EFFECT OF LEACHATE ADDITION ON BIOGAS PRODUCTION FROM WASTE UNDER MESOPHILIC CONDITION

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This thesis is dedicated to my Parents

For their endless affection, support and encouragement

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ABSTRACT

Energy crisis is the main hindrance in economic development of Pakistan. Fortunately, Pakistan has enormous biomass resources available in the form of crop residues, sugarcane bagasse, food waste, wood, dung, feces and poultry litter etc. which could be used to produce biogas, an alternative renewable fuel. The present study was conducted to examine the potential for biogas production from cow dung and vegetable waste with the objective of increasing the biogas production through the addition of municipal solid waste leachate in different proportion under mesophilic conditions. For this reason batch digestion was performed in the laboratory of IESE, NUST. In this experiment eight digesters having working volume of 1.2 liters were used. First four digesters were filled with vegetable waste and other four with cow dung. Different proportions of leachate with water (0, 33, 66 & 100 percent respectively) was used as liquid content in the digesters. For both the substrates Na_2CO_3 was used to buffer any sharp drop in the pH. Results showed that biogas production was increased with the increase in leachate content. Digesters containing highest leachate content of both vegetable waste and cow dung cumulatively produced highest amount of biogas which was approximately 700 L/kg of VS and 708 L/kg of VS while digesters having no leachate content produced 618 L/kg of VS and 437 L/kg of VS respectively. The percentage increase in the gas production was found to be 13% for vegetable waste and 62% for cow dung. Average methane content in biogas after attaining stability was 69% for vegetable waste while 64% for cow dung. From the results it was concluded that leachate addition had a positive effect on biogas production from both type of waste but this effect was more considerable in cow dung as compared to vegetable waste.

Chapter 1

INTRODUCTION

1.1 Background

The simultaneous growth of the human population and the dependence on energy and fuels has increased the need for research into alternative energy resources. Coupled with the increasing threat of climate changes, an effective energy source is greatly desired.

Many sources of alternative energies come from natural resources. Solar energy, hydroelectricity, geothermal power, and wind power can all generate energy using natural occurrences when coupled with technology. One of the many types of renewable energy that has been developed is the use of converting biological materials into usable fuels. This bioenergy can come in many forms. Resources such as char, bio-oil, or gas can be obtained through gasification and pyrolysis. Through fermentation and esterification reactions, liquidized fuels like biodiesel and ethanol are extracted. These and many other fuels are found similar to fossils fuels. If these fuels are marketed and proper equipment is employed and developed for their use, they can be an effective alternative of the established fossil fuels.

In developing countries major environmental problems are associated with the lack of proper disposal of solid waste. This issue can be tackled by adopting sustainable methods for the treatment of organic waste as the waste can be used as a source of energy as well as nutrients. In fact, composting and anaerobic decomposition of organic waste are the best options to be considered. (Saleh, 2012)

A useful energy material is methane. Methane is a carbon-based gas primarily made from biological reactions. One of these biological reactions is anaerobic digestion that takes place without the presence of oxygen by microorganisms. Anaerobic digestion takes place when bacteria convert a biomass feedstock into various other organic compounds, ultimately ending in a mixture of carbon dioxide and methane called biogas. Proportionally the biogas contains 60% methane and 40% CO_2 with traces of other gases. While anthropogenic carbon dioxide is a concern with greenhouse gas emission, the carbon dioxide released in this reaction is considered carbon neutral. The methane can be purified and used for purposes of generating heat or electricity (Ward et al., 2008). Anaerobic digestion serves a dual purpose in both providing the methane and reduction in volatile solids, lowering the risk of possible pollution when the slurry is disposed. The solids can also be used for various agricultural purposes such as fertilization.

1.2 Anaerobic Digestion

Anaerobic digestion is defined as a natural process in degrading organic material in the absence of oxygen. This is done through microbial conversion of biomass through several processes, ultimately ending in the production of biogas. Biogas contains several gases, but primarily is a mixture of methane and carbon dioxide, with concentrations at approximately 60% and 40%, respectively. While multitudes of microorganisms are involved in the digestion process, the processes themselves can be easily identified and analyzed. The basic pathways involved in anaerobic digestion are shown in Figure 1.

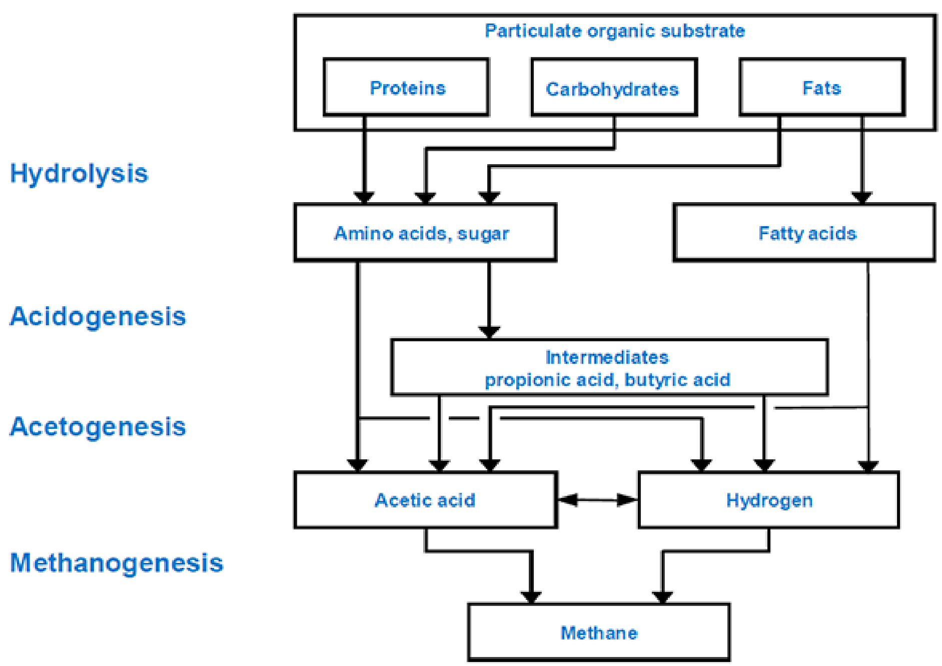


Fig 1: Showing Anaerobic Digestion Process

Anaerobic digestion is typically designed as a stream within an enclosed tank (Chynoweth et al., 2001). The influent stream is composed of an inoculum, found from wastewater treatment residues or active wastewater. This inoculum contains an initial point of microbial activity to begin digestion. Digestion can take place without inoculum, as microbes involved in the digestion process can be found virtually anywhere (this process is regularly found in composting). Using a stream of activated microbes, however, will accelerate the digestion process to increase the rate of initial methane production. Several weeks of residency time would be required for a fresh bacterial composition to reach the levels of activity found in a wastewater stream.

The process of anaerobic digestion is typically composed of three phases (McCarty, 1986). Digestion begins with microorganisms taking in organic matter from biomass. Complex organic molecules such as lipids, proteins, and polysaccharides are broken into simple organic components through hydrolysis with the assistance of enzymes. Hydrolysis reactions will result in the production of monosaccharaides and acids.

The second phase of anaerobic digestion utilizes multiple types of bacteria to convert the simple organic molecules into various acids. Hydrolytic and acidogenic bacteria feed off of the initial components, and produce higher levels of other acids, such as acetic and propionic acids. During this phase, hydrogen production also becomes apparent, which can be used as another source of methane in the final step of digestion (McCarty and Mosey, 1989).

The final step in anaerobic digestion is methanogenesis, the formation of biogas. Methanogenic bacteria convert prior products, including acetic acid and hydrogen, to produce methane gas. The entire digestion process can take several days to several weeks, depending on the amount of feed in the inoculum and the potency of microbes, but typically at least an 80% reduction of volatile solids is seen when fully converted to methane (Gujer and Zehnder, 1983).

During the last decades the process of anaerobic digestion is used more frequently for treatment of organic waste because this process treats the waste in more environmental friendly and also recover energy in the form of biogas which is an alternative renewable fuel to fossil fuels. Another advantage of anaerobic is that it is cheap due to its low startup cost and managing cost. Anaerobic digestion can be easily performed in a digester or reactor where the only technological and energy consuming equipment could be the mixers and heaters. Moreover anaerobic digestion can gain money by the disposal of organic waste and producing biogas. This biogas can be sold directly or combusted for heat or energy generation. The digestate can also be used as fertilizer in agriculture (Esposito et al., 2012).

According to Hamed et al. (2010), for higher and better carbon and nutrient balance, it is necessary that different materials needs to be codigested. This amalgamation of different material like manure etc. enhances the anaerobic digestion process resulting in improved and efficient biogas.

Virtually any organic compound can be converted into methane through anaerobic digestion, including wastewater streams, animal manures, food wastes, crop wastes, and biomass resources. Buildup of animal manures on farm property is an issue that may have to be handled individually, and anaerobic digestion is a simple enough process to treat them.

1.3 Digestion of cattle manure

Manure has proven to be a reliable and efficient source of methane. Among the various animal sources, cattle manure remains one of the strongest feedstock for biogas production (Holm-Nielsen et al., 2009). Due to the abundance of livestock, manure is plentiful resource by default. Slurries from the waste of cattle, swine, fish, and poultry can be used in an anaerobic digestion system to produce a steady stream of methane. This provides a double benefit, as not only can methane be used as an energy source, but anaerobic treatment can also be used as a means of purifying the waste products prior to disposal. This can reduce the risks in pollution found when improperly disposing animal waste. The spent solids can also be utilized as a fertilizer product and recycled by the agricultural business.

The source of the manure can have an impact on the end methane yield. Swine manure shows to have a slightly higher methane yield than beef cattle, though is not as plentiful (Ward et al., 2008). Poultry manure has also shown promise as a methane source, but is susceptible to ammonia toxicity (Bujoczek et al., 2000). Several factors can influence the amount of methane found from manure: species of livestock, bedding material, feed, and livestock growth stage.

Cattle manure is of note due to its bountiful nature. The high population of cattle in the world makes it a near permanent resource in anaerobic digestion. Of note, however, is the high fiber content in cattle waste (Nielsen et al., 2004). Due to the resistant nature of lignocellulosic fiber in the manure mixture, methane conversion will be slowed or hindered completely. A common practice to overcome this obstacle is thermal treatment of the cattle manure.

1.4 Anaerobic Digestion of Vegetable Waste

Vegetables are used in our daily diet because it is a source of protein, vitamins, dietary fibers, minerals, antioxidants and other micronutrients & phytochemicals. A variety of vegetable are grown in the country due to a diverse soil type and climatic conditions. More than forty (40) kinds of vegetables from different families and groups are produced in tropical, subtropical and temperate regions of the country.

Vegetable markets generate high amount of vegetable waste on daily basis. The safe disposal of these kinds of waste is a serious problem. The existing disposal methods of vegetable waste includes open dumping, dumping in municipal landfills, spreading on land and feeding it to animals. These traditional and unscientific methods severe pollute all the segments of environment i.e. land, water and air. Treatment of the vegetable waste with the help of biological methods seems to be economical and also reduce the environmental pollution. (et al., 2006).

Biomethanation is an attractive option among the biological methods since it generates biogas comprising mainly methane and carbon dioxide. Methane can be converted into electricity and effluent from biomethanation plant have nutritive value

1.5 Prospect of Biogas Production in Pakistan

Like other developing countries, Pakistan is also facing severe energy crises. The petroleum import bill of Pakistan is more than 6.18 billion USD annually (State Bank Annual Report 2014 – 2015). This import bill can be drastically reduced if established fossil fuels are replaced by renewable and sustainable energy sources. Pakistan is a predominantly rural society that presents a great opportunity for renewable and sustainable energy sources. There are large amount of animal is rural Pakistan which produces approximately 700 million kg of manure daily. Assuming 50% collectability of the available fresh cow dung having a capacity of to produce 17.5 million m^3 biogas per day and 18.2 million tons of bio fertilizer per year (Hassan, 2002). This enormous energy source is largely underutilized. Bringing this source to use by installing low cost and small budget biogas processing plants and storage facilities

Pakistan can easily overcome some of its energy requirements. Furthermore, the effective utilization of these plants would lead to fulfilling the energy requirements of 70% of rural areas of Pakistan. A national policy needs to be developed that encourages the farmers to utilize these resources and bringing this technology to their doorsteps (Saleh, 2012).

