BIOGAS PRODUCTION FROM POULTRY MANURE USING A NOVEL SOLAR ASSISTED SYSTEM

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إنتاج الغاز الحيوي من مخلفات الدواجن معزز بوحدة نظام الطاقة الشمسية

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The findings, interpretations and conclusions expressed in this study do not necessarily express the views of Birzeit University, the views of the individual members of the M.Sc. Committee or views of their respective employers.

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Dedication

To my parents

for all the love, encouragement, support and prayers

Acknowledgment

My gratitude and sincere thanks are due to Dr. Rashed Al-Sa’ed for being an excellent supervisor, for his suggestions and comments, research assistantships, encouragement his valuable guidance, support, time and encouragement during my research study.

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Abstract

Palestinian farmers are suffering from shortage of energy sources and from bad environmental situations due to the accumulations of manure near their farms. The results of this research can help those farmers, by applying this project on their farms and providing an alternative source of energy from available manure.

In this study, 0.5m^3 biogas plant was built, and operated by poultry manure in continuous feeding mode; poultry manure was suitable substrate , with total solid content 20%, and C: N ratio 32, the daily average of biogas production was108 L per a day. Solar system was used in order to increase the temperature of the digester and enhancement the anaerobic process at October and November months. The biogas production was increased by 88% and the temperature increased by 37% by using solar system.

Biogas and the spent slurry were the two main end products. Biogas was directly used for farm heating purposes as substitute of natural gas; the amount of heat that generated from the biogas was 777MJ. The methane percentage in biogas was 46% to 66%. The spent slurry was an excellent fertilizer; it has an NPK ratio of 1:1.3:1.3. The anaerobic digester and the sun drying of the slurry are able to destroy most of pathogens that may present by reduction the FS to 3log 10.

The financial analysis of the biogas plant shows great potential for making profit on the capital investment. The NPV, IRR, BCR, and payback period of financial analysis are 3,535$, 26.8%, 1.57, and 3.2 years respectively. This shows that the economic profitability of the project is expected to increase, making investment in more worthwhile to farmers, since the substrate available.

الملخص

يعاني المزارع الفلسطيني من قلة توفرمصادرالطاقة اللازمة لممارسة حياته اليومية ، و يتكبد عناء دفع مبالغ طائلة من أجل توفير هذه المصادر، كما أنه يعاني من أعباء التخلص من النفايات والمخلفات الزراعية التي تتراكم حول المزرعة مسببة الكثير من المشاكل البيئية والصحية. يمكن أن يكون لنتائج هذا البحث أثر كبير على المزارعين الفلسطينين حيث يمكنهم الإستفادة من هذه النتائج لإنشاء محطة للغاز الحيوي في مزارعهم، و التي تعتمد على المادة العضوية المتوفرة لديهم في مخلفات المزارع.

في هذا البحث تم إنشاء محطة غاز حيوي ضمن نطاق صغير بحجم يبلغ 0.5 $م^3$ ، حيث تم تشغيل هذه المحطة بتزويدها بشكل دائم ومستمربمخلفات الدواجن ، وكانت مخلفات الدواجن مناسبة للتخمر اللاهوائي. فبلغت نسبة المواد العضوية الصلبة 20% ، ونسبة الكربون إلى النيتروجين 32، بحيث كان معدل إنتاج الغاز الحيوي يومياً 110 لتر.

وقد تم استخدام النظام الشمسي في شهري أكتوبر ونوفمبر للتدفئة الهاضم وللزيادة درجة الحرارة وتعزيز عملية التخمر اللاهوائي ، حيث ساهم استخدام النظام الشمسي برفع درجة حرارة الهاضم بنسبة 37% ، ومعدل إنتاج الغاز بنسبة 88%. وتم استخدام الغاز الحيوي في التدفئة داخل المزرعة كمصدر بديل عن الغاز الطبيعي، حيث بلغت الطاقة المنتجة من الغاز الحيوي حوالي 777 ميجا جول ، وكانت تتراوح نسبة غاز الميثان ما بين 46% إلى 66%.

ويمكن الإستفادة أيضاً من مخلفات الدواجن التي تم تخميرها لفترة زمنية معقولة وتجفيفها بواسطة أشعة الشمس باستخدامها كسماد عضوي ممتاز للأغراض الزارعية. وقد أظهرت التحاليل المخبرية لهذه المواد بأن نسبة النيتروجين إلى الفسفور والبوتاسيوم 1: 1.3: 1.3 ، وتم خفض البكتيرية العقدية البرازية (FS) إلى 3 لوغارثم 10.

في هذا البحث أيضاً تبين أن التحليل المالي لمحطة الغاز الحيوي يظهر إمكانات كبيرة لتحقيق الربح على رأس المال المستثمر. حيث أن صافي القيمة الحالية ومعدل العائد الداخلي ونسبة تكلفة المنفعة وفترة الاسترداد المالي هي 3535 دولار، 26.8٪، و1.57 و 3.2 سنوات على التوالي. هذا يدل على أن من المتوقع أن يزداد الربح الاقتصادي للمشروع، مما يجعل الاستثمار فيه مجدياً للمزارعين، حيث أن المادة العضوية متاحة.

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List of Abbreviations

AD	Anaerobic Digestion
ARIJ	Applied Research Institute Jerusalem
BMP	Biochemical Methane Potential
BCR	Benefit- Cost Ratio
C:N	Carbon to Nitrogen Ratio
CFU	Colony Forming Unit
COD	Chemical Oxygen Demand
CSTR	Continuously Stirred Tank Reactor
FAO	Food and Agriculture Organization
FS	*Streptococcus faecalis*
HRT	Hydrolic Retention Time
ICP	Inductively Coupled Plasma
IIR	Internal Rate of Return
MJ	Mega Joules
NPK	Nitrogen Phosphorus Potassium Ratio
NPV	Net present Value
OLR	Organic Loading Rate
PBP	Payback period
PCBS	Palestinian Central Bureau of Statistics
TAB	Total Annual Benefits
TNK	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
TS	Total Solids
TVS	Total Volatile Solids
VFA	Volatile Fatty Acids
WFO	World Food Organization

Chapter One

Introduction

1.1 Background

Solid waste management and production of renewable energy becomes an important issue around the world; energy production from solid waste is a sustainable strategy to address the worldwide energy and climate change challenges (Khoiyangbam *et al*., 2004).

Biogas produced from animal waste is widely used as a renewable energy source. This source of energy is regarded as cheap and cleans (Thu *et al*., 2012). Chicken waste is being used as feedstock for biogas digesters; chicken manure is consisting not only from bird extra, but also may has feathers, and wood chips or saw dust.

Through the anaerobic fermentation these complex of organic chicken manure are converted to organic acid which transformed finally to a biogas by microorganisms. The slurry which is remaining after this process is rich in nutrients and could be used as biofertilizers and soil amendment.

The biogas that's produced can be upgraded to fuel used in furnaces and stationary engines for heating and electricity generation. The biogas is consist of methane (54% - 80%), carbon dioxide (20% - 45%), and trace amounts of other gases such as hydrogen, carbon monoxide, nitrogen, oxygen, hydrogen sulfide ,and other hydrocarbon (Khoiyangbam *et al*., 2011). Biogas also being used as natural gas substitute for heating (Khoiyangbam *et al*., 2004).

The poultry production sector in Palestine contributes the biggest present of the gross agricultural output and the most important agricultural sector (PCBS, 2013). Therefore; there is a need to install effective treatment technologies, to get rid of these poultry manure. It is reported that the poultry manure can be a good feedstock for processes (Yetilmezsoy *et al*., 2008).

Biogas plant models play an important in anaerobic digestion process; these models can also provide good mechanisms by optimizing mount of biogas. Several factors such as operating temperature, pH, organic loading rates and substrate concentration can affected the stability of anaerobic digestion process, because they can directly affect the activity of microbial population. For this reason, optimal ranges of process-related parameters should be chosen in design and operation of anaerobic digesters to increase the ability of bacterial population and to produce methane as a valuable source of renewable energy.

This is study aim to produce a biogas from poultry manure, which consists mainly of poultry waste, and small wood chips, the biogas produced can be used in heating of a farm this technology can be used by farmers to produce heating or electricity as small-scale application in their farms.

1.2 Problem Description

In Palestine, many chicken farms have bad environmental situations. These farms especially in Palestinian villages are producing a lot of manure every months and this manure accumulates near the farm make a lot of environmental problems, such as insects, orders, along with a bad view. In addition to that, this manure indirectly affects groundwater pollution and eliminates some types of plants.

Palestine is also suffering from less of energy sources. The Palestinians are depending on external sources to meet their energy demands. Around 80% of their energy sources come from neighboring countries (Ismail *et al*., 2013), and it relies on Israel for 100% of its fossil fuel imports and for 87% of its electricity imports. The conversion of animal waste into biogas has the potential to meet the needs of 20% of the rural population. The conversion of unused agricultural residue into biodiesel could replace 5% of the imported diesel (Abu Hamed *et al*., 2012).

Therefore, the renewable energy resources show a significant challenge to the Palestinians for alternative energy sources. As long as there are a lot of resources that can be exploited for the production of energy, for example using biogas technology as energy source (Ouda, 2012). The Palestinians experience in biogas production is still young. There are few research and pilot projects on biogas production (Naima and Al-Aghab, 2001).

Several biogas designs are now used in the world, which matched with different substrates. According to (Khoiyangbam *et al*., 2011) the large biogas production was from poultry manure. Therefore in this study it is necessary to design a small scale biogas digester with a lower cost to achieve efficient process, which allows optimal uses of available resources and optimal of biogas productions.

1.3 Study Objectives

The main objective of this research study is to investigate the feasibility of biogas production through anaerobic digestion of poultry manure at a small-scale in a Palestinian farm. The feasibility of using produced methane as thermal heating will be explored. Production of biogas from poultry manure can help other Palestinian farmers wide spread this technology in their farms to save money and make the environment healthier and less polluted.

This process will give economic and environmental benefits. That can reduce environment pollution and improve health and clean environment. In addition, it will give farmers another source of energy.

1.4 Scope of the Study

- Fresh chicken manure was used as a substrate, which was obtained from the study farm in Bieat Our Al-Foqa – Ramallah.
- The biogas plant (pilot scale digester) was constructed near the farm with volume of 500L, and in contentious mode of feeding.
- The digester was operated at mesophilic temperature using assessed solar system.
- A laboratory scale was done to conduct Biochemical Methane Potential (BMP).

1.5 Project location

This study was carried out on chicken farm in Beit Our Al Foqa village of Ramallah City, which is located 10 km west of Ramallah. Beit Our has a meditation climate, of monthly average temperature ranges from 7.5 to 10 °C in the winter to 30 °C in the summer.

The chicken farm has a total area of 140 m^2 accommodated 1800 birds mainly every 50 day. Annual output of waste and manure from the chicken farm are approximately 6.57 ton (18 kg per a day); natural gas was used in order to heat the farm before biogas project applied. Figure 1-1 shows the exterior and interior of the farm.

a. Exterior view of the farm   b. Interior view of the farm

Figure 1-1: Project site and layout

The site was selected to be close to the farm, in order to reduce the loss of pressure in the gas lines and to keep cost low. The site selection discusses in more details in (Section 3.2).

Chapter Two

Literature review

2.1 Introduction

A Biogas production is a technology that depends on microorganisms that convert fermentable organic matter into a combustible gas and matured organic manure (Khoiyangbam *et al*., 2011). It works in the absence of air, yielding finally, methane, carbon dioxide, and water, this process is called anaerobic decomposition. Biogas obtained through this process could be from several matters (animal or agricultural waste) that are available in surrounding environment. Biogas can be used directly for heating and lighting process, and the effluent released from the biogas digester could be an excellent fertilizer.

The poultry production sector is an important agricultural sector in Palestine. According to (PCBS, 2013) the Number of Broilers is 31.5 million of heads, where is Number of Layers equal to 1.78 million, which means a lot of poultry manure production. Therefore, suitable management of poultry manure is required to mitigate these quantities of manure and helps farmers to produce their own energy resource from this available manure by anaerobic digesting and biogas technology. Not only can anaerobic digestion of poultry manure produce renewable energy in terms of biogas, but also it can reduce waste from manure use and production.

A Biogas production from animals waste is becoming a common practice worldwide. For example India started using animal waste to produced biogas as energy source in the 1940s, the first successful cow dung based biogas plant in India was in 1941. Worldwide, various biogas plant propagation programmes have been launched in over 50 countries, with those in China and India being of the largest scale (Khoiyangbam *et al*., 2011). In Western Europe there is political pressure for developing renewable energy. Therefore, farmers seek developing units for the production of energy using animal dung to produce biogas and earn money with it (Krieg *et al*., 2014). In Arab countries, biogas plants started in 1970s in Egypt, Morocco, Sudan and Algeria while it began in 1980s in other Asian Arab countries.

