.03	1.40
H_2S	0.53	0.51	0.58

Appendix 11: Recorded pH of experimental group at certain time being

Days	T_1			T_2			T_3		
	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3
1	5.4	5.3	5.5	5.6	5.5	5.4	5.3	5.7	5.6
3	5.7	5.6	5.8	5.5	5.7	5.7	5.5	5.8	5.8
5	5.3	5.3	5.6	5.6	5.7	5.8	5.7	5.9	6.1
7	6.2	6.1	6.3	5.8	5.9	5.9	5.8	6.1	6.2
8	6.8	6.7	6.9	6.0	6.1	6.2	6.3	6.4	6.5
9	6.9	6.8	6.7	6.4	6.3	6.2	6.5	6.7	6.9
10	7.1	7.00	7.2	6.9	6.8	6.7	7.2	7.3	7.3
14	7.2	7.3	7.1	7.4	7.3	7.2	7.4	7.5	7.5
21	7.6	7.5	7.4	7.6	7.5	7.6	7.5	7.6	7.7
28	8.1	8.2	8.0	7.9	7.8	7.7	7.6	7.5	7.8
35	7.7	7.6	7.6	8.2	8.1	8.0	7.9	8.1	7.8
42	7.6	7.7	7.5	7.6	7.8	7.5	7.8	7.9	7.6
49	7.8	7.9	8.0	8.1	7.7	7.8	7.7	7.9	7.8

Appendix 11: Composition of digestate from dry anaerobic digestion from three treatment groups

Parameters	**Digestate residue of feedstock**								
	T_1			**T_2**			**T_3**		
	D_1	**D_2**	**D_3**	**D_1**	**D_2**	**D_3**	**D_1**	**D_2**	**D_3**
pH	8.4	8.3	7.9	8.1	8.2	8.0	8.2	8.3	8.5
Total carbon %	35.17	34.11	32.0	33.85	34.13	34.02	35.89	36.01	36.04
Total Nitrogen mg/g	7.21	7.11	7.24	6.42	6.81	7.01	7.86	8.00	8.02
Potassium g/kg	0.034	0.033	0.035	0.48	0.49	0.57	0.23	0.22	0.25
Phosphorus mg/kg	26.43	25.99	26.78	22.54	22.67	22.96	36.30	37.77	38.51
Calcium mg/kg	54.23	54.10	53.97	47.99	48.31	48.83	51.14	51.89	52.07

Appendix 12: Pictorial view of this experiment

Plate 1: Weighing of kitchen waste

Plate 2: Segregation of Kitchen waste

Plate 3: Market waste

Plate 4: Three digestion chamber

Plate 5: Biogas storage bag

Plate 6: Leachate collection in a drum

Plate 7: Digital pH meter for pH test

Plate 8: pH testing by digital pH meter

Plate 9: Gas sample carrying bag for biogas analysis

Plate 10: $NaHCO_3$ for pH balancing

Plate 11: Biogas full bag

Plate 12: Digested collected after complete biogas production