1.5.1 Agriculture

Pakistan is an agricultural country producing major biomass from crops (sugarcane, vegetables, crops residue, and other biomass), livestock and fruits waste which can be utilized to produce biogas (Asif, 2009). Pakistan is a major producer of sugar cane. According to government statistics department 50 million tons of sugarcane is produced annually. This sugar cane is used for producing different products and its residue has a capability to generate 10 million tons fo biogas. Around the globe, an estimated 9GW of electricity is produced by biogas. According to PBIT (2010) estimated that only sugar mills industry can produce 3000 MW of electricity if they tap the potential of sugarcane residue. However only 700 MW are being produced by 80 sugar mills.

Other than Sugarcane the agricultural sector, also produce cotton gin and rice straw which also be used for biogas and ethanol production. Isci and Demirer (2007) in study compared the ethanol production of cotton gin and rice straw and concluded that rice straw produces more ethanol than cotton gin. However due to the co-digested nature of cotton gin with animal manure its biogas production is much higher. Both these substances have immense biogas generation ability and can be utilized for electricity production and other purposes (Rao et al., 2010).

1.5.2 Livestock

According to Rao et al. (2010), Pakistan has various livestock substrates like waste from food industry, poultry waste, MSW, slaughter house waste etc. which can be utilized for biogas production. The Ministry of Finance estimates a 3.7% annual rate of growth on the livestock sector (MoF, 2012-2013). This is a high opportunity for the villages of Pakistan to utilize this existing as well as the growth in the livestock waste to produced biogas. The report by Beta Pak (2010), categorically states the economic, environmental and renewable advantages and potential of energy generation from the manure of animals. Sheikh (2009), estimates approximately 62.5 million buffalos in Pakistan and the manure generated by these buffalos has the capability to produces approximately 16.3 million m3 of biogas. However only half of this manure produced is being collected daily and being used for biogas production.

Organic fertilizer is also a major source for production of biogas and then utilized for fertilizing the land. An estimated 21 million tons of organic fertilizer is produced in t Pakistan annually. The organic fertilizer normally contain high amount of phosphorus ranging from 4000 to 18000 mg/kg dry matter (He et al., 2004). Studies show that of the total manure produced about 57% is collected and used for organic fertilizers. It is also reported by different researches that the losses of fresh manure nitrogen, phosphorous and potassium is 19%, 37% and 29% respectively and even after these losses the organic fertilizer can fulfill 20% to 60% requirements of nitrogen and phosphorus in the fields. Barker and Zublena, (1996) present organic fertilizer as a source of energy, a replacement to chemical fertilizer and an organic soil conditioner.

1.5.3 Vegetable and Fruit waste

Another source of biomass in Pakistan is the fruits and vegetables. An estimated 6.5million tons of fruits and vegetable are produced in Pakistan annually. According to the Ministry of Agriculture, around 30% to 40% of these fruits and vegetables are discarded due the lack of processing facilities and slackness on the part of farmers, markets and government machinery. The fruits and vegetables have a high organic and moisture level, and have an enhanced biodegradable ability which it an efficient biogas production substrate (Misi and Forster, 2002; and Liu et al., 2009). For the municipal solid waste management machinery fruits and vegetables are a major part of their organic fraction. In Pakistan majority of the municipal solid is dumped in landfills. This technique for solid waste management is employed when the municipalities lack economic and technical ability to handle the solid waste (Batool et al., 2008). The dumping of landfills makes it hard to process biogas. Furthermore, researchers have identified many adverse consequences of this technique. Batool and Chaudary (2009) argue that solid wastes dumped in landfills results in heightened greenhouse gas emissions. World Wildlife Fund-Pakistan (2009) reports that fruits and vegetables as part of the solid waste has adverse health and environmental effects. If not properly treated and managed it results in typhoid, cholera, dysentery etc. furthermore it can contaminate the underground water resources that could result in malaria, hepatitis and yellow fever. Lastly, these sites also act as breading grounds for rats, flies, mosques and stray animals that has its own health and environment hazards. To avoid these negative consequences of vegetable and fruits solid waste other technologies may be employees. Furthermore, if this biomass were utilized for biogas production it would not only eliminate its health and environmental hazards but also results in playing its part to overcome our country's energy crisis.

1.6 This Study

In this research, cow dung, vegetable waste along with leachate will be assessed for the use of anaerobic digestion with the objectives of treating the waste to generate biogas and to decrease disposal costs. The biogas produced contains mainly methane and carbon dioxide, and can be used as a source of renewable energy.

This experiment utilizes four resources in anaerobic digestion: cattle manure, vegetable waste, solid waste leachate, and inoculum. The cattle manure was obtained from a dairy in H-13. Vegetable waste was collected from the house hold municipal waste. Leachate was collected from a dumping site located in I-12 Islamabad. Inoculum from a previous anaerobic digestion reactor was used to provide activated microbes for the digestion process to accelerate during initial testing.

1.7 Hypothesis

Biogas production will rise with the increase in the leachate proportion in the digester.

1.8 Objectives

- Biogas production through anaerobic digestion of vegetable waste and cow dung.
- Assess the effect of leachate addition on biogas production.

Chapter 2

LITERATURE REVIEW

In this chapter some basic details and different factors affecting biogas are discussed. The main objective of this chapter is to deliver important material which is helpful for the understanding of the results and discussion in the next chapter.

2.1 Anaerobic digestion

Biogas is generated by a process in which microorganisms breakdown organic matter in the absence of oxygen (O_2) (Hessami et al., 1996). The reaction illustrating the whole process is as under (Vesilind et al., 2002).

$$\text{[Organic material]} + \text{Microorganisms} + \text{Heat} \rightarrow CH_4 + CO_2 + H_2 + NH_3 + H_2S$$

There are several sources of production of biogas such as municipal solid waste (MSW), crop residues, animal manure, sewage sludge etc. Biogas composition and its characteristics are given in Table: 2.1 below (FAO, 1996; Deublein, 2008; Majid, 2006).

Table 2.1: Biogas composition and its characteristics

Biogas Composition	
Gas	**Percentage**
Methane (CH_4)	50 - 70%
Carbon dioxide (CO_2)	30 - 50%
Nitrogen (N_2)	1%
Hydrogen (H_2)	0.1 – 0.5%
Carbon monoxide (CO)	0.1%
H_2S	Traces
Characteristics of biogas	
Density	1 - 2 kg/ m3
Calorific value	20 MJ/ m3
Ignition temperature	650 - 750°
Smell	Odorless
lighter than air	20%

2.2 Biogas Production Mechanism

Biogas is produced by anaerobic digestion of different organic wastes. The process of anaerobic digestion comprises of four different phases performed by different sets of microorganisms. These phases characterized as hydrolysis, acidogenesis, acetogenesis and methanogenesis (Jarvis, 2004). All the phases are elaborated below:

2.2.1 Hydrolysis

Digestion begins with microorganisms taking in organic matter from biomass. Complex organic molecules such as lipids, proteins, and polysaccharides are broken into simple organic components through hydrolysis with the assistance of enzymes. Hydrolysis reactions will result in the production of fatty acids, amino acids, monosaccharides (Yadvika et al., 2004).

2.2.2 Acidogenesis

The second phase of anaerobic digestion utilizes multiple types of bacteria to convert the simple organic molecules into various acids. Hydrolytic and acidogenic bacteria feed off of the initial components, and produce higher levels of other acids, such as acetic and propionic acids. During this phase, hydrogen production also becomes apparent, which can be used as another source of methane in the final step of digestion (McCarty and Mosey, 1989).

2.2.3 Acetogenesis

In this phase, the products, other than acetic acid, produced by the fermentation process in the acidogenic phase transformed further to acetic acid, hydrogen (H_2), and carbon dioxide (CO_2) in different anaerobic oxidation reactions catalyzed by acetogenic bacteria (Jarvis, 2004).

2.2.4 Methanogenesis

The final step in anaerobic digestion is methanogenesis, the formation of biogas. Methanogenic bacteria convert prior products, including acetic acid and hydrogen, to produce methane gas. The entire digestion process can take several days to several weeks, depending on the amount of feed in the inoculum and the potency of microbes, but typically at least an 80% reduction of volatile solids is seen when fully converted to methane (Gujer and Zehnder, 1983).

2.3 Functional parameters important for production of biogas

There are different operational parameters that effect the production of biogas. Important factor that governs the generation of biogas are temperature, pH, organic loading rate, size of particle. Mixing & agitation, hydraulic retention time etc. Any abrupt variations in these parameters can negatively affect the production of biogas (Yadvika et al., 2004).

2.3.1 Temperature

Temperature can be one of the leading factors affecting the end biogas production output. Biogas production occurs at different temperatures i.e. psychrophlic (<25 °C), mesophilic (25–45 °C), and thermophilic (50–70 °C) (Yadvika et al., 2004). Primarily, most reactors operate nominally at mesophilic and thermophilic temperatures, between 35° C and 55° C, respectively. While most research agrees that thermophilic reactors result in higher methane yields, most digestion mixtures should be handled individually to find an optimum temperature. The energy requirement to heat the reactors to the higher temperature should also be taken into account (Cantu, 2014).

2.3.2 pH

pH is the degree of the acidity of a substrate. Therefore, pH of a substrate to be digested is a vital factor affecting the growth of the microorganism during the process of anaerobic digestion. The ideal pH for anaerobic digestion if 6-8 (Yadvika et al., 2004). Microorganisms and their enzymes performs better in the pH range mentioned above and any variation in the pH severely affect the digestion process (Yadvika et al., 2004).The narrow range is mainly due to the varying optimal pH levels for the varying microbes involved in the system (Kim et al., 2003). The optimal level for methanogenesis is 7.0, while the optimal level for hydrolysis and acidogenesis is between 5.5 and 6.5. While the aforementioned pH range can provide a steady level of methane production, many designers opt to divide the process into two phases to optimize them individually (Cantu, 2014).

2.3.3 Type of Feedstock or Waste

Feedstock can have the greatest impact on methane production amounts, as it governs the amount of volatile feed given to microbes in the system. Feedstock can be divided into multiple categories, including municipal solid wastes, manures, fruit and vegetable wastes, and miscellaneous biomass (Ward et al., 2008). Municipal solid wastes are found through commercial streams, and can vary greatly in terms of consistency and solids content. Inhibitory materials such as nonbiodegradable waste and toxic additives may also be found in these streams, so a preliminary separation should be utilized (Cantu, 2014). Manures from varying animal sources show promise as a methane source, and have been tested extensively for methane production. Fruit and vegetable wastes in anaerobic digestion function similarly to composting, and can be easily degraded within the digester. However, acid content of these wastes can lead to inhibition (Sagagi et al., 2009). Other biomass sources can be used in a digestion system, though on an individual basis, inhibitory factors may include recalcitrance from fibers, harvesting time, and low energy yields.

2.3.4 Carbon to Nitrogen (C/N) ratio

For better performance of a biogas plant, the influent substrate must have the preferred range of carbon to nitrogen ratio because balance nutrients can enhance the growth of the microorganisms and its activities (Nijaguna, 2002). Carbon and nitrogen are essential nutrients required by the microorganism for better digestion. Amount of carbon is always 20 – 30 times more than nitrogen for anaerobic digestion. Therefore, for better performance of microorganisms carbon to nitrogen (C/N) ratio should be 20 – 30: 1. Any deviation from this ratio effects the efficiency of the whole digestion process. The carbon portion is more because it is easily biodegradable. Mixing of different substrate varieties together in a single digestion process enhances the nutrient balance and fulfill the need of the missing nutrients and results in higher production of biogas (Nijaguna, 2002). Therefore, cow dung and other organic wastes are mixed to optimize the process of digestion and enhance the biogas production (IEA, 2005, Nijaguna, 2002). Carbon to nitrogen (C/N) ratio of cow dung is around 16 – 25: 1 (Nijaguna, 2002).