This chapter introduces the status in the poultry industry; it has brought out the most recent research of biogas technology, various plant designs, and review details of potential energy and biofertilizers.

2.2 Poultry industry

2.2.1 Poultry industry in Palestine

The poultry production sector in Palestine contributes the biggest present of the gross agricultural output and the most important agricultural sector (PCBS, 2013).The annual values and numbers of livestock in palatine through 2012/2013 years are surmised in (Table 2-1). This percentage does not include what produced by Israelis settlements, but only it is limited to the West Bank and Gaza.

Table 2-1: Livestock numbers in 2013 in Palestine (Data from PCBS, 2013)

Indicator	Year	Value
Number of Cattle	2013	33,980
Number of Sheep	2013	730,894
Number of Goats	2013	215,335
Number of Broilers	2012/2013	3,1515,383
Number of Layers	2012/2013	1,776,778
Number of Beehives	2013	46,226

The Total number of poultry in West Bank and Gaza Strip are shown in (Figure 2-1); which is illustrating the distribution of the total numbers of poultry through West Bank and Gaza Strip governorates in year 2013.

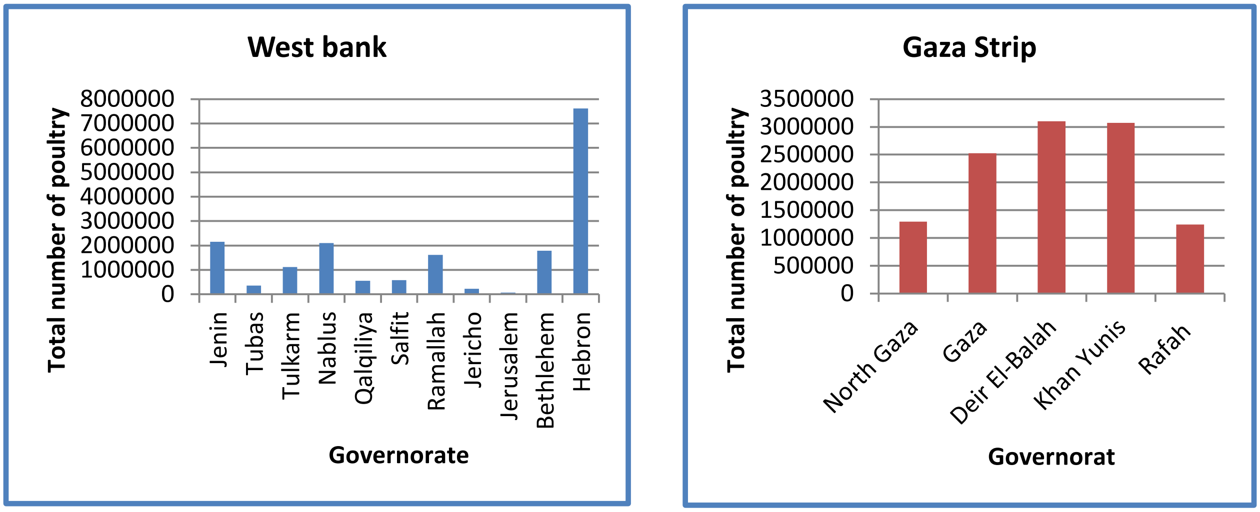

Figure 2-1: Total number of poultry in the West Bank and Gaza Strip, 2013 (ARIG & WFP, 2013).

Hebron, Deir El-Balah and Khan Yunis are the three major governorates of total poultry numbers, where the percent of Hebron was 42% of the total number of other governorates in West Bank, while Deir El-Balah and Khan Yunis was 55% of total numbers in Gaza Strip.

2.2.2 Poultry industry worldwide

The worldwide heads of poultry by regions in 2010 is presented in (Figure 2-2). Poultry continue to be significant, growing at an average of 3 percent per year (FAO, 2013).

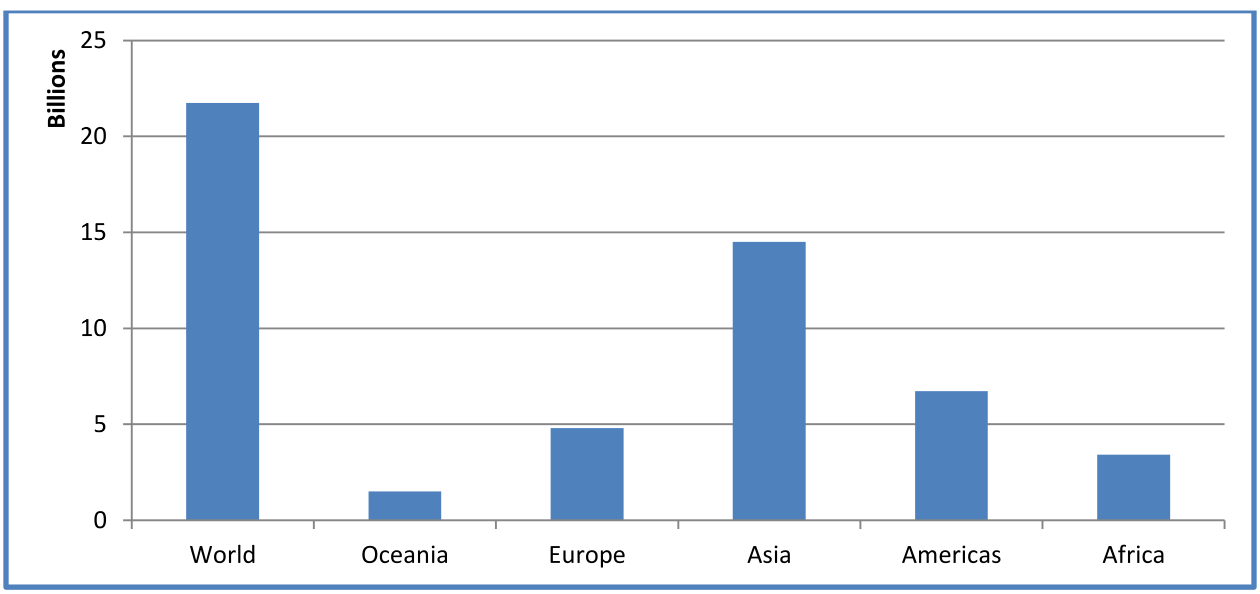

Figure 2-2: Poultry birds (2010), Data from (FAO Statistical Yearbook, 2013).

The number of poultry in the world is around 21 billion. The largest number by region is in Asia, followed by Americas, Europe, Africa and Oceania.

2.2.3 Environmental Impacts of Poultry Production

Recently, poultry industry has become a fast growing with an average of 3 percent per year (FAO, 2013). The reason may be attributed to population increase and rising demand for poultry meat and egg. However, one of the problems confronting this industry is the accumulation of waste near farms causing many environmental problems such as fly breeding, odor, nuisance and greenhouse gas emission if not disposed of or managed appropriately (Adeoye *et al*., 2014).

Not only the accumulation of poultry manure cause air pollution put also pollution of soil and water with nutrients, pathogens and heavy metals that occurs where manure is stored (Saidur *et al.*, 2011).

Poultry manure farm is main source of environmental contamination with microorganisms, decreasing of the distance from poultry buildings, led to increasing in soil and air pollution (Petkov *et al*., 2006). It is also a source of odor and flies attraction that carries disease. Odor emissions soil, and water contamination, caused by a large number of contributing compounds including ammonia, carbon sulfide and phosphorus (Szogi *et al*., 2009).

Greenhouse gases emission got increased up from the poultry facilities and waste such as Carbon dioxide, and methane that can become hazardous to the environment as well as being harmful to the health and safety of both humans and animals. More than 60% of greenhouse gases are yielding from these wastes (Teodorta *et al*., 2013).

2.2.4 Management of poultry manure in Palestine

Poultry Manure is considered as a source of pathogens and high content of nitrogen (Liu *et al*., 2012b); in many countries there is strategy and guidelines for manure treatments technology.

In Palestine, many chicken farms have bad environmental situations and sights. These farms especially in Palestinian villages are producing a lot of manure every months and this manure accumulates near the farm make a lot of environmental problems, such as insects, orders, along with a bad view. In addition to that, this manure indirectly affects groundwater pollution and eliminates some types of plants.

In Palestine there's no strategy or system for manure treatment; disposal of manure is challenges that faces Palestinians farmers, in Palestine management of manure is a routine farm activity which is beyond traditional disposal like using the manure as crop fertilizers by using it directly on the crops or olives trees; which can cause a pollution of the ground water because of high nitrogen content (Wilawan *et al*., 2014b), It is also can cause diseases for both humans and animals whose consuming the crops product.

Another way in disposal of manure used by Palestinian farm is represented by direct combustion of it providing heating in farm or using it in cooking as (in Tabon); these ways contribute significantly to air pollution in and the issuance of odors (Billen *et al*., 2014). Third way that using by farmers is composting or biogas technology, although, they have not an experience in this technology and to proof the sustainability for those type of technology in Palestinian farms, it is necessary to run a pilot scale of biogas plant.

2.3 Biogas Technology

Biogas plants are technologies that produce biogas from organic waste by the bacterial degradation under anaerobic conditions. The waste could be liquid manure, feed waste, harvest waste energy crops, waste from private households and municipalities and industrial waste (Gomez *et al*., 2013).

Biogas plant is a simple and low cost process, which can be economically carried out in ruler areas (Starr *et al*., 2014), where organic waste is available, which otherwise pollutes the environment and public health. In the recent years, biogas technology has attracted wide attention, it is characterize as an efficient and nonpolluting energy source in which it can replace the fossil fuel.

Biogas can be used directly for heating and lighting purposes or convert it by driven generator to generate electricity (Gomez *et al*., 2013), otherwise the effluent that released from the biogas plant can be an excellent biofertilizers, which tends to improve the physical, chemical and biological properties of the soil such as aeration ,nutrients and microbial biomass (Abubaker *et al., 2013)*. Biogas technology helps in improving environment by providing ways for the safe disposal of animals and humans waste. An integrated energy system based on biogas can also help in preventing soil erosion and deforestation (Khoiyangbam *et al*., 2011) besides, biogas provides some efforts and solutions to counter global warming problems by minimizing fossil fuel consumption. It is suggested that biogas technology will be able to fulfil forthcoming demands for increased energy efficiency and sustainability (Mauky *et al*.2013).

2.3.1 Biogas as a renewable energy source

Energy source can be divided into two main categories, a renewable and nonrenewable energy (Tahvonen and Salo, 2001). Renewable resources are the resources that have the ability to reaper and renew themselves by recycling, reproduction, regeneration or replacement.

Biogas is a renewable energy source (Khoiyangbam *et al*., 2011). Like all other renewable energy sources, the energy for biogas generation comes from plant biomass or animals waste after it is subjected to anaerobic digestion in biogas plant (Vijay *et al*., 1996). Inside the biogas plant, the complex organic matter, primarily carbohydrates, lipids and proteins, in the biomass are fermented to produce biogas, which mainly yields methane and carbon dioxide. Since biogas contains about 60% methane, this gas is especially important in biogas production pathways (Dumont *et al*., 2013). In the last few decades, biogas has assumed considerable importance as an alternative to conventional energy sources throughout the world, particularly in developing countries like china and India which is rank as second country in the world in biogas utilization (Khoiyangbam *et al*., 2011).

In other countries like Ghana, the conventional use of cow dung as source of fuel for cooking has been a common practice (Arthur *et al*., 2011). Also, mesophilic anaerobic digestion of wastes in turkey shows that it is possible to recover methane as a source of renewable energy (Alkanok *et al*., 2014). In malizia 90% of oil mills consumption is replaced by energy that produced from biogas (Hosseini and Wahid, 2013). On the other side biogas technology represented in the large scale in Serbia (Cvetković *et al*., 2014); and investment of the biogas technology in Brazil has a large returns according to the price of the produced electricity sold and availability of power plant operation (Souza et al., 2013). The renewable and sustainable energy resources are best substitute to the conventional fuels and energy sources (Amjid *et al*., 2011).

2.3.2 History of using poultry manure for biogas production in the world

Biogas production from animals waste is becoming a common practice worldwide (Avcioğlu *et al*., 2012*)*. For example India started using animal waste to produced biogas as energy source in the 1940s, the first successful cow dung based biogas plant in India was in 1941 (Avicenna *et al*., 2015). Worldwide, various biogas plant propagation programmes have been launched in over 50 countries, with those in China and India being of the largest scale (Khoiyangbam *et al*., 2011).