2.3.5 Size of particle

Size of particle of the substrate is also an essential factor affecting the biogas generation process. Too large size of particle create problems for microbes in the digestion and sometimes blocks the digester. Whereas, small size of particle can be digested easily due to large surface area available for the microorganisms which results in biogas production enhancement (Yadvika et al., 2004).

2.3.6 Water content

Water or moisture content is an important factor effecting the proper growth and activities of the microorganisms. The quantity of water existing in the digester regulates the mobility and other enzymatic activities of microorganisms (Nijaguna, 2002). For better performance the water content in the digesters should be sustained in the range between 60 – 95 % for anaerobic digestion (Demetriades, 2008). Different feedstock's have different ideal moisture content levels which depends on the biological and chemical characteristics (Nijaguna, 2002).

2.3.7 Mixing/Agitation

Mixing and agitation is another important factor better for the enhancement of biogas production. The interaction between the microbes and the available feedstock must be very close for healthier digestion. This wanted effect can be attained by mixing and agitation inside the digester. Mixing and agitation of the substrate can be done in many ways i.e. propeller or scraper, installing piston or by feeding the digester daily instead of feeding after long pauses (Yadvika et al., 2004).

2.3.8 Organic loading rate

Organic loading rate (OLR) denotes the quantity of substrate introduced daily into the digester and most of the time, it is stated in kilograms of volatile solids per cubic meter per day (Kg VS/m^3/day). The daily gas produced in a digester strongly depends on its organic loading rate (OLR) (Yadvika et al., 2004).

2.3.9 Hydraulic retention time (HRT)

Hydraulic retention time (HRT) is the time spent by the feedstock in a digester for digestion process. Hydraulic retention time depends on the thermal conditions of the system. For high temperature the hydraulic retention time is less as compared to the lower temperatures. For thermophilic environment the required hydraulic retention time is about 15 to 25 day while that required mesopilic conditions ranges between 30 – 50 days (Demetrides, 2008).

2.4 Batch digestion

Digesters functioning under batch mode once introduced with substrate, inoculum to start the digestion process and in some cases some chemicals are also added for the buffering of pH changes. After that the digesters are tightly closed and the process of anaerobic digestion is allowed to start (Nijaguna, 2002). In batch digestion mode the digesters are filled once for anaerobic digestion and when the process is completed the whole feedstock material is removed from the digester. The gas production gradually builds up and after some time reaches to its highest point and then the decline in the gas production starts, creating a bell shape curve (Nijaguna, 2002). This method supports easy management of the waste material but the difference in the production of gas is more both quantity and quality wise. Therefore different digesters are functioned simultaneously giving a gap of a few days to avoid any disruption in production and consumption of gas. This method also provide high degradation of feedstock if the time of the digestion is increased (Demetriades, 2008).

2.5 Continuous digestion

In continuous digestion the feedstock material is fed and removed from a digester about 1 – 8 times per day (Demetriades, 2008). During this process the fresh feedstock material added pushes the same volume of old feedstock material from the digester whose hydraulic retention is nearly finished, thus sustaining the constant volume in the digester. Continuous type of digestion delivers a consistent and stable production of biogas, in comparison to batch digestion, due to continues feeding of material to the digester (Demetriades, 2008).

2.6 Studies on Production of Biogas

Pena et al. (2011), conducted anaerobic digestion experiment to study the potential of methane production from fruit waste and vegetable waste. Batch reactor showed that by maintaining the pH and by the addition of nitrogen in the reactor, improved results can be attained for the biogas production (0.42 m3 / kg VS), production of methane (50%), and high consumption of volatile solids from the substrate.

El Mashad et al. (2010) assessed the results of the screening of cattle manure on biogas production from dairy waste under mesophilic (35^{o}C) thermal conditions in batch type of digestion. This research study examined the biogas production potential from co-digestion of unscreened cattle manure and food waste and its comparison the generation of biogas when these wastes were digested alone. The results clearly showed that production of biogas from co-digestion of manure and food waste was significantly increased up to 60% of initial volatile solids.

Budiyono et al. (2010) tested the influence of different proportions of total solids content in the substrate material for the production of biogas at laboratory scale. The results indicated that 7.4% and 9.2% total solids in the substrate showed best efficiency in the digestion.

Guangqing et al. (2009) conducted experiment on the digestion of food waste, green waste and their mixture in batch mode of digestion under mesophilic (35^{o}C) and thermophilic (50^{o}C) thermal ranges for the generation of biogas. In the mixture of food and green waste, both were present in 50% ratio. In the first 10 days of digestion process almost 80% of the biogas was produced. It was also observed from the results that, in comparison to mesophilic thermal conditions, digestion under thermophilic range was more efficient and generated higher biogas and methane for all the used substrates.

Saevet et al. (2009) carried out a research on the co-digestion of wasted tomatoes and cow dung. It was clearly observe from the outcomes that the addition of more than 10% of tomato waste with cow dung did not deliver satisfactory results. While by adding more than 20% resulted in choking of the digester. 10% of tomato waste addition to cow dung produced better results and enhance the biogas production by 51.51%.

Kabouris et al. (2009) carried out batch anaerobic biodegradability test for fat, oil and grease (FOG). Due to high carbon content and methane potential FOG is suitable feedstock material for co-digestion. The results reported says that dewatered FOG produced higher methane yield of 0.993 L/g of VS added.

Alvarez et al. (2007) inspected the methane potential through co-digestion of various waste material including cattle manure, slaughterhouse waste and fruit & vegetable waste under mesophilic thermal conditions in a semi continuous mode of digestion. The results depicted that the waste mentioned above can be treated better in co-digestion as compared to the separate digestion of these wastes. The volatile solids (VS) reduction was ranged between 50% – 65% with the production of methane around 0.3 m^3/kg of VS added.

Zhang et al. (2007) studied food waste under thermophilic (50°C) conditions in batch mode of digestion. After sample collection, the average water content and volatile solids (VS) out of total solids (TS) on day to day basis was 70% and 83% respectively. Analysis of samples depicted that nutrient content of food waste delivers sufficient nutrient to anaerobic microorganisms. After 10 and 28 days of digestion, the generation of biogas was recorded to be 0.348 and 0.435 L/g of VS respectively having methane (CH_4) content around 73%. Reduction in volatile solids (VS) was about 81% after 28 days of digestion. This research also showed that food waste is a favorable feedstock material for anaerobic digestion because of its higher organic matter degradation rate and high potential of methane generation.

Mahanta et al. (2005) testified the effectiveness of a digester affected by thermal conditions, therefore the generation of biogas was lower in winter season. Different yields of biogas was given by methanogenic microorganism at different temperature conditions. Optimum generation of biogas under mesophilic thermal conditions ranged between 35°C – 40°C at which methanogenic microorganism delivered highest yield of biogas. While optimum production of biogas under thermophilic conditions ranged about 50°C – 60°C at which methanogenic bacteria provided maximum production of gas. However, the natural climatic conditions affected the internal temperature of the digester.

Parawira et al. (2004) estimated the potential of methane production through anaerobic digestion of potato waste separately as well as in co-digestion with the leaves of sugar beet. Effect of different proportion of potato waste and substrate to inoculum ratio on the production of methane and its stability was tested. The percentage share of potato waste ranged between 10% – 80% of total solids, while the ratio of inoculum to substrate ranged between 9.0 – 0.25 was evaluated. Results illustrated that maximum quantity of biogas produced was about 0.320 L/g of VS consumed having 84% methane content. The concentration of total solids was around 40% and the ration of inoculum to substrate was 1:5. In comparison to the separate anaerobic digestion of potato waste, the co-digestion mixture of potato waste and leave of sugar beet in different concentrations showed that the generation of biogas was enhanced around 31 – 62%.

Bouallagui et al. (2003) studied semi continuous tubular digester. The results he got indicated that the hydraulic retention time (HRT) of about 20 day delivered healthier results with a loading rate of 2.8 kg of VS per cubic meter per day. In the hydrolysis phase the pH of the substrate drops down to 6.1but then remained near the neutral pH. The process of digestion was severely affected when the hydraulic retention time (HRT) was decreased to 10 days and pH reduced to 5.0.

Mata-Alvarez et al. (2000) carried a research on fruit and vegetable waste and stated that both the waste are easily biodegradable because of high content of carbohydrate due to which it rapidly produces volatile fatty acids (VFA). But this high potential also effect the digestion process negatively in some cases due to the accumulation of volatile fatty acids (VFA) which ultimately lowers the pH, create acidic environment and inhibit the activities of the microorganisms.

Lo et al. (1985) conducted a study on the comparison of mesophilic and thermophilic conditions for digestion. From the results it was clearly observed that thermophilic mode of digestion was more beneficial as compared to mesophilic mode of digestion. In thermophilic digestion higher stability of the substrate was achieved because of the high degradation rate by the microorganisms.

Zeeman et al. (1985) worked on anaerobic digestion of cattle manure and found out that decreasing of pH from 7.5 – 7.0 under thermophilic conditions enhances the generation of methane four times.

Lane (1979) carried out experiment on the anaerobic digestion of fruit and vegetable waste. The result showed that the organic loading rate higher than 4 g of VS per liter per day decrease the pH in the digester which adversely effected the digestion process and reduced the methane production rate and high production rate of carbon dioxide.

2.7 Studies conducted at IESE, NUST

Gillani (2012) carried out a research on biogas production through anaerobic digestion of cow dung, vegetable waste and co-digestion of these wastes under thermophilic conditions in batch and continuous mode of digestion. He reported that in batch mode, biogas production from cow dung, vegetable waste and co-digestion was 47.7 L, 65 L and 56L per 1 kg of waste respectively. Average methane content in the biogas produced was 50%, 62% and 55% respectively. In continuous mode of digestion cow dung produced 44 L/kg of waste, vegetable waste produced 71.9 L/kg and co-digestion of both wastes generated 55 L/kg. The average methane content was around 50%, 55% and 52% respectively.

Azhar (2012) conducted experiment on biogas production using food waste under thermophilic conditions in batch mode of digestion and reported that food waste produced 0.04 cubic meter of biogas per kg of waste having 60% methane content in it.

Afeeq et al. (2012) also studied biogas production from food waste under thermophilic condition in batch mode of digestion. Their result showed that the cumulative gas produced under these condition was about 38.5 m^3 with gas production rate of 61.61 liter per kilogram of waste.

Chapter 3

METHODOLOGY

In this chapter, the methodology of the whole experimental work like setup of the digester for biogas production, the operational parameters under which the digestion was carried out and different other analysis of the feedstock material done before and after the digestion process will be discussed.

The adopted methodology for the entire experimental work done is as follows,

1. Collection of waste
2. Cutting and chopping of vegetables waste
3. Setup and feeding of the Digesters
4. Estimation of moisture content, dry matter and volatile solid (before digestion)
5. Maintenance of Temperature and pH (during experiment)
6. Biogas collection system (during experiment)
7. Estimation of moisture content, dry matter and volatile solid (after digestion)

3.1 Collection

In this experiment the discarded vegetable waste were used. The sources of vegetable wastes are markets, hotels, restaurants, hostels and domestic wastes. These kinds of wastes have high energy potential but still their destiny in Pakistan is open dumps. Due to this high energy potential vegetable waste was selected for this experiment and for this purpose the discarded vegetable waste produced from Rumi Hostel, NUST was collected. The second feedstock selected for this research was cow dung because it also have high energy potential but thrown to open dumps or applied to agriculture fields as fertilizer untreated. For the experiment fresh cow dung was collected from a dairy facility in H-13 Islamabad. The third material used in this study was leachate. Leachate have high potential of surface and ground water pollution as well as soil and air pollution due to the high organic load present in it. The reason leachate selection for this experiment was its treatment and to enhance the biogas production from the above mentioned waste by the addition of leachate in different proportion to it. The Leachate used in this experiment was collected from a solid waste dump site in I-12 Islamabad.

After collection the waste was weighed by an electronic balance model number SF-400. The total weight of waste used in this experiment was 4.8 kilograms, 2.4 kg vegetable waste and 2.4 kg cow dung. The total volume of 2.4 liters of leachate used in this experiment.

Figure 3.1: Collection of Waste

3.2 Layout of Experimental Setup

The experimental setup used in this research work was based on the setup designed by Salam et al. (2011) in their experiment. Digesters after filled with substrate were placed in hot water container to raise the temperature of substrate. Temperature was controlled with the help of heating rod. The generated gas when released was passed through a tube to a gas collector, made from Graduated glass cylinder, where the volume of gas was noticed by the amount of liquid displaced from the measuring cylinder. Diagrammatic view of complete experimental setup representing water displacement method is shown the in Figure below.

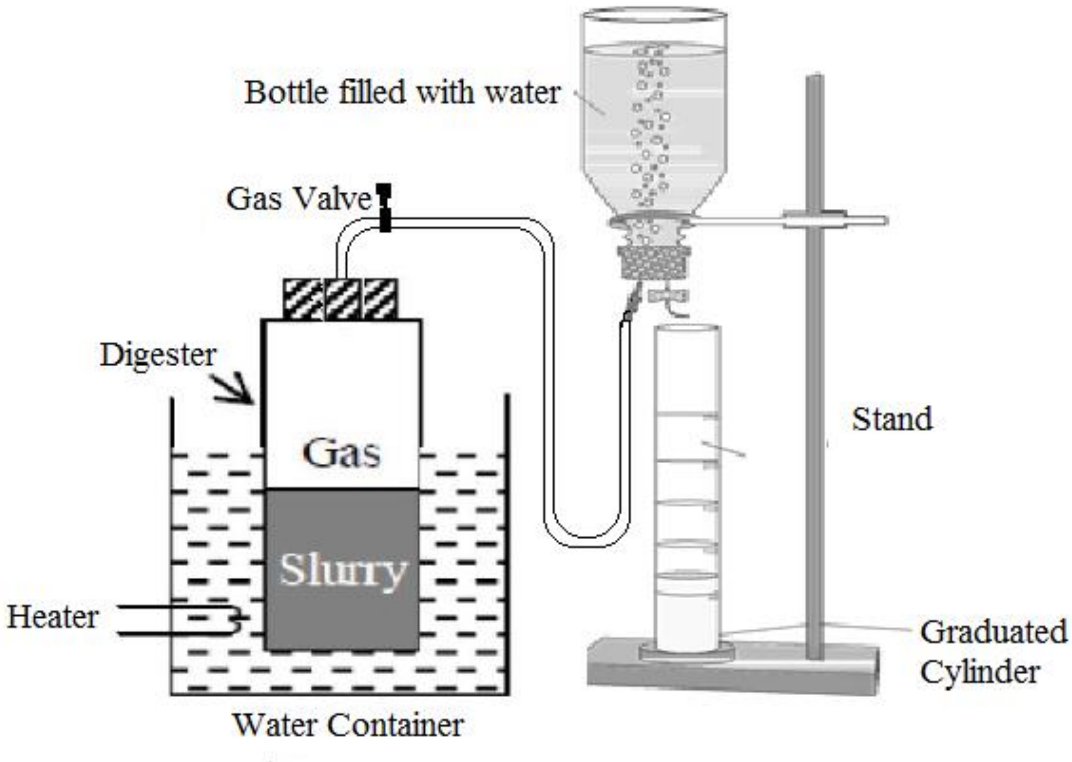


Figure 3.2: Schematic diagram of experimental setup

3.3 Experimental Setup

The digester used in batch experiment was 1.2 liter Plastic Container (used as covering container for water filter). The reason for using this plastic container is that it is rigid and good barrier for gas. To make container completely air tight the top cap was closed tightly. A plastic pipe almost 6 inch in length was pierced through the top of the container. One end of pipe was inside the container for gas collection and other side was connected to plastic pipe which was attached to gas valve. These digester were placed in glass container having water. A 300 watt water heater was used to raise the temperature of water to maintain the temperature of the digesters at the required level.

Figure 3.3: Experimental setup assembly

3.4 Digester filling

After cutting/chopping the vegetable waste, the waste was filled in the digester. Eight digester containers were used for the experiment. The digesters were labeled from one to eight (1-8). Four were used for cow dung and four for vegetable waste. 600 g of waste was put into each digester. For solid part, digester one to four (1-4) were filled with vegetable waste, digester five to eight (5-8) were filled with cow dung. For liquid part, leachate was used in different proportions with water to assess its effect on biogas production. In digester one and five (1&5) 600ml of water was used. In digester two and six (2&6) 400ml of water and 200ml of leachate was used, in digester three and seven (3&7) 200ml water and 400ml leachate was used and in digester four and eight (4&8) 600ml of leachate was used. In this experiment the waste to liquid ratio was 1:1.

Table 3.1: Feed stock proportion in digesters

Digesters	Cow Dung (gm)	Vegetable Waste (gm)	Volume of Water (ml)	Volume of Leachate (ml
1	0	600	600	0
2	0	600	400	200
3	0	600	200	400
4	0	600	0	600
5	600	0	600	0
6	600	0	400	200
7	600	0	200	400
8	600	0	0	600

3.5 Temperature control

Temperature is an essential factor in digestion process. Proper temperature maintenance is important for the better performance of microorganisms. In this experiment the temperature was controlled with the help of hot water. The digester were placed in a glass container filled with water. Water heater of 300 W capacity was used to raise and maintain the temperature of water at the required level i.e. 35^{o}C.

3.6 pH control

pH is an important factor on which the whole digestion process is dependent. For better digestion the required pH ranges from 6 – 8. pH meter was used for the measurement of pH in this experiment. Initially the pH of the substrate used was very low which was adjusted by the addition of the required amount of sodium carbonate (Na_2CO_3) in the digesters containing the substrate. Initial pH of digesters and its adjustment is given in a Table below:

Table 3.2: pH and amount of Na_2CO_3 used for pH adjustment

Digesters	**Iinitial pH**	**Na_2CO_3 added (gm)**	**Final pH**
1	1.1	10	7.63
2	2.82	10	7.52
3	2.71	10	7.1
4	2.33	10	7.15
5	4.85	2	8.21
6	4.82	2	7.81
7	4.63	2	7.21
8	4.81	3	7.28

3.7 Measurement of biogas volume

For the measurement of the volume of biogas produced, liquid displacement method was used. In water displacement method the volume of biogas is measured by the amount of liquid displaced from a tightly sealed gas collector, consisting of bottle full of water, by the biogas released from the digester (Parajuli, 2011). For this purpose a gas measuring equipment or a gas collector was fabricated from a 500 ml gas cylinder sealed with the help of a rubber cork having two openings one as gas inlet and the other as water outlet.

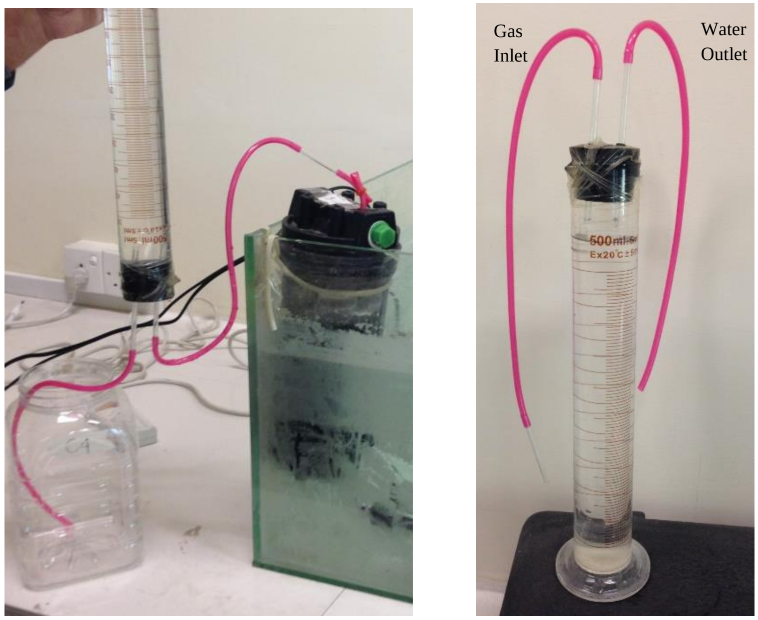


Fig 3.4: Gas collector and gas collection

3.8 Gas Composition

Ghani and Idris (2009) analyzed biogas contents using gas chromatography, therefore the composition was determined for biogas samples by gas chromatography. The gases to be measured by this method were CO_2, CH_4, H_2 and O_2. They were determined using a GC-MS.

3.9 Carbon to Nitrogen ratio

Estimated values for the carbon nitrogen ratio in the substrate used in the experiment were obtained from the vast literature review. No testing was done. Carbon and nitrogen values , which were obtained from the final analysis in the literature were used in the calculations to estimate the C / N ratio in the experiment. For both substrates, the C / N ratio is considered suitable for anaerobic digestion (Barker and Zublena, 1996). The C / N ratio on the substrates given below,

Table 3.3: C/N ratio

C/N ratio of substrate	
Substrate	**C:N ratio**
Cow dung	20:1
Vegetable	33:1

3.10 Organic loading rate

This experiment was carried out under batch mode of digestion and in batch mode of digestion the digesters are fed only once at the beginning of the experiment. The digesters used in this experiment had a working volume capacity of 1.2 liters and a total of eight (8) digesters were used, four (4) for vegetable waste and the other four (4) for cow dung. Each digester was filled with 600 grams of waste either vegetable waste or cow dung as solid portion and 600 ml of liquid portion, the liquid portion consisted of different proportion of leachate with water. This feeding of the digesters was done at the start of the experiment and no further addition was made after that.

3.11 Moisture content in solids

After the preparation of the substrate for the process of anaerobic digestion, a sample was taken for the moisture content analysis. For this purpose a china dish was used. The china dish was thoroughly washed and oven dried at 105^oC.the weight of the empty china dish was measured. The china dish was weigh again after taking a representative sample of the substrate in it. After that the sample was for drying in an oven at 105^oC for 24 hours to get the precise amount of dry solid mass of the substrate. When the sample was dried completely, it was cooled in a desiccator and the weight was measured again. All the reading were noted and the moisture content was

$$\text{Moisture content (\%)} = \frac{A2 - A3 - A1}{A2 - A1} \times 100$$

A1 = China Dish weight in gm

A2 = China Dish + wet sample weight in gm

A3 = China Dish + dried sample weight in gm

3.12 Dry matter content

Along with the measurement of moisture content, dry matter content in the substrate was also acquired in the same experiment. Once the sample took from the substrate was placed in oven for a period of 24 hours, the moisture content was evaporated and the chain dish was left with the dry solid matter only. After the drying the china dish was weighed along with the dry matter and the calculation was done by putting the readings in the formula given below (APHA, 2005).

$$\text{Dry Matter (\%)} = \frac{A3 - A1}{A2 - A1} \times 100$$

A1 = China Dish weight in gm

A2 = China Dish + wet sample weight in gm

A3 = China Dish + Dry sample weight in gm

3.13 Volatile solids

After the measurement of the dry solid matter, the sample dried before was burnt in a muffle furnace for 2 hours at a temperature of 550^{o}C. By doing so all the volatile organic matter was evaporated and only the ash or fixed solids content was left behind. The china dish containing the ash or fixed solids was placed in a desiccator for cooling. After that the weight of the china dish along with the ash content was measured for the final time and the readings were placed in the following formula for the calculation of the volatile organic solids content (APHA, 2005).

$$\text{Volatile solids (\%)} = \frac{A2 - A3 - A1}{A2 - A1} \times 100$$

A1 = China Dish weight in gm

A2 = China Dish weight + dried sample weight in gm

A3 = China Dish weight + ash content weight in gm

3.14 Chemical Oxygen Demand (COD)

The Chemical Oxygen Demand (COD) was measured by using the Open Flux Method. For Chemical Oxygen Demand (COD) 1.5ml of $K_2Cr_2O_7$ (99.5%) & 3.5ml of H_2SO_4 reagents were added to 2.5ml of leachate sample. The samples in the PTFE vial were heated in COD reactor (HACH Company Box 389, Loveland, Colo U.S.A.) at 120^{o}C for 2 hrs. Ferrous Ammonium sulfate (FAS) was used as titrant in the presence of fermion indicator. COD was calculated using the following formula:

$$\text{COD} = \frac{(A-B) \times M \times 8000}{\text{Volume of sample (mL)}}$$

A= Volume of FAS used to titrate the blank in mL

B= Volume of FAS used to titrate the sample in mL

M= Molarity of FAS solution.