In Western Europe there is political pressure for developing renewable energy. Therefore, farmers seek developing units for the production of energy using animal dung to produce biogas and earn money with it (Krieg *et al*. 2014).

Many research using chicken manure in improved biogas production and poultry manure was used to produce biogas in many countries worldwide (Owamah *et al*., 2014), for example in Japan biogas production from chicken dung by convert 80% of nitrogen in manure into ammonia then 82% of ammonia is removed and then used the slurry manure to produced methane gas (Niu *et al*., 2013). Methane was successfully produced from the treated chicken manure and the mixture of treated chicken manure (Abouelenien *et al*., 2009).

In India many studies are carried out on comparative biogas yield from different animal manures and the studies observed that poultry dropping showed higher gas yield (Khoiyangbam *et al*., 2011).

In China many studies investigated the possibilities of improving methane yield from anaerobic digestion of multi-component substrates, using a mixture of dairy manure, chicken manure (Shi, 2014). And there are many biogas plant that produce methane from dry poultry manure by increase ammonia inhibition in the methanogenesis system (Liu *et al*., 2012b).

In Turkey biogas production from digestion of two different types of manure sources from chicken and cattle is applied at a biogas plant (Gomec and Ozturk, 2013). In Africa there are many studies, which the results suggest that chicken droppings can be used for biogas production and as biofertilzer (Adeoti *et al*., 2001). The production of biogas and methane is done from the starch-rich and sugary material which found in poultry manure and is determined at laboratory scale using the simple digesters (Dai *et al*., 2015).

In Italy a laboratory anaerobic digester was designed and built to evaluate biogas production from different substrates like poultry and pig manure and considering the highest methane production was found in poultry manure which gives a better performance (Fantozzi and Buratti, 2011).

In Arab countries, the applying of biogas plants started in 1970s in Egypt, Morocco, Sudan and Algeria while it began in 1980s in other Asian Arab countries as Iraq, Jordan and Yemen (Chedid and Chaaban, 2003).

2.3.3 History of using poultry manure for biogas production in Palestine

Palestine in particular suffers from less of energy sources. The Palestinian Territories is dependent on external sources to meet their energy demands. Around 80% of their energy sources come from neighboring countries (Ismail *et al*., 2013) and it relies on Israel for 100% of its fossil fuel imports and for 87% of its electricity imports. The conversion of animal waste into biogas has the potential to meet the needs of 20% of the rural population. The conversion of unused agricultural residue into biodiesel could replace 5% of the imported diesel (Abu Hamed *et al*., 2012).

Therefore, the renewable energy resources show a significant challenge to the Palestinians for alternative energy sources. As long as there are a lot of resources that can be exploited for the production of energy, such as household waste and animal manures that accumulates significantly in the Palestinian territories, causing health problems and pollution to the environment (Ouda, 2012) and which can be exploited for the production of biogas.

The Palestinian experience in biogas production is still young. There is little research and pilot projects are being on biogas production (Naima and Al-Aghab, 2001), these pilots' projects depend on wastewater treatment plants as organic source and not depend on animals manure. Some Palestinian companies focused on the production of anaerobic digester reactors as a kind of trade and marketing without used it (Palestinian biogas, 2013). Moreover, according to study in AL-Najah University there is one farm plant for producing biogas from cow dung (Madyn, 2004).

There is a significant lack of detailed data on the biogas production in Palestine, although the existing studies provide some analysis and information on it, as no research has investigated the different factors that influence biogas production.

2.4 Anaerobic digestion

Anaerobic digestion may be defined as the engineered anaerobic decomposition of organic matter (Razaviarani and Buchanan, 2015). It is a term commonly applied in waste treatment, to a process in which the waste is stabilized through the microbial activity in the absence of oxygen that utilizes methane and carbon dioxide (Khoufim *et al*. 2015). This process involves a mixed of different species of anaerobic microorganisms that function in concert to degrade organic matter and complete the carbon cycle biogas production is a biochemical process occurring in the stages during which different bacteria act on the organic matter (Mao *et al*., 2015). The three stages involved are hydrolysis, acidification, and methane formation. Initially, a group of microorganisms convert s organic materials into simpler form, which a second group of organisms utilizes to from organic acids (Xu *et al.*, 2014b). Methane producing bacteria utilize these acids and complete the decomposition process. Anaerobic decomposition is a complex process (Chen *et al*., 2015). As long as proper condition prevails, anaerobic bacteria will continually produce biogas. The main factors that influence biogas production are, seeding, pH, temperature, loading rate, retention time, carbon: nitrogen ratio, total solid and so on (Shi *et al*., 2014).

Almost any organic materials can be used as feed materials for biogas system (García-Gen *et al*., 2014). Substrate may be in the form of liquid, suspension of solid in liquid or solid materials with less than 70% water content (Zhou *et al*., 2011). Mostly, organic matter can be decomposed by the fermentation process, without chemical or physical pretreatment. Anaerobic digestion has been applied for decades for the treatment of domestic sludge, animals waste, industrial waste, and more recently, for processing the organic fraction of the municipal solid waste (Zhang et al., 2015b).

2.4.1 Anaerobic digestion process

Anaerobic digestion process in biogas plant consists of three phase (Figure 2-3). Namely, the enzymatic hydrolysis, acid formation, and gas production (Khoiyangbam *et al*., 2011). The gas production is the end product which is released at the final stage of the anaerobic digestion; the gas may contain hydrogen supplied, ammonia, and carbon dioxide besides methane (Koblenz *et al*., 2015).

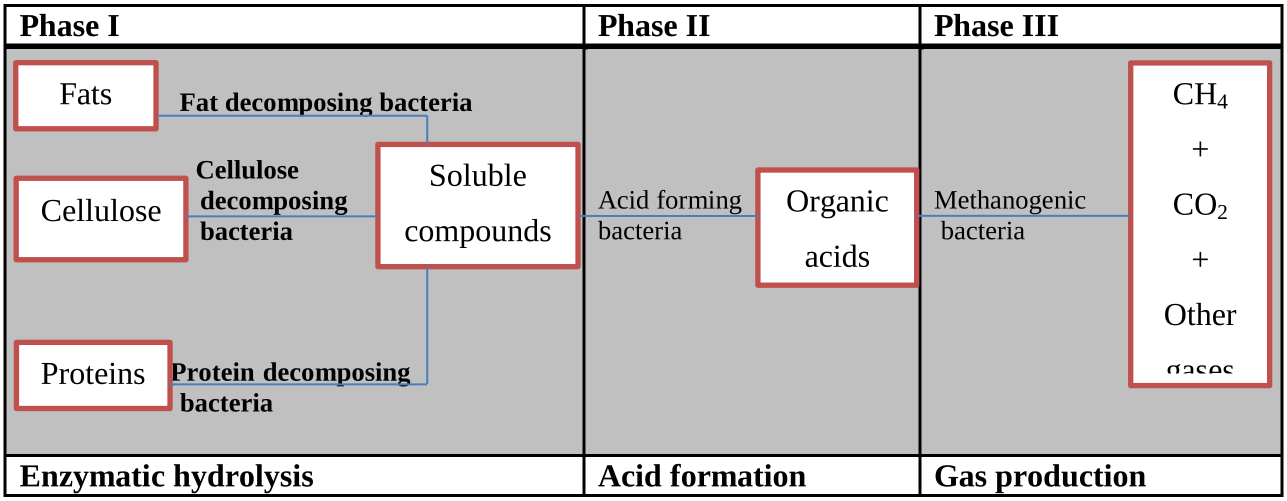

Figure 2-3: Phases of anaerobic decomposition in biogas plan (Source from: biogas technology towards sustainable development, 2011).

The first phase (hydrolysis Phase) cellulosic bacteria act upon the complex organic matter, such as carbohydrates, lipids or fats, proteins and cellulose (Borja *et al*., 2005), these organic matter are converted to soluble compound like sugars, fatty acids, amino acids, etc.

During second phase (acidgenesis phase), acid producing bacteria convert the material produced in the first phase to volatile fatty acids (VFAs), hydrogen (H_2), and carbon dioxide (CO_2). In the process of acidification, the facultative anaerobic bacteria utilize oxygen and carbon, therefore anaerobic condition is important for methanogenesis (Chen and Lin, 2003).

In the third phase (methanogenesis stage), the methanogenic bacteria produce methane either by fermenting acetic acid to form methane and carbon dioxide , or by reducing carbon dioxide to methane by using hydrogen gas or format produced by other bacteria (Yang *et al*., 2012).

2.4.2 Microbiology of anaerobic digestion

Microbial diversity in biogas digester depends on the type of feedstock in the digester (Francisci *et al*., 2015). Four different autotrophic bacteria groups are currently recognized in anaerobic processes. Figure 2-4 shows a distinction of the microbial population in anaerobic digester, into four trophic groups. The cooperation of these four types is required for to ensure stability of anaerobic (Murphy *et al*., 2013).

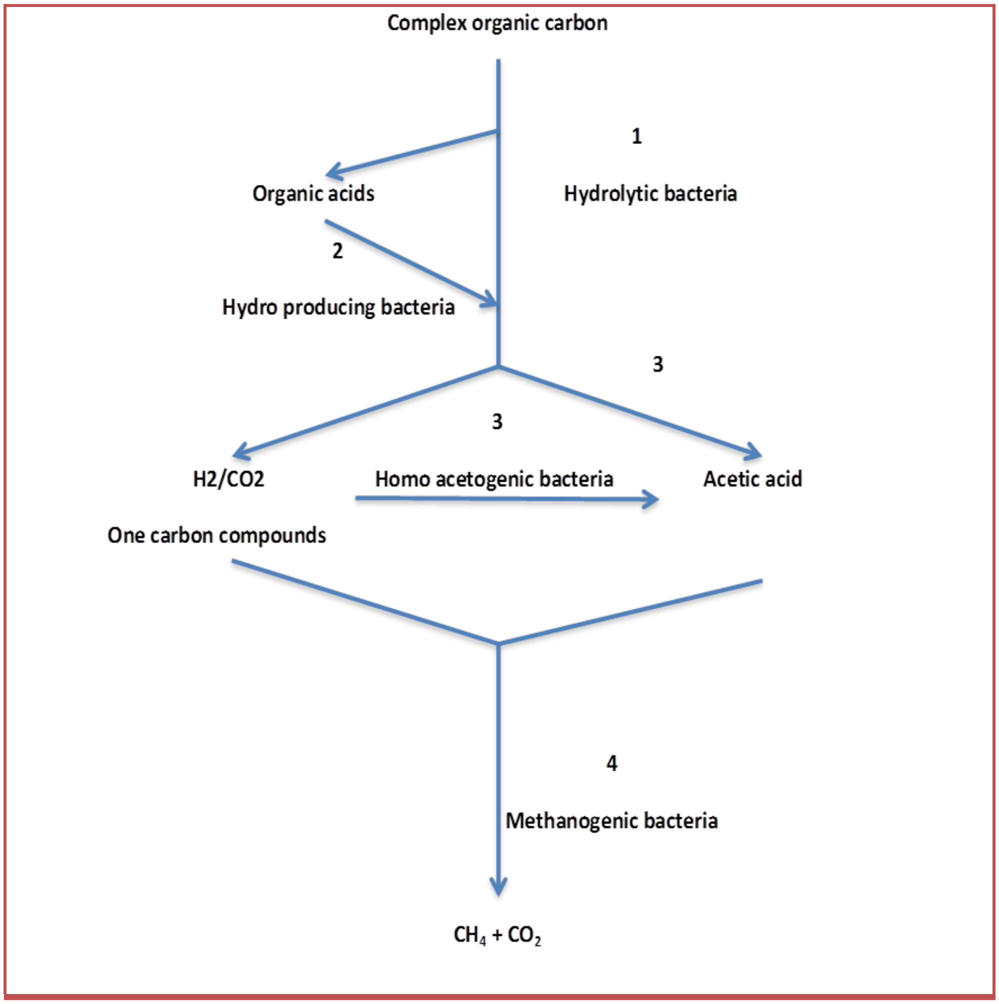

Figure 2-4: Microbial trophic groups in anaerobic digester based on carbon catabolism (Source from: Biogas Technology towards Sustainable Development, 2011)**.**

These bacteria can be classified according the substrates fermented and metabolic end products formed:

a. Hydrolytic and fermenting bacteria

Known as anaerobic acidogenic bacteria, Hydrolytic bacteria, breaks down the polymers to monomers to make it more soluble, it converts polysecrides, lipids, and proteins into acetic acid

(Ziganshina *et al*., 2014). Fermenting bacteria ferments these monomers which is may be hydrogen or carbon dioxide, monocarbon compounds, organic fatty acids, and neutral compounds to fermentation end products. End products of the acidogenic stage include acetic acid, hydrogen and carbon dioxide. However, the majority of the products are higher carbon number volatile fatty acids such as propionate, butyrate and alcohols.

b. Acetogenic bacteria

The hydrogen producing acetogenic bacteria including both obligate and facultative bacteria, the two types of bacteria must act together on the substrate materials, these bacteria can converts the products of the first group such as butyrate, propionate, ethanol, and propanol into hydrogen and acetate (Borja *et al*., 2005).

c. Homoacetogenic bacteria

Hydrogen-consuming acetogens appear to be outcompeted by methanogens for hydrogen (Francisci *et al*., 2015). Homoacetogenic bacteria can convert a very wide of monomers and multi compounds such as Monocarbon compounds into acetic acid (Chen and Lin, 2003).

d. Methanogenic Bacteria

Methanogenic bacteria are very diverse group of bacteria (Khoiyangbam *et al*., 2011). This group consists of hydrogen trophic methanogenic bacteria which convert hydrogen, carbon dioxide, methanol, carbon monoxide, methyl amine and acetate or convert decarboxylation of acetate into methane (Yang *et al*., 2012). Approximately 70% of methane produced comes from acetate Methanogens (Murphy *et al*., 2013).

2.4.3 Parameter affecting anaerobic digestion

The anaerobic digestion process in biogas plants depends on the complex interaction of several different groups of bacteria, these bacteria affected by a variety of chemical and physical parameters (Kwietniewska and Tys, 2014); any change of these parameters can change the environment of bacteria and microorganisms activity inside the digester, results in failing of digestion process (Shi *et al*., 2014). Therefore these parameter needs to monitoring to optimize the biogas production.

2.4.3.1 Seeding

One of the problems of the anaerobic digestion is the long startup period for microorganism to establish their activity (Lins *et al*., 2012); therefore seeding can speed up and stabilize the digestion process (Lagerkvist *et al*., 2015). The common materials (inoculum) that used in seeding could be cow manure, anaerobic sludge or biogas slurry that contains a lot of microorganisms that enhance the process (Tao *et al*., 2013). According to the guidelines, the seeding materials should twice of the fresh manure during the startup phase, with gradual decrease in the mount added within three weeks period (Martin *et al*., 2003). The efficiency of the inoculum depend on the type of its materials, some studies found that goat rumen fluid is more efficient and have a higher anaerobic microbial population than other types of feedstock (Khoiyangbam *et al*., 2011).

2.4.3.2 Temperature

Biological methanogensis has been reported at temperature ranging from 2°C to over 100°C (Megonigal *et al*., 2014), but they have best activity at of temperature around 35°C in mesophilic condition and 55 °C in thermophilic condition (Khoiyangbam *et al*., 2011).Biogas production is more rapid in thermophlic range than in the mesophilic range in anaerobic digestion (Scaglia *et al*., 2014). Increasing the process temperature from the mesophilic (32–428 °C) to the thermophilic (45–578 °C) level also speeds up degradation and improves the health status of the substrate (Gomez and Claudius, 2013), But thermophilic temperature is reported as more sensitive process to disturbances as fluctuation between side and outside of the digester and increase the ammonia inhibition for the microorganisms inside the digester (Drosg *et al*., 2013);

on the other hand the high temperature can have a negative effect on the microbes in anaerobic digestion (Turekian *et al*., 2014).

2.4.3.3 pH value

The pH value determines the acidity or basicity of an aqueous solution. Its unit is the negative logarithm of the concentration of hydronium ions (Drosg *et al*., 2013). Quite a wide range of pH values of biogas feedstock is acceptable due to the usually high buffer capacity of the anaerobic digestion broth. The pH value in anaerobic fermentation is between 6.8 and 8.0 and efficient digestion occurs at pH near neutrality (Zhai *et al*., 2015). The buffer capacity depends mainly on CO_2 concentration in the gas phase, ammonia concentration in the liquid phase and water content in general. If the pH in the feedstock is too high or too low so that the buffer capacity is exceeded and the pH in the reactor is changed significantly, it is preferable to have a neutralization step before feeding to the biogas plant (Zhang *et al*., 2015). If slight acidification occurs during anaerobic digestion, the pH can be increased artificially by adding base such as lime in the reactor (Netter *et al*., 1990).

2.4.3.4 Carbon: Nitrogen Ratio

The relationship between the amount of carbon and nitrogen present in organic materials is represented by the carbon: nitrogen ratio (Wang *et al*., 2012). Anaerobic digestion is proceeding most rapidly when the carbon: nitrogen ratio of the raw materials is 25 to 35: 1 (Khoiyangbam *et al*., 2011). If the ration is higher, the nitrogen gets exhausted while there is still a supply of carbon left (Resch *et al*., 2011). This causes some bacteria to die, releasing nitrogen in in their cells and eventually restoring equilibrium (Cui *et al*., 2011). Optimum C: N ratios of the digester materials can be achieved by mixing materials of high and low C/N ratios, such as organic solid waste mixed with sewage or animal manure (Kondusamy and Kalamdhad, 2014).

2.4.3.5 Total Solid

Biogas production is insufficient if the fermentation materials are too diluted or too concentrated (Abbassi *et al*., 2012). All waste materials fed into a plant consist of solid matter and water. Solid matter is made of volatile and non-volatiles (Xu *et al*., 2014). During anaerobic fermentation process, volatile solids undergo digestion and non-volatiles remain unaffected it has been established that in the digestion of sewage sludge, the optimum solids concentration is in the range 8% - 10% (Khoiyangbam *et al*., 2011).

Biogas digesters can be designed to operate in either high solids content, with a total suspended solids concentration greater than 20%, or a low solids concentration less than 15 % (Saady, Noori M. Cata, Massé 2015a). If feedstock with a very high water content are used the volume of digestate will be high and, consequently, its nutrient concentration will be low (Drosg *et al*., 2013). The moisture content and TSS of the feed stock is important to increase the circulation of materials between the microorganisms and their food (Lin *et al*., 2014). This enables the bacteria to more readily access the substances on which they are feeding, and increases the rate of gas production.

2.4.3.6 Loading Rate

The loading rate can be defined as the mount of organic materials that feed the digester per unit of volume per a day (Agyeman and Tao, 2014). The loading rate takes into account the food to bacteria ratio (Zuo *et al*., 2013). Loading is expressed by kilograms of volatile solids fed to the digester per day per cubic meter of the digester volume (Liu *et al*., 2012). Loading rate is determined by the concentration of active bacteria in the digester, solid content, retention time, and digester temperature (Guo *et al*., 2014). Optimum loading rate vary with different digesters and their sites of location. Higher loading rate is used when the ambient temperature is very high (Saady et al., 2015). The loading rate should be expressed either by weight of TSV added per unit volume or by the weight TVS added per a day per unit weight of TVS in the digester. There is an optimum loading rate that have maximum of biogas production (Khoiyangbam *et al*., 2011).

2.4.3.7 Retention Time

The HRT describes the theoretical time period that the substrates stay in the digester (Bachmann *et al*., 2013). It describes the mean retention time that, in reality, deviates from this value (Saady *et al*., 2015). The HRT must be chosen in order to allow adequate substrate degradation without increasing the digester volume too much (Zuo *et al*., 2015). Washout of the microbes must be avoided; therefore the HRT must not be below 10 days. The HRT also decreases by increasing the temperature, a thermophilic digester has a lower retention time of the mesosphilic digester (Guo *et al*., 2014).

2.4.3.8 Stirring

Stirring of the digestion material is important for distributing the substrates, and providing a uniform of microorganisms and heat (Bachmann *et al*., 2013), by increasing the contact between the microorganisms and their food; it also helps to drive out gas bubbles and avoid the formation of floating or settling layers (Tian *et al*., 2015). Agitation can be done either mechanically or manually, and it could be placed vertically or horizontally into the digester. Agitation is also done to break up the floating scum layer that may be formed epically in the feedstock that have large parts of other materials (Mao *et al*., 2015) such as wood chips which is found in some type of manure like chicken manure.

2.4.4 Type of Feedstock

Almost any organic material can be used as a feed material for biogas system (WTE, 2013). Substrates may be in the form of liquid, semi-solid, or solid. Biogas plants have been deigned to digest these physically different forms of feedstock (Wilawan *et al*., 2014). Energy of biogas can be produced from animal manure, human excreta, biomass and crop waste, vegetable and fruit waste, aquatic weeds, algae, and municipal solid waste (Bachmann *et al*., 2013). A large number of feedstock has been evaluated for their biogas generating potential. The potential for the biogas production depends on the status, type, and constituents of the feed stock undergoing fermentation and these affect the quality and quantity (Murphy *et al*., 2013). The more complex of substrate, the longer it takes to get degraded to VFA_S, and the lower is the proportion of methane in the biogas produced (Wang *et al*., 2014). Sometimes the problem of feed stock associated with anaerobic digestion may be solved by modifying the feed (Zhai *et al*., 2015).

2.5 Biogas plant models

Biogas plants are a closed system in which the parameters of the anaerobic fermentation are optimized to yield and supply of usable gas (Holm-Nielsen *et al*., 2009). Biogas plants can be built from concreate, steel, brick, or plastic placed underground or in the surface (Nathalie *et al*., 2013). All designs have the same two basic components, a digester and gas collection chamber; biogas plant can be classified in many ways depending in the design and mode of working. Based on the mode of feeding, digester can be batch or contentious types (Shi, 2014). Biogas plants can also be vertical or horizontal in displacement mode, depending in the location of the digester (Biernacki *et al*., 2013).

There are several ways to design biogas plant (Singh and Sooch, 2004), the anaerobic digester can be more than one phase or one chamber, the digester also can be floating drum type or fixed dome type , both of these type have own characteristic (Bojesen *et al*., 2014).

2.5.1 Popular biogas models

Several deign and structure of biogas plant are developed; simple structured biogas digesters, which is used as household digesters, are used around the world to provide energy to families or farmers, due to cost effective and simple operation. In India more than 30 deign are developed in the country (Khoiyangbam *et al*., 2013). In China there is more than 30 million of household digester that are supported from the government (Teng *et al*., 2014).

Several developing countries in Asia and Africa, such as Nepal, Bangladesh, Cambodia, Vietnam, Kenya, Rwanda, and Tanzania, are using biogas technology. These developing countries are using three major types of biogas plant models, namely, the fixed dome digester, the floating drum digester, and the plug flow digester (Cheng *et al*., 2014). The most popular models of simple biogas digester are shown in (Figure 2-5), which illustrates the simple household's digester models that widely used.

2.5.1.1 Fixed dome type

The first developing of fixed dome digesters was in china (Khoiyangbam *et al*., 2013). Which are composed of a fermentation chamber ,that can be built from several materials like concrete, bricks ,stones, even steels or plastics and it can laying under the ground (Raheman, 2002). In the dome type biogas that produced from the fermentation process are gathered in the upper part of the digester which takes dome shape; as the biogas accumulates, it presses the slurry of the digester and displaces it into the displacement chamber (Cheng *et al*., 2014). The fixed dome type is relatively cost effective has fewer problem and lower maintenance than the others type (Walekhwa *et al*., 2014).