Chapter 4

RESULTS AND DISCUSSION

In this chapter the result obtained during the experiment and correlation between different parameters will be discussed.

4.1 Initial Analysis

Results of the characterization of digestion substrate are given below. Initial analysis shows a high total solid content in cow dung. Volatile solids content was higher in vegetable waste as compared to cow dung. Leachate showed highest moisture content due low total solids.

Table 4.1: Initial analysis of the substrates

Parameters	Vegetable Waste	Cow Dung	MSW Leachate
Moisture Content (%)	87.35	80.21	99
Total Solids TS (%)	12.65	19.79	1
Volatile Solids VS (%)	91.33	85.77	95
COD (mg/L)	35612	53478	6749

4.2 Biogas Production

As discussed earlier, in this experiment 600 g of waste and 600 ml of liquid content (different proportions of leachate with water) was used for each substrate. The biogas production started after 2 days for all the eight digesters. After reaching the peak, gas production started decreasing. This increase and decrease of gas showed a decent bell shaped trend which normally happens in batch digestion.

The experiment concluded after 45 days. Gas levels over the first 2 days were factored out. This gas is also typically not necessary as most of the gas is composed of sulfides as digestion begins. Therefore, the data collected shows 45 days of the digestion. Gas analysis after the 2 day period showed a steady increase in methane content. Cumulative gas production rates are shown below.

During the digestion trials, an issue arose regarding the pH of the digesters. The pH in the digester containing vegetable waste drops down to the range of 3.5-4, far below the acceptable levels while the pH in the digesters containing cow dung dropped to the range of 4.5-5.5. To adjust the pH, 6 gm of Na_2CO_3 was added to the digesters (1-4) containing vegetable waste and 4 gm of Na_2CO_3 was added to the digesters (5-8) containing cow dung.

After the pH adjustment the observations of biogas production shows a higher production rate in digesters containing cow dung. Average daily production rates are also higher in these digesters. The reactors containing vegetable waste showed a long startup time to produce biogas in comparison to the digesters containing cow dung.

Amongst the four digesters (1-4) containing vegetable waste, Digester 4, containing highest amount of leachate, produced the overall highest amount of biogas and showed the maximum production of 27.2 L/Kg of VS on day 32, gas production remained high and above 20 L/Kg of VS for almost 13 days. Digester 2 & 3 showed the maximum production of 25 & 26.5 L/Kg of VS respectively on day 32. Biogas production from Digester 1 containing no leachate reached its peak production of 25.5 L/Kg of VS on day 34, production of gas remained consistently high above 20 L/Kg of VS for almost 10 days. Gas production from Digester1 was low amongst the four Digesters (1-4) containing vegetable waste.

For Cow Dung the biogas production from Digester 8 Containing maximum leachate content amongst the four digesters (5-8), produced the overall highest amount of biogas and showed the maximum production of 26.3 L/Kg of VS on day 16, gas production remained high and above 20 L/Kg of VS for almost 17 days. Digester 6 & 7 showed the maximum production of 22 & 22.2 L/Kg of VS on day 26 & 27 respectively. Biogas production from Digester 5 containing no leachate reached its peak production of 16.5 L/Kg of VS on day 30, production of gas remained consistently high above 10 L/Kg of VS for almost 24 days. Gas production from Digester1 was low amongst the four Digesters (5-8) containing cow dung.

The graphical results of biogas production from both vegetable waste and cow dung are given below.

Fig. 4.1: Daily biogas production from vegetable waste

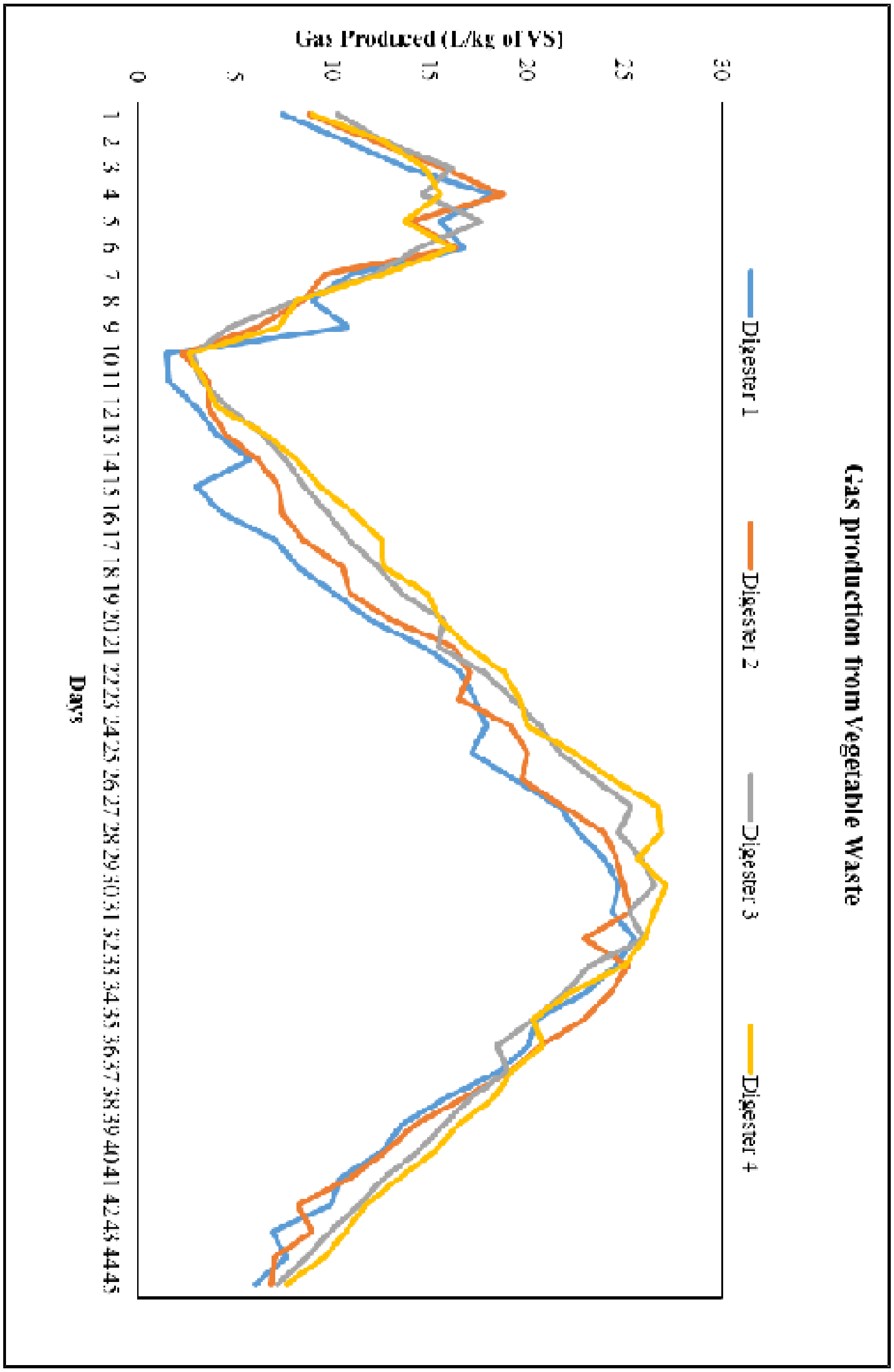
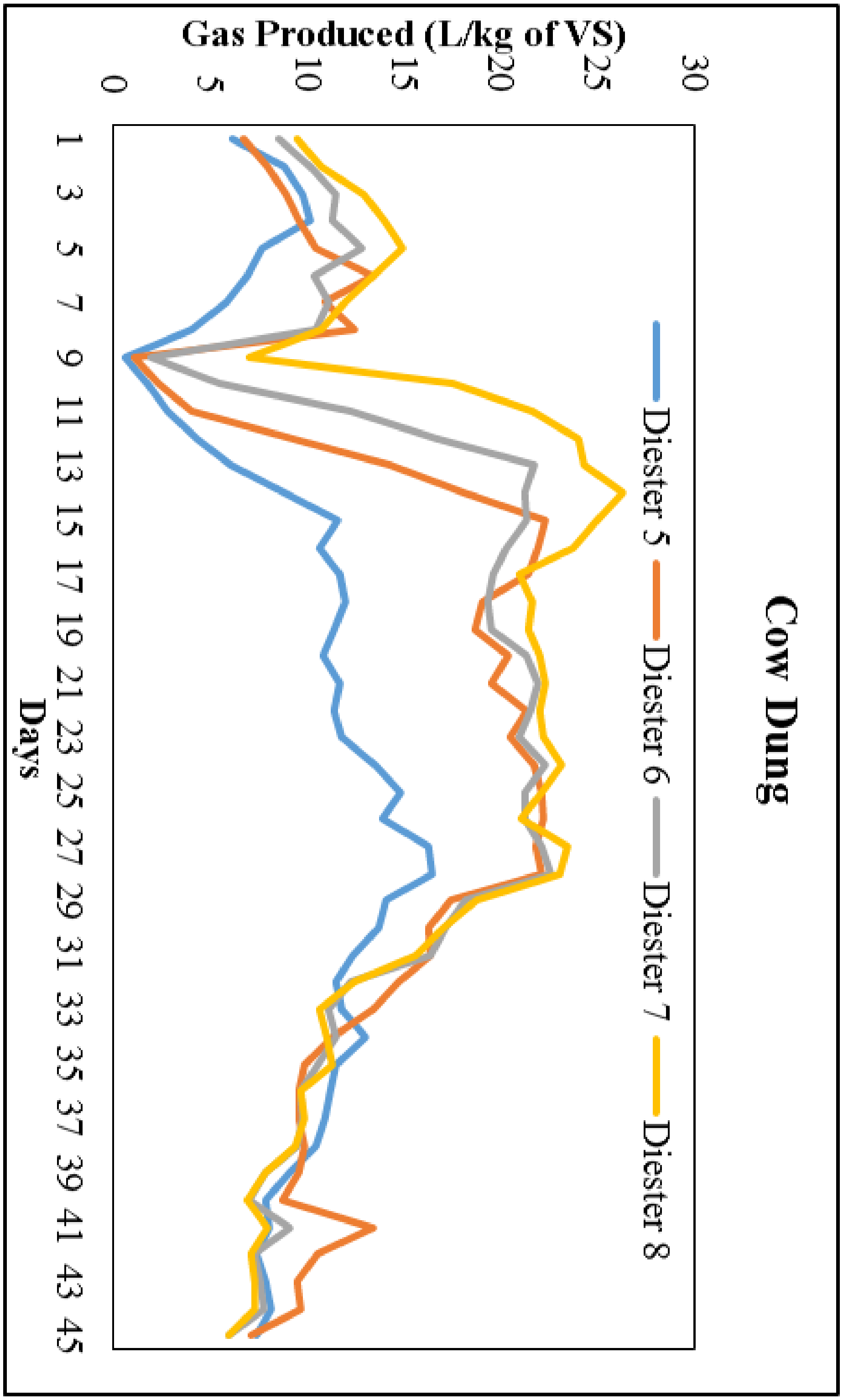


Fig. 4.2: Daily biogas production from cow dung



4.3 Cumulative Biogas Production

Cumulative biogas produced from all the digesters operated under batch digestion conditions is presented in figures below. From the figures it is evident that biogas production was increased with the increase in leachate content in both vegetable waste and cow dung. Digester 4 of vegetable waste containing highest leachate content cumulatively generated highest quantity of biogas which is about 44 litres per 1 kg of waste in a time period of 45 days, with production rate of approximately 700 litres of gas for 1 kg of volatile solids. Cumulative gas production from Digester 8 of cow dung with maximum amount of leachate content produced 63 liters from 1 kg waste, with production rate of approximately 708 litres of gas for 1 kg of volatile solids, which is higher than gas produced from vegetable waste.