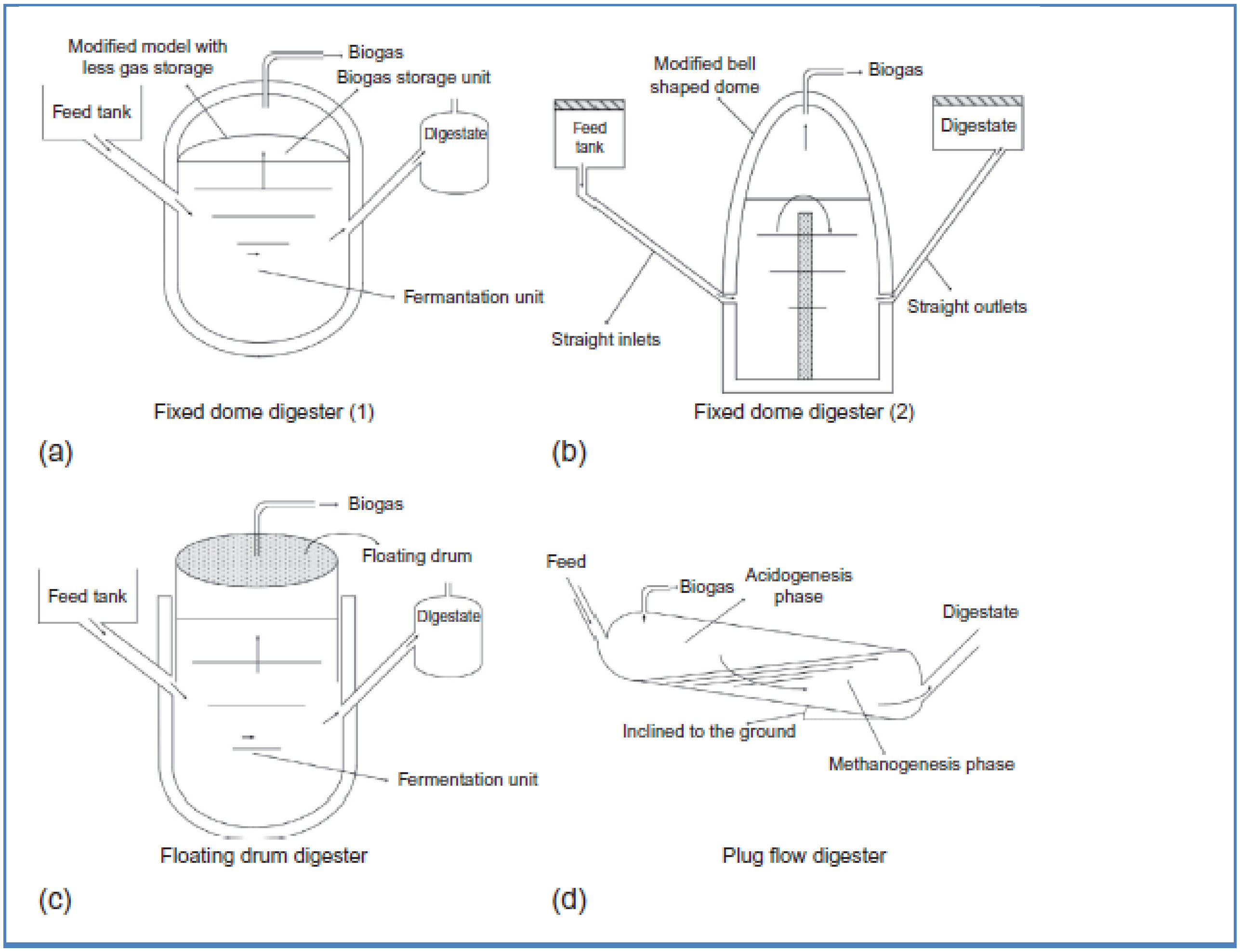

Figure 2-5: different household digester models (Source from: Design and optimization principles of biogas reactors in large scale applications, 2014).

2.5.1.2 Floating drum type

Floating drum digesters are similar to fixed dome digesters, but the floating one has a drum usually made from steel located on the top of the digester to separate the gas production and collection and provide a constant gas pressure (Teng *et al*., 2014), the gas holder can move up and down (Singh and Sooch, 2004). However the floating drum digester cost is very high and need for yearly maintenance, for this reason the floating drum type is not popular (Singh *et al*., 1997).

2.5.1.3 Plug flow type

Plug flow digester is consist of trenches which does not allow the mixing occur, the digester covers with plastic balloon (Chanakya and Sreesha, 2012). The length of the digester should be greater than width and depth to ensure right plug flow conditions (Teng *et al*., 2014). The inlet and the out let of the digester have opposite ends, to helps the feeding mode which is semi-continuous , the design are very simple and cost effective have low capital cost and required less water consumption (Cheng *et al*., 2014).

2.5.2 Reactor configuration

2.5.2.1 Feeding system

Feeding systems includes transport and mixing of the substrate before entering the digester (Bacenetti *et al*., 2013), substrate is bringing from the storage place (aerobic condition) into the digester (anaerobic condition, then it is mixing and milling with water until being more homogenized (Crolla *et al*., 2013).

The feeding system needs to be adapted to both the feedstock and the reactor type (García-Gen *et al*., 2014). For example batch digesters needs discontinuous feeding, while Plug-flow and CSTR digesters are fed continuously or semi- continuously. Substrates can be fed in separately, through the sidewall or the ceiling of the digester to avoid clogging of the pumps (Wang *et al*., 2012). Mixers for homogenizing the material are options to complete the system.

More than one feeding system can be used in confederation of different feedstock types (Mao *et al*., 2015). Feeding management has a significant influence on the fermentation process. A high load of organic matter affected microbial community and result in a reduction in gas production (Shi *et al*., 2014). To design a feeding system, two aspects should takes into account; volume of the substrate and the storage capacity (Holm-Nielsen *et al*., 2009).

2.5.2.2 Reactor type

Digestion reactors are characterized by the feeding mode (batch or continuous) and by the mixing type (CSTR or plug-flow); Reactor design depends on the characteristic and type of feedstock (Bachmann *et al*., 2013), the plug flow used when dry matter content of the substrate mix is above 20%, while the CSTR is used when the dry matter content below 15%. Nearly 90% of modern biogas plants are CSTRs (Bensmann *et al*., 2013). Reactors may be dry or wet, batch or continuous, one-step or multi-step and one-phase or multi-phase (Orozco *et al*., 2013). Reactors may be operated under mesophilic or thermophilic temperature conditions.

2.5.2.3 Number of phase

Most biogas plants are with one phase, which means that all the steps of microbial degradation take place in the same tank (Adinurani *et al*., 2015). These methods are simple processing and having a lower cost (Tahvonen and Salo, 2001). In contrast, a plant with two phase system separates the hydrolysis stage from the process; this system needs to optimize the pH, temperature and retention for each phase (Klocke *et al*., 2008). This leads to better degradation kinetics and is recommended for substrates with a high content of sugar, starch or proteins (Bachmann *et al.*, 2013). The advantage of the two phase system is separate the large amount of acids that is produced in the hydrolytic phase, these acids can inhibit methane formation in a one phase system (Muha *et al*., 2013).

2.5.2.4 Reactor temperature

According to temperature the digestion process can be psychrophilic (10-25°C), mesophilic (25-45°C) or thermophilic digestion (50-58°C) (Bacenetti *et al*., 2013). The temperature in the reactor affects many parameters, each having a significant influence on the digestion process (Mao *et al*., 2015). When the temperature inside the reactor increase the degradation rate will be increase, therefore the thermophilic digestion needs short retention time, also the high temperature can kill most of pathogen that may present in the digester (Chen *et al*., 2015); on the other hand high temperature increase the amount of ammonia in the digester; when substrate is rich in nitrogen, most of nitrogen converts to ammonia at high temperature, causing inhibition of microbial activity within the digester and reducing the biogas production (Niu *et al*. 2014).

Thermophilic temperature is mainly used for substrate with a hygiene risk like food wastes. The plant design can be combining both thermophilic and mesophilic to avoid the pathogen risk and reduce the cost of energy used in thermophilic reactors (Orozco *et al*., 2013).

2.5.2.5 Reactor insulation and heating

Constant temperature inside the digester is very important to provide the perfect temperature for microbial activity and for the enhancement of the process of biogas production (Bachmann *et al*., 2013); therefore the digester can be insulated and heated to reduce the heat lost (Teng *et al*., 2014). The feedstock can be heated before entering the digester to keep constant temperature. The heating could be external or internal and the insulation could be placed outside or inside the digester (Chen *et al*., 2015).

For reactor heating, hot water passes through pipes in the digester. Heating pipes used to be cast in the concrete wall and floor, but tension due to temperature differences can cause cracks in the concrete and wear the system. Hence, heating pipes are now commonly placed on the inside of the digester wall (Teng *et al*., 2014).

2.5.2.6 Agitators

Agitation of the digestion material is important for distributing the substrates, micro-organisms and heat; it also helps to drive out gas bubbles and avoid the formation of floating or settling layers (Bachmann *et al*., 2013). Agitation can be done either mechanically or manually, and it could be placed vertically or horizontally into the digester (Tian *et al*., 2015). Agitation is also done to break up the floating scum layer that may be formed epically in the feedstock that have large parts of other materials such as wood chips which is found in some type of manure like chicken manure (Mao *et al*., 2015).

2.5.3 Selection of site and size of biogas plant

The biogas plant should be constructed near the point of the gas consumption and closed to the source of raw materials and water, in order to reduce the loss of pressure in the gas lines and to keep cost low (Khoiyangbam *et al*., 2011). The plant site should offer possibilities for energy use or transport (Shi, 2014). In order to save the cost of piping the plant should be conveniently closed to site consumption (Biernacki *et al*., 2013). Transport distances for feedstock and digestate on the site must be kept as short as possible in order to ease operation of the plant.

As far as possible, the gas plant site selection is particularly important for community biogas plants as they need to be located at sites convenient to several users (Khoiyangbam *et al*., 2011). adequate space is required for the storage of raw materials and water mixing as a well as for slurry handling and storage, the size and design of the biogas plant depend on the factors such as raw material availability, quantity of gas required , capital available for investment , climatic condition , soil , water table and so on.

2.6 Biogas as energy source

Biogas is a sustainable and renewable energy source that can provide energy, a better environment and new jobs (Cvetković *et al*., 2014).Biogas production has the potential to be one of the most flexible and adjustable energy sources (Holm-Nielsen *et al*. 2009). In general, the biogas composition and production rate are influenced by the type of digestion process and feedstock used. Biogas composition and energy content will also affect the choice of equipment for biogas utilization (Kaparaju and Rintala, 2013)

Biogas produced in anaerobic digestion composed of mainly of methane (54%-80%), carbon dioxide (20%-45%), and other gases in small mount such as hydrogen, carbon monoxide, nitrogen, oxygen, and other gases. The gas is usually saturated with water (H_2O) and, depends on the feedstock used; biogas may also contain hydrogen sulphide (H_2S), ammonia (NH_3), and siloxanes (Owamah *et al*., 2014).

The biogas that produced from anaerobic digestion is a quite similar to natural gas, where natural gas have a verity of hydrocarbon compound instead to methane, because of these hydrocarbons compound the natural gas has 10% energy higher than biogas (Khoiyangbam *et al*., 2013). The characteristics of methane make it an excellent fuel for certain uses. Biogas can be used as a fuel for heating, cooking, lightening or for operating engine. It is also possible to use the gas as fuel for small industries.

The digested effluent of the biogas plant can also be a good fertilizers f or soil amendment. Due to the removal of carbon during anaerobic digestion process results in organic materials that's rich in nitrogen and phosphorus (Murphy *et al.*, 2013). The digestate quality depends on the quality of the feedstock that enters the digester, the retention time which this feedstock spend in the digester and the temperature inside the digester (Chen *et al*., 2015).

Chapter Three

Materials and methodology

This chapter will cover the materials and methods that used in biogas plant design and construction, the site selection of the plants, and the factors that affecting each steps of plant design. This chapter also will cover the methods that used in the laboratory analysis including biochemical methane potential and the chemical and biologicals analysis of substrate, manures, biogas production and the spent slurry.

3.1 Experimental methods

This study starts from April 25, 2014 and run until November 30, 2014. Daily routine monitoring like temperature, pH, and biogas flow rate was done along the study period. The startup period also was monitored by measuring the volatile fatty acid and the alkalinity. In October and November solar hot water system was used in the digester to increase the temperature and enhance the anaerobic process, since the temperature in those months starting to fall, then the impact of solar energy on rates of anaerobic fermentation was followed up.

3.2 Site selection

The biogas plant was constructed closed to chicken farm with a sufficient space for the equipment and the plant itself, the plant's site was selected to be near the point of the gas consumption and closed to the source of raw materials and water, in order to reduce the loss of pressure in the gas lines and to keep cost low; such as the cost of piping and transportation. The collector unit of the solar system was selected to be on side which is exposing to the sun radiation during the day. Figure 3-1 shows the biogas plant layout.

a. Biogas plant anterior

b. Biogas plant posterior

Figure 3-1: Biogas plant layout and site characteristic.

3.3 Plant Design

Plant design is a basis step in the development of a biogas production project. It includes technology, equipment, determine of volume and dimensions of the plant, plant site and ambient conditions. The objectives is to achieve efficient process, which allows optimal use of available resources and optimal of biogas productions.

The biogas plant was consisting of five main parts (units): Mixing tank, Main fermentation tank, hot water solar system, storage balloon, and solid waste collective tub (Figure 3-2). These units are described below.