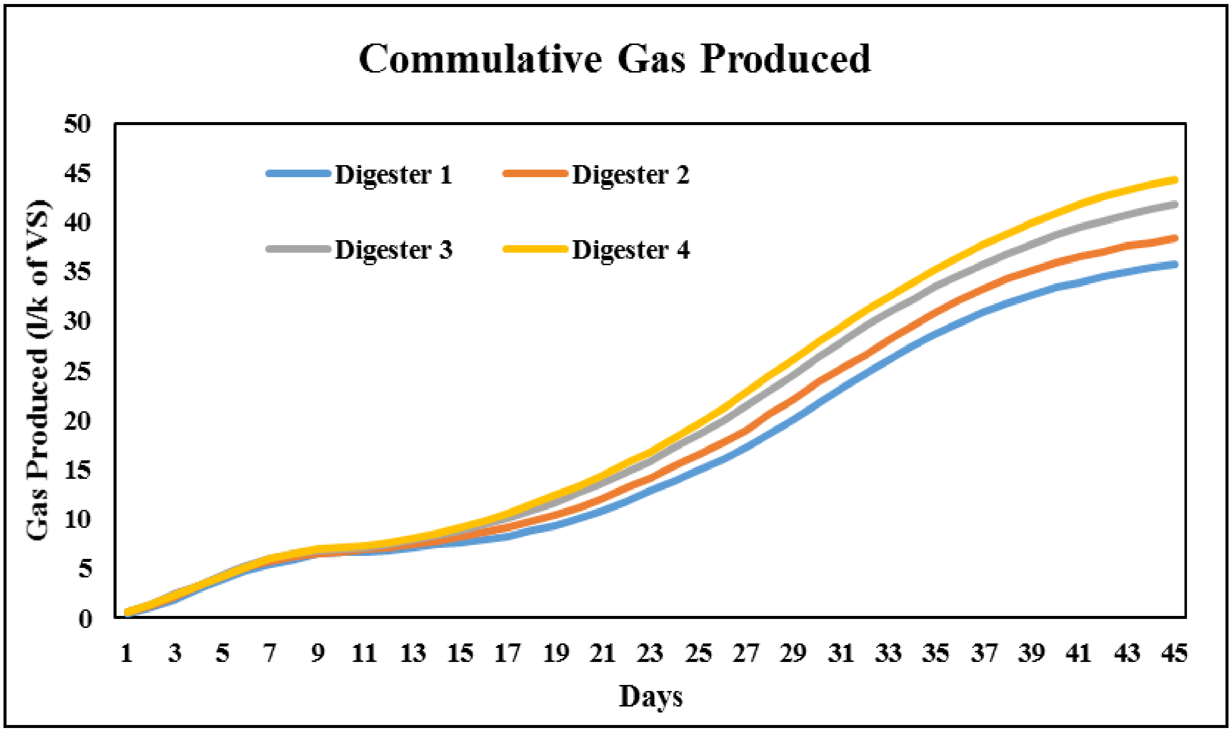


Fig. 4.3: Cumulative gas production from vegetable waste

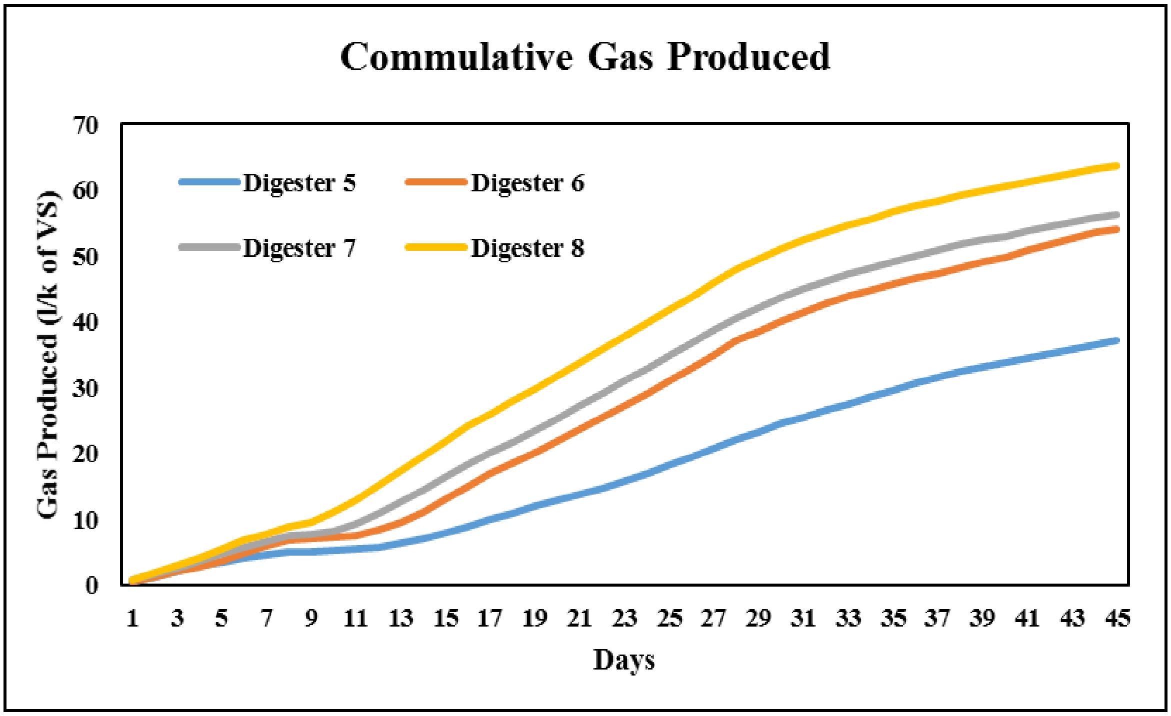


Fig. 4.4: Cumulative gas production from cow dung

4.4 Methane Content

Gas analysis tests were as done using GC-MS. Gas samples were collected and analyzed, primarily to check methane and carbon dioxide content. Samples taken in the Tedlar bags.

The highest methane concentration was found in vegetable waste of about 69%. Biogas produced from Cow dung contain 64% methane content lower than that of vegetable waste.

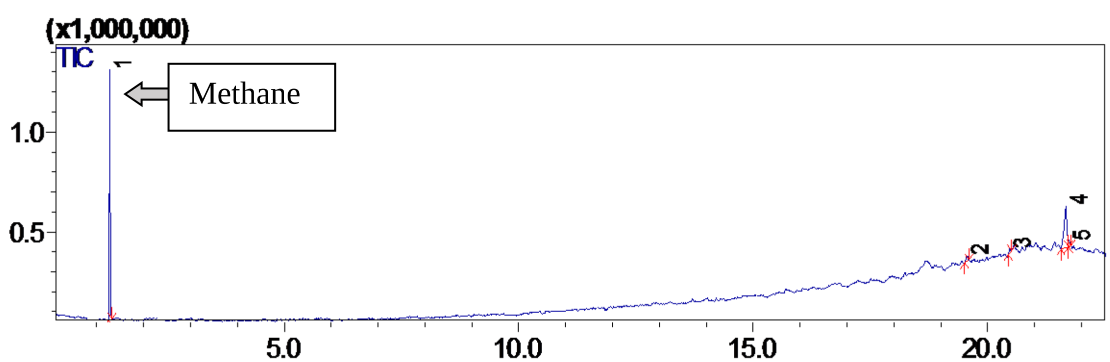


Fig 4.5: Methane content in biogas produced from Vegetable Waste

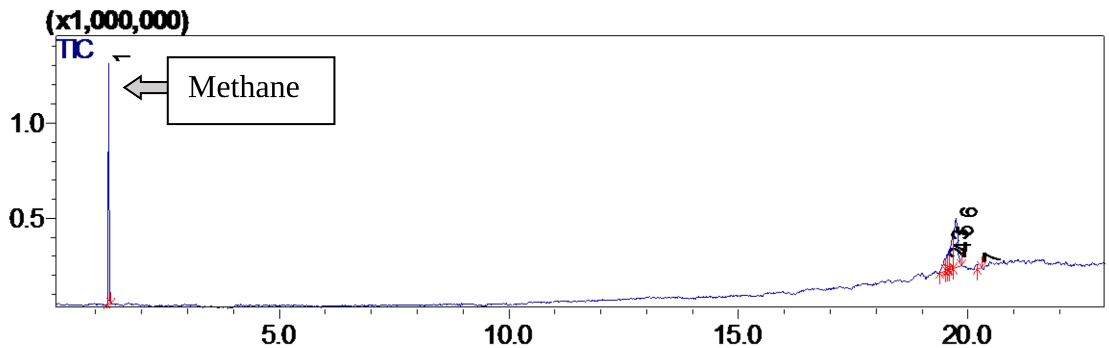


Fig 4.6: Methane content in biogas produced from Cow Dung

4.5 pH of the Digesters

After the preparation of the substrate for anaerobic digestion, pH of the substrates was adjusted to the required optimum level. According to Williams (1998), the preferred range of pH for the efficient functioning of the methanogenic micro-organisms is around 6.8 – 7.5. Metcalf and Eddy also reported that the most appropriate range of pH for the growth of bacteria is around 6.5 – 7.5.

Initially the pH of the substrates was low. The pH of digester (1-4) containing Vegetable waste was very low ranges from 1.1 to 2.8. While that of the digesters (5-8) containing Cow Dung ranges from 4.63 to 4.85. The pH needed to be adjusted so the required amount of Na_2CO_3 was used to raise the pH to the required level adequate for digestion as shown in Table 4.1.

The pH of the digesters was noted weekly. It is necessary for biogas production that pH should become acidic so that methanogeic microorganisms can utilize that acid to produce methane and CO_2 and afterwards pH comes to its neutral state.

Table 4.2: Amount of Na_2CO_3 used for pH adjustment before digestion

Digesters	**Iinitial pH**	**Na_2CO_3 added (gm)**	**Final pH**
1	1.1	10	7.63
2	2.82	10	7.52
3	2.71	10	7.1

4	2.33	10	7.15
5	4.85	2	8.21
6	4.82	2	7.81
7	4.63	2	7.21
8	4.81	3	7.28

4.6 Effect of pH on biogas production

In the process of digestion pH plays a key role. In this experiment it was observed pH is related directly to the production of biogas, as the pH deviated from the required range the production of biogas was effected and decreased. According to Lane (1979) when the organic loading rate (OLR) is above 4 gm of volatile solids (VS) per liter (L) per day for fruit and vegetable waste (FVW) causes decrease in the pH, due to which the gas production also decreases and higher carbon dioxide content is produced. Alvarez et al. (2000) stated in his report that substrates rich in carbohydrate like fruit and vegetable waste (FVW) produce higher quantity of volatile fatty acids (VFA) therefore have a potential tendency of volatile fatty acids (VFA) accumulation which may lead to acidity, lower pH and process inhibition. The pH optimum for the digestion process ranges from 6.0 – 8.0. Any deviation from this range either above or below create problems for the digestion process because the microorganism and their enzymes are very sensitive to variations in pH (Yadvika et al., 2004).

During this experimental work the maximum and steady biogas production was obtained at pH range of around 6.7 – 7.3 in the digesters. From the figures given below it can be clearly observed that the decrease in the pH at the start of the experiment effected the digestion process and the biogas production also decreased. After the adjustment of pH in all the digesters, rise in the production of the biogas can be seen in the graphs. It can also be noted that the rise in the biogas production in the digesters containing cow dung (digesters 5 – 8) was quick while the biogas production increase in the digesters containing vegetable waste (digesters 1 – 4) took more time.

Figures 4.7 & 4.8 depicts the effect of pH on production of biogas from vegetable waste and cow dung.