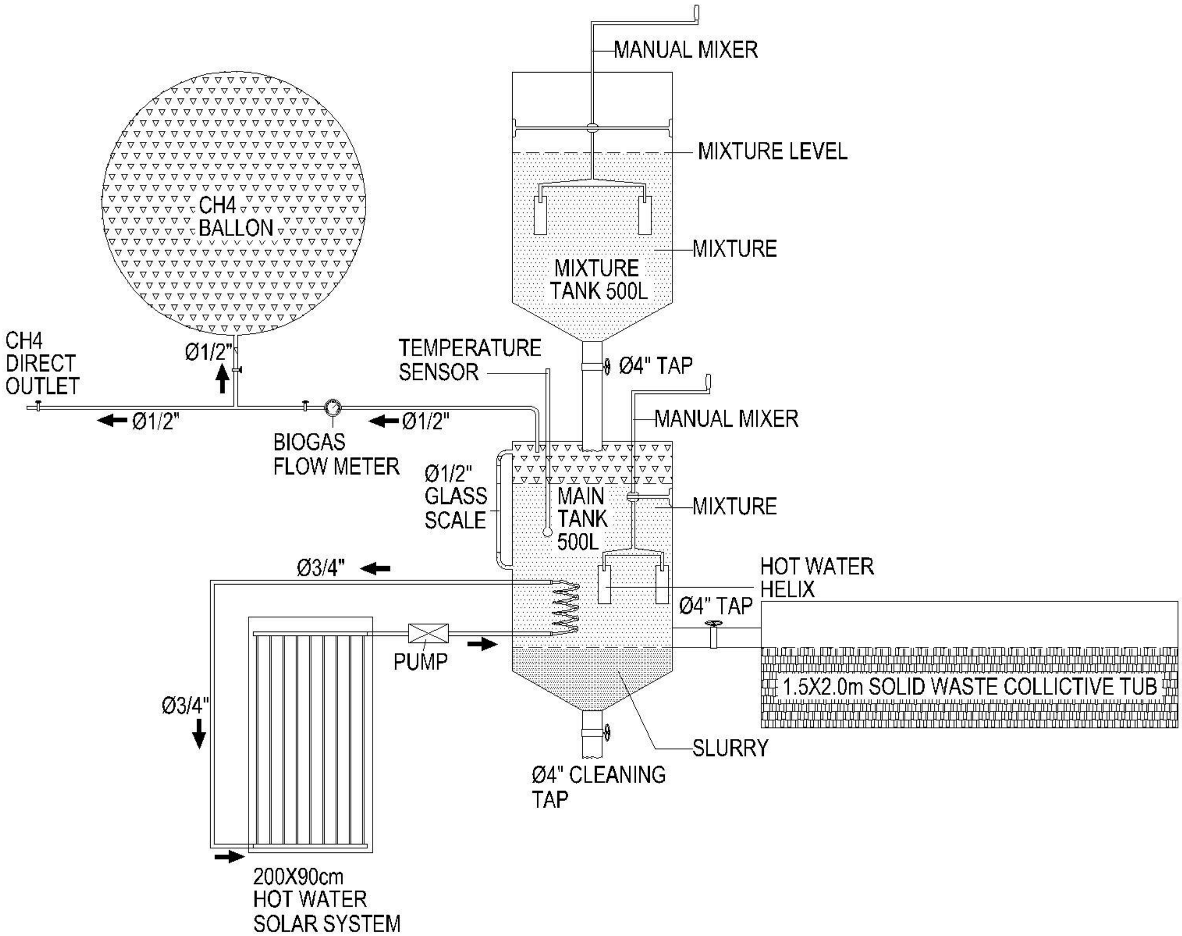

Figure 3-2: Shows the component and design of biogas plant.

3.3.1 Mixing unit

The mixing unit has a volume of 500L (0.5m^3) it was made from plastic, the function of this unit is soaking and mixing of solid chicken manure with water, because of chicken manure consist of solid segments which are difficult to separate, this unit came as soaking place; where manure remaining in this unit for 24 to 72 hours until became more homogeneous (slurry), before transferring to digestion unit where the anaerobic fermentations were take place. Mixing of the reactors is performed by one main agitator situated at the top of the tank. In addition the capacity of this unit is adapting to content volume over a number of days. The mixing tank is connecting to digestion tank by 4 inch valve. In the mixing tank pH value, manure slurry discharge and loading rate of organic matter were monitored and regulated. Then the slurry was flows continuously to the digestion unit.

3.3.2 Digestion unit

The digestion unit is the main unit of a biogas plant; this is where microbial activity takes place and organic matter is transformed to biogas. The digestion unit is composed of one digester with 500L volume, including feeding, manual agitation and heating systems, mixing of the reactors is performed by one main agitator situated at the top of the reactor. The HRT was calculated and it was 28 days. Digestion reactor was design to adapt with the feeding mode.

The temperature of the substrate (slurry) fed to this reactor was controlled by sensor to be between (25 - 45°C). The pH of the slurry was daily monitored and regulated by pH meter to be between (6-8). At this time the content was heated by solar heater to rise up temperature for enhancing the fermentation process. The top agitator mixing and pumping the substrate down through a central circulation; during this circulation, organic materials in the wastewater were digested by anaerobic microorganisms and biogas is formed. The biogas bubbles lift up waste particles to the surface of the liquid which concentrate at the top of the reactor, when the gas concentration increased the pressure would be increased, in which the gas flow to the gas storage balloon due to difference of pressure, the biogas flow rate per cubic meter was measured by gas rate flow meter. The treated slurry of digested manure transformed to waste collecting tub, through 4 inch tap located in the bottom of the reactor. The quantity of digested waste that taken from the reactor was equal to the quantity of the manure that loading to reactor.

3.3.3 Feeding systems

In this study two aspects were taking into account for feeding system design, the volume of feedstock substrate and the storage capacity of the feeding system , storage capacity for 1-3 days was applied to allow feeding over number of day; and digestion reactor was characterized by continuous feeding mode and by the mixing type for liquid and solid feeding.

For feeding the substrate of chicken manure was brought from their storage place; then liquid substrates were pumped from a mixing tank into the digester. Before pumping, the content was fully homogenized by mixing with water until being fluid to avoid clogging and keep influence of total solid concentration inside the digester. Then the solid substrates were fed in separately, through valve in the upper part of the digester side wall.

3.3.4 Reactor temperature

According to literature the temperature in the reactor was chosen to be mesophilic (25–45°C), which allow satisfactory retention times and moderate energy demand, to keep the environment inside the digester mesophilic, the solar assistance were used and the temperature was monitoring by temperature sensor that set on the side wall of the reactor. The solar system is descried in more details at (Section 3.3.8).

3.3.5 Reactor volume

The reactor volume was chosen to be adapted with the amount of feedstock and the degradation rate of the substrates. Where the amount of manure that produced by the farm is equivalent to 18 kg per day; therefore to achieved the right balance for reactor volume, two parameters were used to calculate the digester volume the organic loading rate (OLR) and the hydraulic retention time (HRT).

The OLR describes as the amount of feed processed per unit of the reactor volume per day (Khoiyangbam *et al*., 2011), expressed in kilograms of total volatile solid TVS per day and per cubic meter of digester (kg TVS/m^3day). The ORL was calculated by Equation (3-1).

$$OLR(kgTVS/m^3 day) = \frac{Substrate\ input(kg/day) \times TS\% \times TVS\%}{Digester\ volume\ m^3} \qquad (3-1)$$

The HRT describes as theoretical time period that the substrates stay in the digester (Bachmann, *et al*., 2013).The HRT was calculated from the Equation (3-2) which was 28 days.

$$HRT(day) = \frac{net\ digester\ volume\ (\ m^3)}{Substrate\ input\ (\ m^3/day)} \qquad (3-2)$$

3.3.6 Reactor material and protection

Both mixing and digestion tanks were built above the ground from high-quality materials of plastic to prevent corrosion and leaks in the tank wall. The materials of both tanks were also chosen to be resistant to temperature variations, humidity and to aggressive substances that may be resident within reactors.

3.3.7 Agitators (Manual mixer)

Agitation of the digestion material is important for distributing the substrates, micro-organisms and heat (Bachmann *et al*., 2013); it is increased contact of substrate with the biogas producing microorganisms, resulting in accelerated decomposition and increased production of biogas. Agitation of the digestion material breaks the scum on the surface of slurry, it also helps to drive out gas bubbles and avoid the formation of floating or settling layers.

Therefore, the plant design has two agitation in both mixing and digestion tank, the agitator was built from iron, which was situated at the top of the reactor vertically in the middle of reactor, agitator also has a small brushes at the upper part to avoid formation of settling layer, and allow the manual agitation to be done periodically.

3.3.8 Solar system

A constant temperature in the digester is essential for a stable digestion process; digesters are therefore heated in order to reduce and compensate heat losses. In this study the digester was heated by using solar unit, which is consisting of: solar collector device (flat plat collector with1.6m^2 area), pump, pipes, and spiral heat exchanger.

Flat plate collector is advices in where the sun radiation is absorbed by exposing a dark surface of the collector to the sun with angle 30 degree. A solar collector acts as a heat exchanger; heat from the absorber (dark surface) is transferred to the secondary side and then to water. Then hot water moves through the pipes to reach the spiral exchanger which is running inside the reactor, the exchanger turn to heat the slurry materials inside the digester. Heat of digester materials is important to enhance microbial process and increase the biogas flow, heat inside the digester also controlled to be between 25 to 45°C and it was distributes by agitator. Solar system is simple in design, requires little maintenance, therefore it was constructed using local materials and skills.

3.3.9 Gas storage

Two storage balloon were made from ethylene propylene dienemonomer, one with 5L for testing and analysis, where the other with 250 L for storage in case the biogas does not use directly, test balloon where located on the upper of digestion reactor, while the storage balloon was lay externally in the lower part of the reactor, the materials of each balloon was chosen to be resistant to pressure, UV irradiation, temperature variations and harsh weather conditions. The storage volume was chosen to fit with biogas production rate; it has 3 days storage capacity. The materials and balloon were made by local expert.

3.3.10 Pipework and valves

The material of the pipe and valves was chosen to be resistance for physical and chemical stress that may be caused by substrates and biogas. Pipe material and diameter were chosen with regard to the transported media and its temperature, pipe location and pressure in the pipe. For example valves that were located at contact points were made from copper while the pipes from plastic, the diameter of those valves and pipes was 4 inch to avoid clogging by materials; hot water pipes outside the digester was from iron with diameter ¾ inch, while the pipes inside the digester were made from copper and it were ¾ in diameter. The gas pipes were made from copper and rubber with ½ inch diameter.

3.3.11 Solid waste collector tub

Spent slurry from the anaerobic digestion were places in the collector tub, which was made from iron with $2m^3$ area, the digistate were drying under the sun light in order to reduce the solid content and to kill most of the pathogens presents.

The waste collector tub was divided into four parts as shown in (Figure 3-3); each part was separated by wood slab. The slurry was separated in shallow collector tub with the thickness does not exceeded 2.5 cm to allow the slurry to dry. It was then scraped and stored with plastic bags to avoid excess of sun drying and losing the nutrient, until the sampling or using in the agricultural field for application.

a. A waste collector tub as a part of plant design

b. Slurry into the waste collector tub during drying process.

Figure 3-3: The waste collector tub as a one of biogas plant component.

3.4 Laboratory analysis

All experimental analysis of this thesis was generated in the laboratory at BZU, the sample and analysis was according to VDI 4630 standards, in order to obtain best results and correct methodology of sampling. In this section explain the procedure, instrument, and materials that used for this experimental analysis.

3.4.1 Sampling procedure

Details on sampling of biogas feedstock in this study were according to VDI 4630 and details for sampling of digestate were according to ISO 5667-13. The samples of chicken manure were collected from different locations and depths of disposal manure source and mixed well together to be more homogenized; For slurry, the materials in the digester was mixed well before sampling; the samples were taken through waste valves of the digester , after cleaning the valves by rejected the first materials that leaving the valve; then samples were placed in a labeled plastic bottle, these bottles were transport to laboratory using 4°C cooling chamber until analysis, which was at the same day of sampling.

At the laboratory, preparation of the sample was depend on the analysis type, some sample was diluted, and the other was mixing, while some samples were dried before the analysis. More details of samples preparations for each analysis will be described in the next sections.

3.4.2 Analysis of feed stock

3.4.2.1 pH value

The pH value measures the acidity or basicity of a solution. Its unit is the negative logarithm of the concentration of hydronium ions (Murphy *et al*., 2013). It is one of the most parameter that affecting the anaerobic digestion, the pH range for anaerobic fermentation is between 6 to 8, the efficient digestion and biogas production occur at a pH near neutrality (Khoiyangbam *et al*., 2011), The pH value below or above this interval may inhibit fermentation process in the reactor, low pH inhibits the growth of methanogenic bacteria, thereby lowering of biogas generation, since these bacteria and their enzymes are sensitive to pH deviation. There are also situations in anaerobic fermentation which can highly affect the pH in the digester. These include high amounts of volatile fatty acids, acetic acid, and carbon dioxide produced by the microbes and ammonia. These factors can have an impact on the pH in the reactor and might inhibit the activity of the microbes.

In this study pH value was determined in a liquid feedstock with a standard potentiometric electrode. For solid feedstock, the sample was mixed with water and then analyzed. pH was measured 1-2 times per day directly from the digester.

3.4.2.2 Total solid

Production of biogas is inefficient if fermentation materials are too diluted or too concentrated. Therefore, TS is important to determine because it needs to know the present of water need to add to the reactor, if the manure has a high TS content, it needs to add more water to the reactor.
All waste materials fed into a plant consist of solid matter and water. Solid matter is made of volatile organic matter and non-volatiles. During anaerobic fermentation process, volatile solids undergo digestion and non-volatiles remain unaffected. It has been established that in the digestion of sewage sludge, the optimum solids concentration is in the range 8% to 10% (Gupta *et al*., 2011).

In this analysis sample of manure was dried at 105 °C oven for 5 hours according (standards EN 12880 and APHA 2540 B). The chicken manure has a solid concentration of 20% there for the manure was mixed with the same amount of water in a 1:1 ratio; this was corresponded to a total solid concentration of 12% by weight in inlet slurry.

3.4.2.3 Volatile solids (VS)

Total volatile Solid determination was carried out together with the TS determination just described above. The samples of manure were dried to constant weight in a drying chamber at 103–105 °C. Then the samples were ignited to constant weight in a furnace at 550 °C. (According to EN 12879 and APHA 2540 E standards) then samples were cooled down to room temperature and weight on balance. The volatile solids have combusted and the remaining solids are inorganic solids, triplicate samples were analyzed for single manure in order to determine VS and TS.

3.4.2.4 Chemical oxygen demand (COD)

Chemical oxygen demand is a parameter that indicates the total chemically oxidisable material in the sample and therefore indicates the energy content of a feedstock. Since microbes convert chemical energy to methane, this is also the maximum energy that can be recovered as biogas (Drosg *et al*., 2013).

In this analysis 2.5 ml diluted manure sample was placed with 1.5 ml digestion solution ($K_2Cr_2O_7$) and 3.5 ml sulphuric acid solution, a blank sample also prepared from distilled water. Then samples were digested for 2 hours at 150°C in HACH heating oven. The samples were colorimetric determined using HACH DR-2000 spectrophotometer wavelength set at 600 nm. Before reading the samples, the instrument was calibrated to zero by the blank. Triplicate samples were analyzed for single manure in order to determine COD.

3.4.2.5 Nitrogen content

Determination of TKN in a sample is important, primarily to evaluate if there is sufficient nitrogen available for the growth of anaerobic bacteria. In most cases there will be excessive nitrogen in the biogas reactor, so determination of the TKN content in a biogas feedstock helps to estimate nitrogen concentrations in the biogas reactor. This is important to know, because ammonia inhibition can occur if the ammonia concentration in the reactor exceeds certain levels.

The nitrogen content of a feedstock was determined by the total Kjeldahl nitrogen (TKN) determination (APHA 4500–Norg). In this analysis, organic nitrogen was converted to ammonia nitrogen by boiling the feedstock sample in the presence of sulphuric acid and a catalyst at 380°C. After that, a base was added to make ammonia distilled from the alkaline solution to an acid solution, where ammonia was absorbed quantitatively. The amount of ammonia then was determined by potentiometric acid titration method (H_2SO_4 (0.02 N)) as titrant).

3.4.2.6 Total organic carbon (TOC)

Total organic carbon (TOC) is an organic matter that can either be dissolved or particulate matter. In this analysis the TOC was measurement by colorimetric method, manure samples were placed with 10 ml of (0.1667 M $K_2Cr_2O_7$) and 20 ml of concentrated H_2SO_4. A zero blank sample also prepared from distilled water. Then the samples were digestion, after that, the samples were placed in a calorimeter set to measure the light absorbance at a wavelength of 660 nm. Quantification was performed by comparison of the results against a standard curve.

3.4.2.7 Carbon: Nitrogen Ratio

Anaerobic digestion will proceed most rapidly when the carbon: nitrogen (C: N) ratio of the biogas feedstock is between 25:1 to 30:1; according to (Mital, 1996). If the ratio is higher, the nitrogen gets exhausted while there is still supply of carbon left. This may cause death for some bacteria or suffering from nitrogen deficiency. And if the C: N ratio is low it may cause inhibition for bacteria due to high ammonia formation.

In this analysis the C: N ratio was calculated from dividing total carbon over the total nitrogen that was determined for manure and feedstock as it is described in previous sections

3.4.3 Biochemical methane potential (BMP)

Biochemical methane potential tests are mainly used to determine the possible methane yield of a feedstock. These tests also provide information on the anaerobic degradability of a feedstock, including the degradation rate (Drosg *et al*., 2013). The BMP test in this study was according to (DIN 38 414 (S8)).

Simplified BMP test was set up as shown in (Figure 3-4). For every feedstock sample, a triplicate BMP test was carried out. In addition, for every row of BMP test, a triplicate of blanks (inoculum) was set up. In standard BMP tests, anaerobically stabilized sewage sludge was used as inoculum; the feedstock sample and the inoculum were weighed and filled into a glass bottle of capacity 1 L. A magnetic stirrer was added for each bottle. Then the bottles were placed on hot plate with temperature 35 to 37 °C.

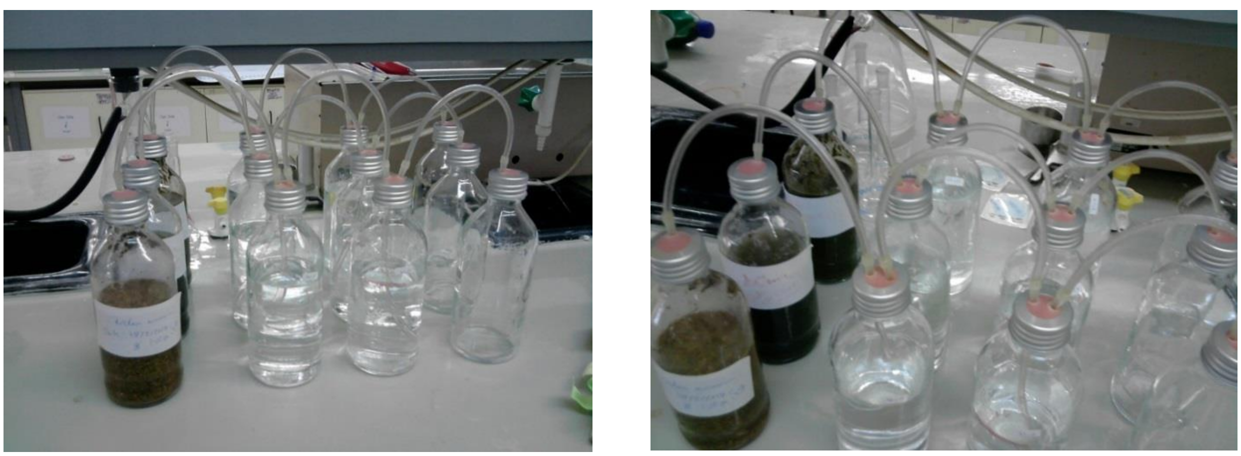

Figure 3-4: Biochemical methane potential tests; the laboratory sets

Methane concentration was determined without carbon dioxide by connect the feedstock sample and the inoculum with a bottle of alkaline solution (2mol/L NaOH), which was then connected to the water displacement bottle (1 L). The gas production was measured by water displacement; the water volume in the water displacement bottle was daily measured; BMP test was carried out for period of 30 days, where the biological degradation was almost finished.

Daily gas production was obtained by subtracting the gas production of the blanks from the daily gas production of the tests with samples. Depending on the daily gas production, a degradation rate was evaluated by graphing.

3.4.4 Analysis of start up

All analysis in this section was according to VDI 4630 and ISO 5667-13 standards, in order to obtain best results and correct methodology of sampling.

3.4.4.1 Biogas plant start up

Startup is a time required for establishing a balanced microbial population in which fermentation process take place, in this study along start-up phase was required to start the anaerobic digestion which toke more than 40 days, there for seeding done by mixing chicken manure with cow manure and sewage sludge as inoculum; by 10% anaerobic sludge, 20% cow manure and 70 % was chicken manure.

The anaerobic sludge was obtain from Nablus wastewater treatment plant, cow manure was obtain from a local cow farm in Beit Our, and the chicken manure were obtained from the study farm, the content of the inoculum was greater than 50 % of the total solids content according (VDI 4630 standards).

The reactor then started up to produce biogas after four days from seeding, while biogas began produced with high after a week. As relatively at start-up phase some laboratory analysis were done, volatile fatty acid and alkalinity were weekly measured along one month of the start- up period, by four times each sample was taken every week. The number of measurements was limited to four samples due to the high costs of chemical analysis, and time consumption.

3.4.4.2 Volatile fatty acid

Volatile fatty acids (VFAs) were analyzed by distillation method. Four samples of slurry were obtained from the digester; these samples were taken weekly for the first month of startup period, the samples were centrifuged at 4400 rpm for 10 min, then the supernatant was transferred to beaker and diluted with 100ml of distilled water and 5 ml of H_2SO_4. After that mixture was distillation; the distillate was titrated with NaOH. For calculation stock solution from acetic acid was prepared and distillation to determine the recovery factor. Then the volatile acid was calculated according to Equation (3-3).

$$mg/l\ (VFA_s) = ml\ (NaOH)\ \times N\ \times\ 60{,}000/ml\ \times f \qquad (3-3)$$

Where N is the normality of $NaOH$; and f is the recovery factor.

3.4.4.3 Alkalinity

At the same time for VFAs determination, the alkalinity was measured from the same samples, this measurement was according to (IS: 3025 standard). The samples were diluted with distilled water and then titrated with sulfuric acid until pH reach 4.5, then alkalinity were calculated by Equation (3-4).

$$Alkalinty = \frac{Volume\ of\ H_2SO_4 \times Normality \times 50 \times 1000}{Volume\ of\ the\ sample} \qquad (3-4)$$

3.5 Biogas production and composition analysis

Biogas produced in anaerobic digester consist of methane (50%-80%), carbon dioxide (20% - 45%) , and trace amount of other gases like hydrogen, nitrogen, oxygen, hydrogen sulfide, and others (Khoiyangbam *et al*., 2011).

Biogas flow meter was used to measure the amount of biogas production per day. The reading of biogas flow, temperature, and pH was recorded on Microsoft excel every day to calculate the biogas production all the study period. Methane production and flow were compared and evaluated with pH and temperature value.

Biogas composition was analyzed using a biogas analyzer (BioGas Check CDM), this analyzer can measure CH_4, CO_2, and O_2 % by Volume. Five tests were done for biogas analysis; these tests were carried out in Royal Scientific Society at Amman.

3.6 Fertilizers analysis

The biogas digester is more important as a source of organic manure, the digester effluent or slurry can be used as agricultural biofertilizers, and soil conditioner or improver, due to the removal of carbon during digestion, the remaining organic materials is richer in nitrogen and phosphorus than the original material.

In this study four samples were taken from digester effluent weekly during one month, then these samples were placed in the waste collector tub, which was divided into four parts each part was carried one sample, with arrangement that first part cried first sample, which was taken in the first week and the second one was carried the second sample and etcetera ; then these samples were dried through sunlight , to be more useable and reach to quality standards, where sunlight kills most pathogens that may present, as well as the percentage of nitrogen would be decrease.

After drying the samples, laboratory analysis were done to calculate the main parameter in fertilizers, these analyses were including total organic carbon, total nitrogen, phosphorus and potassium. Total organic carbon and total nitrogen of fertilizers was measured as describe in (Section 3.4.2) phosphorus and potassium analysis will describe in next sections.

3.6.1 Phosphorous content

Phosphorous analysis can be a valuable indicator for the fertilizer value of the digestate after anaerobic digestion. Total phosphorous content was determined by Gravimetric method according to (APHA). As a first step, fertilizer samples were dissolved in water. The samples were then digested in a mixture of magnesium sulfate and ammonia in order to solubilize all existing phosphorous. The complex mixture was filtered and dried to calculate the phosphorus percent in samples of fertilizer.