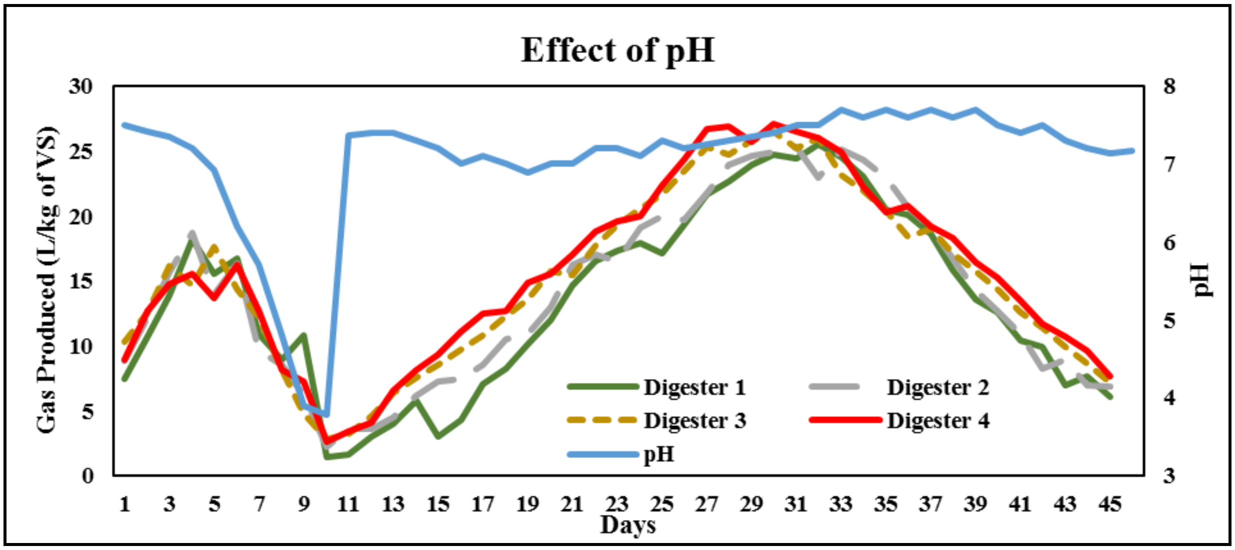


Fig. 4.7: Effect of pH on biogas production from vegetable waste

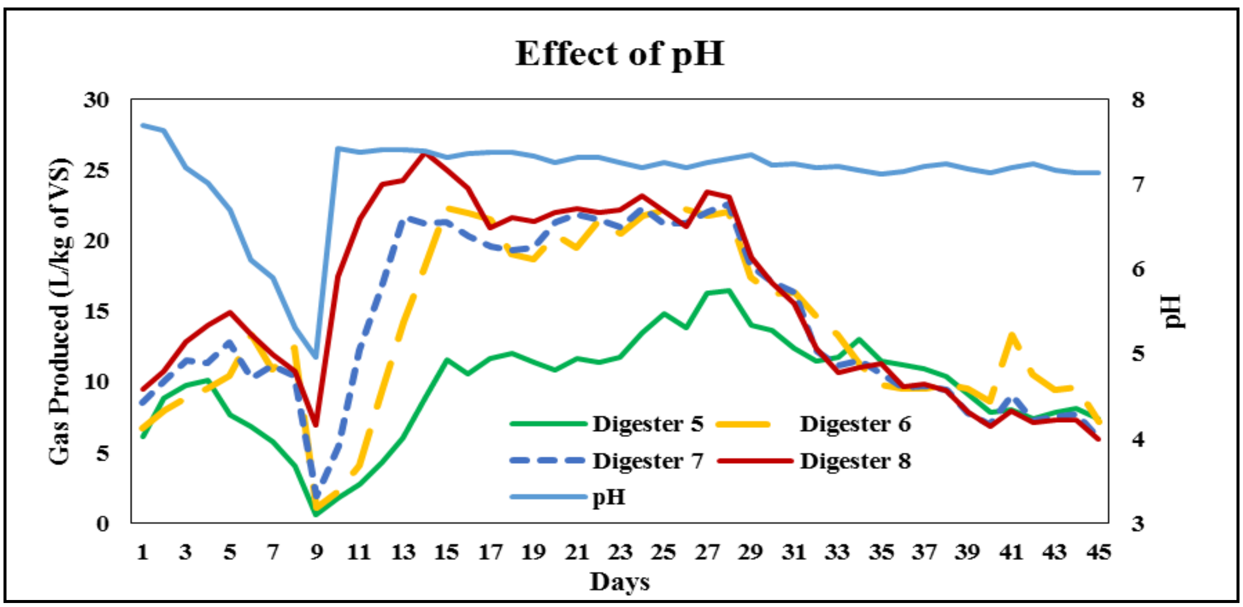


Fig. 4.8: Effect of pH on biogas production from cow dung

4.7 Total Solids and Volatile Solid Reduction

According to Budiyono et al. (2010) the most suitable level of total solids (TS) for the efficient production of biogas through anaerobic digestion ranges between 7.4 % – 9.2 %.

Dairy waste after excretion contains total solids (TS) around 12% and volatile solids (VS) above 85% of the total solids (TS). Vegetable and fruit wastes are recognized for having high quantity of moisture content mostly above 80%, high organic volatile solids (VS) above 95% of the total solids (TS). These wastes have the ability of fast degradation due to which it is considered as the most suitable raw material for anaerobic digestion and energy recovery (Appels et al., 2011; Arvanitoyannis et al., 2008). Bruke (2001) stated in his report that total solids (TS) level that ranges between 6 % - 7% gives higher reduction efficiencies and better digestion.

In this batch experiment the total solids (TS) and volatile solids (VS) were tested before and after the digestion process. Tables and graphs given below depicts the quantity of total solids (TS) and volatile solids (VS) and the reduction due to digestion.

4.7.1 Total Solids (TS)

Total solids of the substrate was measured before and after digestion. Before digestion the total solids of the digesters (1-4) containing vegetable waste ranges from 6.3% to 6.9%. While the TS after digestion ranges from 3% to 3.3%. The maximum reduction of 70.23% occurs in the digester 4 containing the highest leachate content (600 ml) and the minimum reduction of about 64.07% occurs in the digester 1 containing only water and no leachate content.

Before digestion the TS of the digesters (5-8) containing cow dung ranges from 9.8% to 10.5%.While the TS after digestion ranges from 3.8% to 5%. The maximum reduction of 66.67% occurs in the digester 8 containing the highest leachate content (600 ml) and the minimum reduction of 51.82% occurs in the digester 5 Containing only water and no leachate content.

Both Vegetable waste and Cow Dung shows the same pattern of increase in the reduction of total solids (TS) with the increase in the leachate content.

Table 4.3: Reduction total solids (TS) before and after digestion

Digesters	Before (%)	After (%)	Difference (%)	%age Decrease
1	6.32	2.27	4.05	64.07
2	6.52	2.11	4.41	67.59
3	6.72	2.09	4.63	68.92
4	6.92	2.06	4.86	70.23
5	9.89	4.87	5.03	50.82
6	10.09	3.93	6.16	61.05
7	10.29	3.74	6.55	63.63
8	10.49	3.49	6.99	66.67

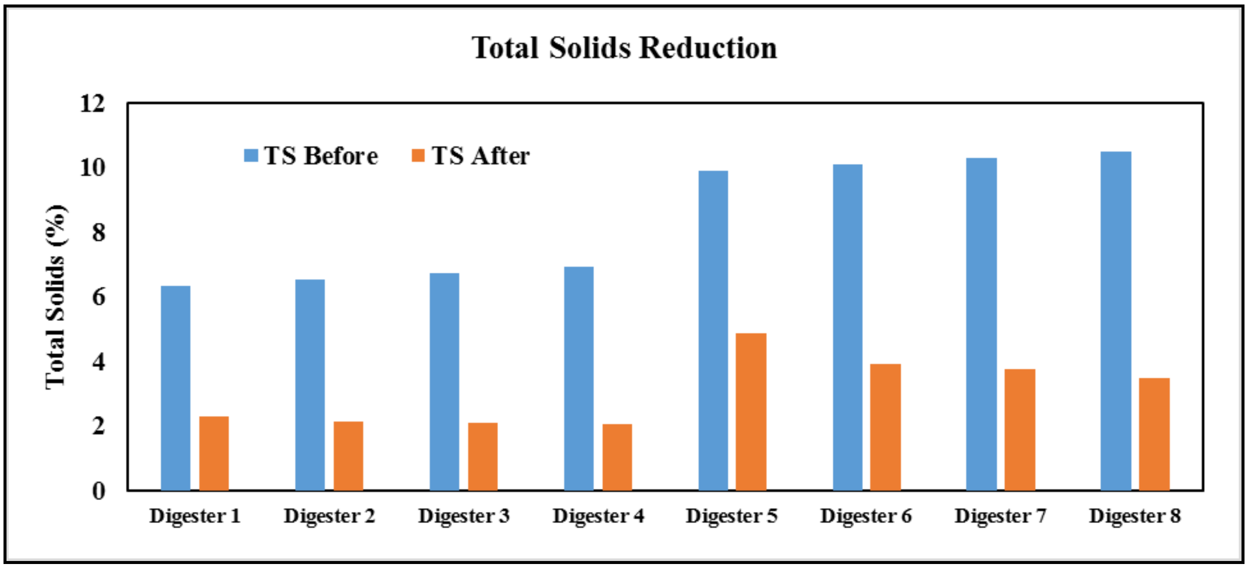


Fig. 4.9: Reduction total solids (TS) before and after digestion

4.7.2 Volatile Solids (VS)

Volatile solids (VS) of the substrate was measured before and after digestion. Before digestion the volatile solids (VS) of the digesters (1-4) containing vegetable waste was 91%. While the VS after digestion ranges from 22.6% to 26.4%. The maximum reduction of 84.69% occurs in the digester 4 containing the highest leachate content (600 ml) and the minimum reduction of about 78.76% occurs in the digester 1 containing only water and no leachate content.

Before digestion the TS of the digesters (5-8) containing cow dung was about 85%. While the TS after digestion ranges from 63% to 78%. The maximum reduction of 78.34% occurs in the digester 8 containing the highest leachate content (600 ml) and the minimum reduction of 54.25% occurs in the digester 5 Containing only water and no leachate content.

Both Vegetable Waste and Cow Dung shows the same pattern of increase in the reduction of Volatile Solids (VS) with the increase in the leachate content.

Table 4.4: Reduction Volatile Solids (VS) before and after digestion

Digesters	Before	After	Difference	%age Decrease
1	91.33	19.39	71.93	78.76
2	91.33	17.22	74.10	81.14
3	91.33	15.98	75.34	82.49
4	91.33	13.98	77.35	84.69
5	85.77	31.24	54.53	63.57
6	85.77	22.63	63.14	73.61
7	85.77	20.77	64.99	75.78
8	85.77	18.57	67.19	78.34

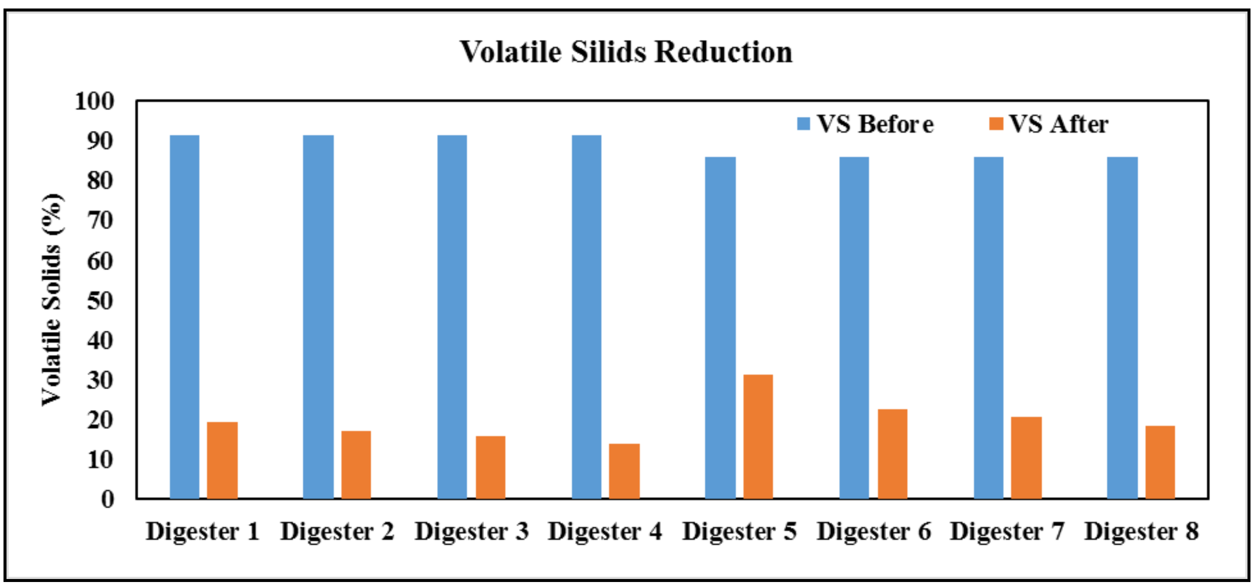


Fig. 4.10: Reduction Volatile Solids (VS) before and after digestion

4.8 COD

Chemical oxygen demand (COD) is the degree of measurement of oxygen consumption when organic matter is chemically broken (Metcalf and Eddy 2003). COD of all the eight digesters was determined before and after digestion. Before digestion the COD of the digesters (1-4) containing vegetable waste ranges between 17806-21855 mg/L while the COD of the digesters (5-8) containing cow dung ranges between 26739-30788 mg/L. The percentage removal of COD for the digesters (1-4) of vegetable was 77%-86%. Whereas the percentage reduction in the digesters (5-8) containing cow dung was found between 66%-77%. Sakar et al. (2009) carried out anaerobic digestion of livestock waste treatment, where the chemical oxygen demand (COD) removals ranged from 57 and 78%. Dawood et al. (2011) found that the percentage COD reduction has been observed to be 50.0% at the retention time of 72 days. The percentage COD reduction increases with increase of leachate content in the digesters. The COD reduction of vegetable waste was more as compared to that of cow dung. The comparison of percentage removal among the digesters is given in the figure.

Table 4.5: Reduction COD before and after digestion

Digesters	**COD (mg/L) (Before)**	**COD (mg/L) (After)**	**Difference**	**%age Reduction**
1	17806	4069	13737	77.15
2	19155.8	3776	15379.8	80.29
3	20505.6	3417	17088.6	83.34
4	21855.4	2984	18871.4	86.35
5	26739	8923	17816	66.63
6	28088.8	8128	19960.8	71.06
7	29438.6	7936	21502.6	73.04
8	30788.4	6784	24004.4	77.96

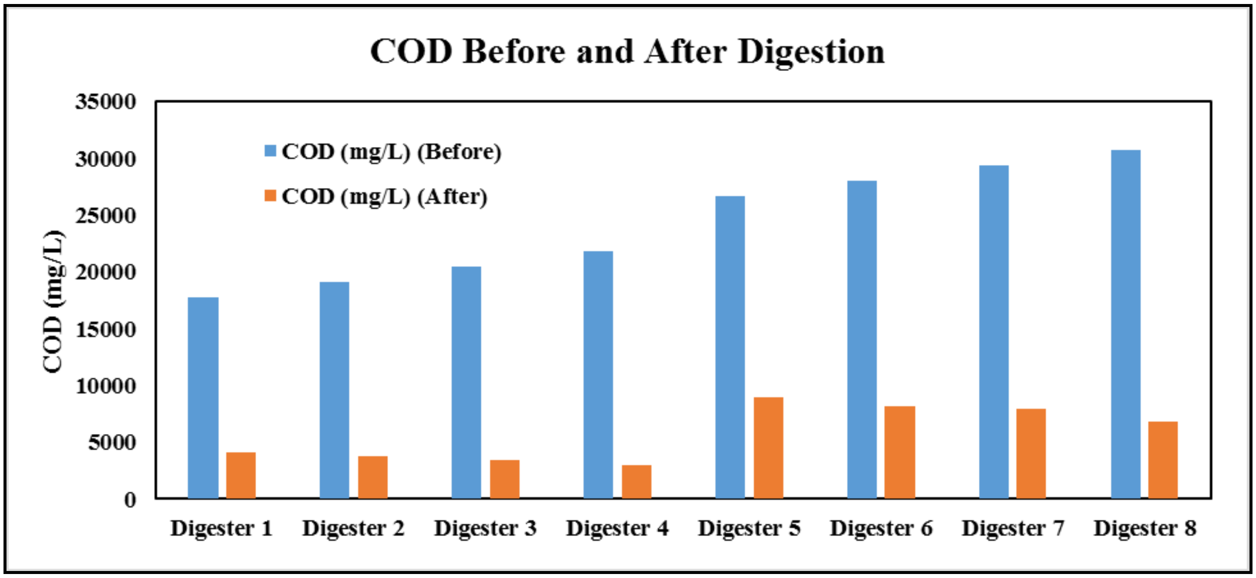


Fig. 4.11: Reduction COD before and after digestion

Chapter 5

CONCLUSIONS AND RECOMENDATIONS

5.1 Conclusions

The research conducted here set out to show a possible means of increasing biogas production potential of cow dung and vegetable waste through addition of municipal solid waste leachate. In agreement with past studies, this methods tested had a positive impact on production rate from both kinds of waste.

The results of this research on the production of biogas from vegetable waste and cow dung has shown that:

- Flammable biogas can be produced from these wastes through anaerobic digestion for biogas generation. 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 cow dung and vegetable waste has great potentials for generation of biogas and its use should be encourage due to its early retention time and high volume of biogas yields.
- It was also observed that biogas production was enhance with the increase of the leachate content within the digester of both kinds of waste.
- The increase in biogas production due to leachate addition was more visible and considerable as compared to vegetable waste.
- Biogas composition comparison showed that vegetable waste produced high methane content as compared to cow dung.
- The reduction of Total Solids (TS), Volatile Solids (VS) and Chemical Oxygen Demand (COD) was also amplified with the increase of the leachate content in the digesters.
- Also in this study, it has been found that temperature variation, PH and Concentration of Total solid etc., are some of the factors that affected the volume yield of biogas production.

5.2 Recommendations for future studies

Noted in this experiment is the fact that while the procedure concluded after 45 days of testing, gas production could have continued. For a full view of the methane production potential of these mixtures, the experiment could be run similarly for a longer period of time. This can also be done through a reduction of the amount of solids introduced into the reactors at the start of the experiment.

Future studies in the anaerobic digestion and co-digestion of these materials can focus on further optimizing the digestion environment, through nutrient addition or additional pretreatment strategies. Nutrient balance could have an impact on the actions of the waste within the system as well as the process of microbial digestion.

Different studies can also be conducted under different temperature ranges. This study was conducted under mesophilic conditions.

The experiment conducted focused on lab-scale batch operations. If this procedure is to be expanded, a pilot-scale experiment would show the viability of producing methane efficiently from co-digestion. Obtaining a steady supply of digestion material, producing a stream of methane, and potentially switching to a continuous system can all provide studies into the possibility of adapting this data to a larger scale. In this way, a potential efficient methane source could be derived.

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ANNEXURES

Annexure # 1

Daily Gas Production

Gas Produced (L/Kg of VS)								
Day	Digester 1	Digester 2	Digester 3	Digester 4	Digester 5	Digester 6	Digester 7	Digester 8
1	7.50	8.81	10.31	8.96	6.09	6.74	8.49	9.44
2	10.68	12.17	12.62	12.65	8.84	7.99	10.10	10.74
3	13.85	15.66	16.15	14.76	9.72	8.85	11.51	12.87
4	18.18	18.74	14.65	15.55	10.11	9.53	11.32	13.98
5	15.58	13.98	17.64	13.70	7.66	10.39	12.81	14.90
6	16.73	16.36	14.38	16.21	6.87	13.38	10.29	13.42
7	10.96	9.65	12.21	12.65	5.79	10.87	11.13	11.94
8	8.94	8.53	8.14	8.17	4.03	12.41	10.47	10.74
9	10.82	6.15	4.75	7.25	0.59	1.06	1.89	6.94
10	1.44	2.24	2.85	2.64	1.77	2.31	5.47	17.49
11	1.59	3.64	3.26	3.43	2.75	4.04	12.27	21.57
12	3.03	3.64	4.61	4.08	4.32	9.24	16.70	23.97
13	4.04	4.47	6.38	6.59	5.99	14.24	21.70	24.25
14	5.77	6.15	7.60	8.17	8.84	18.09	21.23	26.29
15	3.03	7.27	8.55	9.36	11.58	22.33	21.33	24.99
16	4.33	7.41	9.77	11.07	10.60	21.94	20.29	23.70
17	7.07	8.53	10.85	12.52	11.68	21.46	19.63	20.92
18	8.22	10.49	12.35	12.65	11.98	19.05	19.34	21.66
19	10.10	10.91	13.57	14.89	11.39	18.67	19.53	21.38
20	11.97	13.01	15.74	15.55	10.80	20.40	21.33	22.03
21	14.72	16.22	15.47	17.00	11.68	19.53	21.89	22.31
22	16.59	17.06	17.77	18.84	11.39	21.36	21.51	22.03
23	17.31	16.50	19.27	19.63	11.78	20.50	20.95	22.21
24	17.89	19.16	20.62	20.03	13.45	21.75	22.27	23.14
25	17.17	20.00	21.71	22.40	14.82	22.13	21.23	22.12
26	19.33	19.72	23.47	24.38	13.84	22.23	21.23	21.01
27	21.64	21.82	25.37	26.75	16.30	21.77	22.08	23.42
28	22.67	23.99	24.74	26.88	16.49	22.06	22.61	23.05
29	23.95	24.61	25.87	25.69	14.04	17.42	18.21	18.79
30	24.70	24.97	26.54	27.14	13.65	16.26	17.08	17.03
31	24.40	25.31	25.24	26.56	12.37	16.36	16.32	15.55
32	25.54	22.93	26.05	26.04	11.49	14.72	12.27	12.40

33	24.56	25.17	23.20	24.98	11.78	13.38	11.13	10.64
34	23.08	24.33	21.98	22.27	13.06	11.26	11.51	11.01
35	20.49	22.93	20.35	20.29	11.49	9.82	10.57	11.29
36	20.05	20.70	18.45	20.82	11.19	9.53	9.62	9.63
37	18.61	19.16	19.00	19.24	10.90	9.53	9.72	9.81
38	15.87	16.78	17.10	18.32	10.41	9.82	9.44	9.35
39	13.56	14.26	15.74	16.47	9.13	9.53	7.83	7.87
40	12.55	12.73	14.38	15.28	7.85	8.66	6.98	6.85
41	10.39	10.91	12.62	13.44	8.05	13.38	9.06	7.96
42	9.95	8.25	11.40	11.73	7.36	10.49	7.27	7.13
43	6.92	8.95	9.90	10.67	7.85	9.43	7.55	7.31
44	7.65	6.99	8.68	9.62	8.15	9.62	7.74	7.31
45	6.06	6.85	7.19	7.64	7.36	7.12	5.94	5.92

Annexure # 2:

Snapshots of Different Activities and Equipment

<u>Waste Collection</u>

<u>Leachate Collection</u>

<u>Weighing of Waste</u>

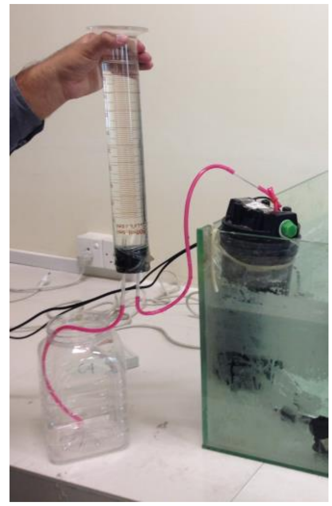
<u>Chopping of Waste</u>

<u>Digester Filling</u>

<u>Setup Assembly</u>

Digester

Gas Collector



Gas Collection

Gas Collection For Analysis

Tedlar Bag

pH Meter

Oven

Muffle Furnace

Digestion Reactor

GC-MS