3.6.2 Potassium content

Total potassium content was determined according to (ISO 11885 by ICP-OES). This analysis was carried out in Center of Birzeit University Testing Laboratory at BZU. Where the samples was dried and milled, the sample was then digested in a boiling aqua. For subsequent analysis, ICP-OES (inductively coupled plasma – optical emission spectroscopy) was used. This test can also assess nutrient content for the evaluation of digestate use as fertilizer.

3.6.3 Microbiological analysis

All microbiological analysis for the biofertilizers was carried out at Center of Birzeit University Testing Labs. In this study, E. coli, Streptococcus faecalis, and Total coliform were selected as indicator organisms in order to represent the efficiency of AD process, those microorganisms have a high heat tolerances and resistance. Three samples were taken respectively at the first four months from plants operation; these samples were taken after drying of the slurry under the sun light, on the other hand fresh slurry sample was also taken to measure the reduction of indicator microorganism through the anaerobic digestion process at mesophilic temperature.

3.7 Energy production

The energy production in this study was observed to evaluate the potential energy produced in from the biogas system to evaluate the economy of the process. Biogas is directly used for farm heating proposes as substitute of natural gas, according to (Khoiyangbam *et al*., 2011) one cubic meter of biogas with 60% methane is equivalent to 4713 kcal or 4.698 kWh electricity; in this study the mount of the energy from those quintets was calculated by the (Eq. 3-5):

$$Calorific\ value\ of\ 1m^3 of\ the\ biogas(KJ) = 4713kcal \times Total\ biogas\ volume\ (m^3/year) \times\ 4.18\ KJ/kcal \qquad (3-5)$$

3.8 Financial analysis

The financial analysis was done to analyze and calculate the benefit and cost of the biogas system, in order to assess its financial feasibility.

The operation and maintenance costs of the biogas plant were done by calculate, the operation cost includes the costs of water consumption which needed for mixing the substrate for daily feeding; the water consumption was calculated according to Equation (3-6); where C_{water} is water cost, and P_{water} is water price; assuming the price of one cubic meter of water is 1.4$ per based on the market price.

$$C_{water} = (365V\ m^3/day)P_{water} \qquad (3-6)$$

The replacement cost was calculated according Equation (3-7), taking into account the lifespan for each parts of the biogas system (Walekhwa et al., 2014).

$$R_{yearly} = \sum_{i=0}^{n} \left\{ \left(\frac{T_{plant}}{T_{part}} - 1 \right) \times \frac{C_{part}}{T_{plant}} \right\} \qquad (3-7)$$

Where R_{yearly} is the yearly cost of replacement, C_{part} is the cost of replacement for each parts, T_{plant} the plant life and; T_{part} is the lifespan of the parts.

The monetary benefits were calculated as the saving cost from using biogas as an alternative of natural gas, and on fertilizer costs substituted by digester slurry. Values of the spent slurry (S_b) were calculated from the Equation (3-8):

$$S_b = 365 \times W \times P \qquad (3-8)$$

Where S_b is the total annual benefit from the spent slurry, W is the mount of biofertlizers produced per a day in kg (considered as 10.7 kg), and P is the market price of organic fertilizers (considered as 0.11$/kg).

After quantification and valuation of the costs and benefits of the biogas systems; four main evaluation criteria used in this study namely, payback period (PBP), net present value (NPV) and internal rate of return (IRR).

Payback period (PBP) refers to the number of years it would take for an investment to return its original cost of investment through the annual net cash revenues it generates (Walekhwa *et al*., 2014). The PBP was calculated from Equation (3-9):

$$PBP = TI/NR \qquad (3-9)$$

Where, TI is the total amount of investment; and NR is the annual net revenue.

Net present value (NPV) is a way of comparing the value of money now with the value of money in the future (Adeoti *et al*., 2000). To calculate the NPV of the biogas investment Equation (3-10) was used:

$$NPV = \sum_{t=0}^{n} (B - C)_t \, (1 + i)^{-t} \qquad (3-10)$$

Where is B a cash benefit of the investment, C is a cash cost of the investment, $(B - C)_t$ is a net cash flow in the year (t), n is the calculation period, which is equal to the project life-cycle; and i the discount rate. Internal rate of return (IRR) is a financial analysis tool that estimates the interest rate that would make the present value of a stream of net cash revenues equal to zero. It was calculated as:

$$\sum_{t=0}^{n}(B - C)_t(1 + IRR)^{-t} = 0 \qquad (3 - 11)$$

Where is B a cash benefit of the investment, C is a cash cost of the investment, $(B - C)_t$ is a net cash flow in the year (t), n is the calculation period, which is equal to the project life-cycle; and i the discount rate.

The Benefit–Cost Ratio is defined as the ratio of the equivalent worth of benefits to the equivalent worth of costs (Adeoti *et al*., 2000). It's given by equation (3-12):

$$BC_{Ratio} = \frac{\sum_{t=0}^{n} B_t(1+i)^{-t}}{\sum_{t=0}^{n} C_t(1+i)^{-t}} \qquad (3 - 12)$$

Where B_t is the benefit in time t and C_t is the cost in time t. If the BCR exceeds one, then the project might be a good candidate for acceptance.

The financial assessment and analysis will be discussed in more details in chapter five.

Chapter Four

Result and Discussion

This chapter will focus on the results from the laboratory analysis, BMP analysis and biogas plant operation with continues feeding mode under mesophillic condition using a chicken manure as a feed stock. This chapter will also discuss the utilizations of the biogas and bio fertilizers as results from the biogas project.

4.1 Continuous Anaerobic Digestion

Solid waste sample was collected from study chicken farm as feedstock, and for seeding the samples were collected from local cow farm and local municipal wastewater plant as mentioned in chapter three. The chemicals and physical analysis of samples were carried out for every collection in triplicate and the results are illustrated in (Table 4-1) in average value.

Table 4-1: Solid waste and seeding characteristics.

parameter	Chicken manure	Slurry	Cow	Sludge
TS (%)	85.41	12.49	30.29	29.04
TVS(%)	87.81	97.53	93.41	92.63
COD (mg/L)	70473.68	43368.42	23894.73	3105.263
TOC(mg/L)	16396.51	23472.12	1124.18	2104.58
NTK (mg/L)	502.64	769.54	57.75	169.93
C:N	32.62	30.50	19.46	12.38

The dominant factor over the characteristic of raw waste was the high volatile solid content. In the other words high moisture content was cause by the high water and high organic fraction of manures. However, the presented parameters could not exactly reflex the degradation and potential of the waste in the anaerobic digestion process. Methane potential would be more valuable to examine the response of the waste to anaerobic digestion which is described in the next section.

The chicken manure has a solid concentration approximately 20% there for the manure was mixed with the same amount of water in a 1:1 ratio; this was corresponded to a total solid concentration of 12% by weight in inlet slurry**.**

The digestion process and biogas production in the anaerobic digestion depends not only on the process configuration, but also on the waste characteristics. Nutrients and C: N ratio is the important parameters which results in a stable digestion process and good digestate fertilizer quality (Crolla *et al*., 2013). Therefore, in addition to the chemicals characteristics of feed stock and inoculum, C: N analysis of substrate has been done (Table 4-1). The C: N ratio was determined from total organic carbon over total nitrogen of the feedstock. C: N of feedstock in this study was found for solid manure and anaerobic digestion slurry as illustrate in (Table 4-1); C: N ratio for solid chicken manure was 30; which considered being in optimum range for a biological treatment according to (Khhoiyangbamet *et al*., 2011). Thus, sufficient nutrients are available as the C: N ratio of substrate was 32, and the C: N ratio for the slurry was 30.

4.2 Biogas generation

Biogas production is a primary indicator for biogas plant efficiency. The biogas flow was measured along the period of plant operation, which started from 25 of April to 30 of November. It was noted that biogas began produced immediately after seeding; the first production was at (23 May) after one month from plant operation. During the first 4 weeks, there was no feeding applied since the biogas production was increasing gradually, then it was sharply increased in the fourth week; after that production of biogas was fluctuated (Figure 4-1). Likewise, biogas quality was tested by burning on 26 May and it was not burn, flowing this day the biogas was burned with blue flame that indicates a high quality of the biogas. The highest volume of biogas production was (236 L/ day). The daily and accumulative of the biogas production is shown in (Figure 4-1). The trend of accumulative gas production is figured out to provide the better explanation of the relationship between daily gas productions versus time. It is clearly seen that the volume of gas is increase with the longer operational days indicating the good performance of the reactor.

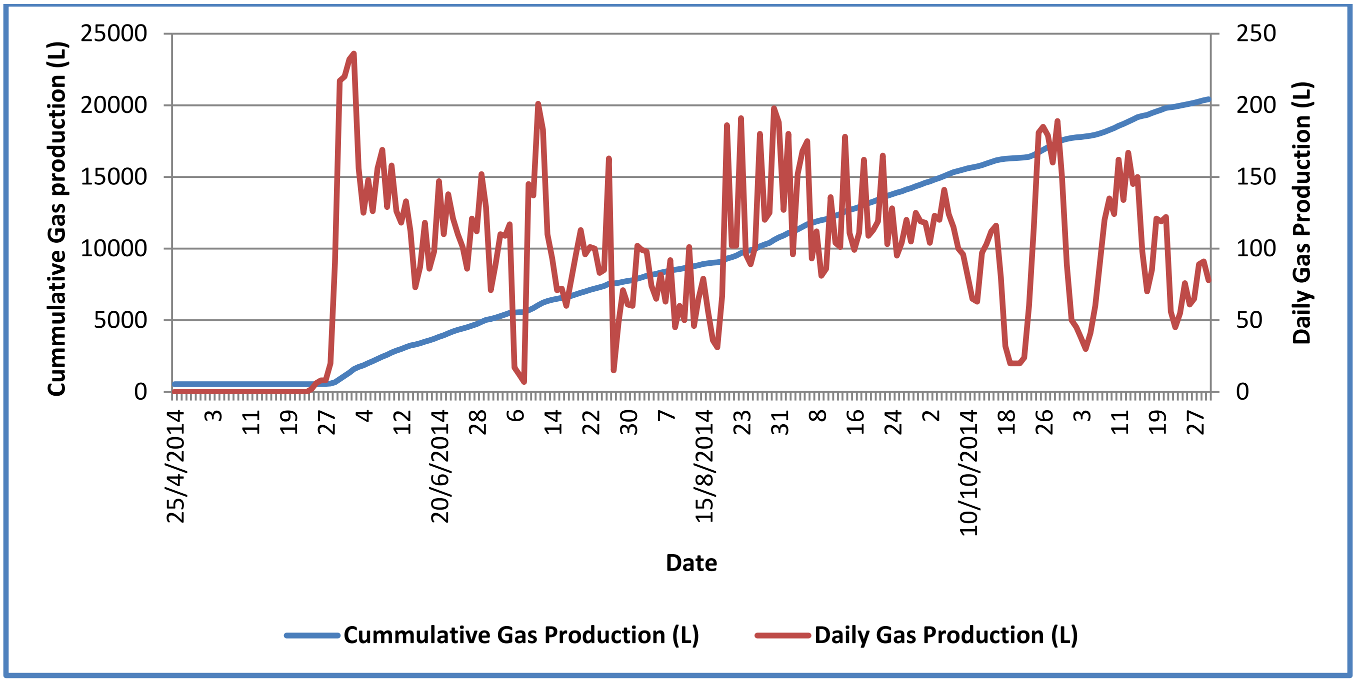

Figure 4-1: Daily and accumulative gas production during biogas plant operation (25 April-30 Sep.)

4.3 Digstate (slurry) characteristics

Volatile fatty acid and the alkalinity of slurry were determined every week during the first month of the start-up. Table 4-2, illustrates the reading by date for VFA and alkalinity of the digestate. Volatile acids/alkalinity was greater than 0.3–0.4, that means an anaerobic digestion process was stable and no risks of acidification according to (Murphy *et al*,. 2013).

Table 4-2: Slurry characteristics in startup period

Date	VFA (mg eq. acetate /L)	Alkalinity (mg $CaCO_3$/L)	VFA/Alkalinity mg/L
May 8, 2014	1722	15240	0.1129
May10, 2014	1567	14560	0.1076
May17, 2014	800	14830	0.0539
May 24, 2014	720	14513	0.0446

The pH and alkalinity variation during the started up period are shown in (Figure 4-2). pH was measured daily as mentioned in previous section, however during the second week of operation, pH value was below 7. This is because of accumulation of the fatty acids in the digester, then pH start to increase after this week. From day 14 to day 29 of May, the pH and alkalinity value were relatively stabilized and biogas begun produced.

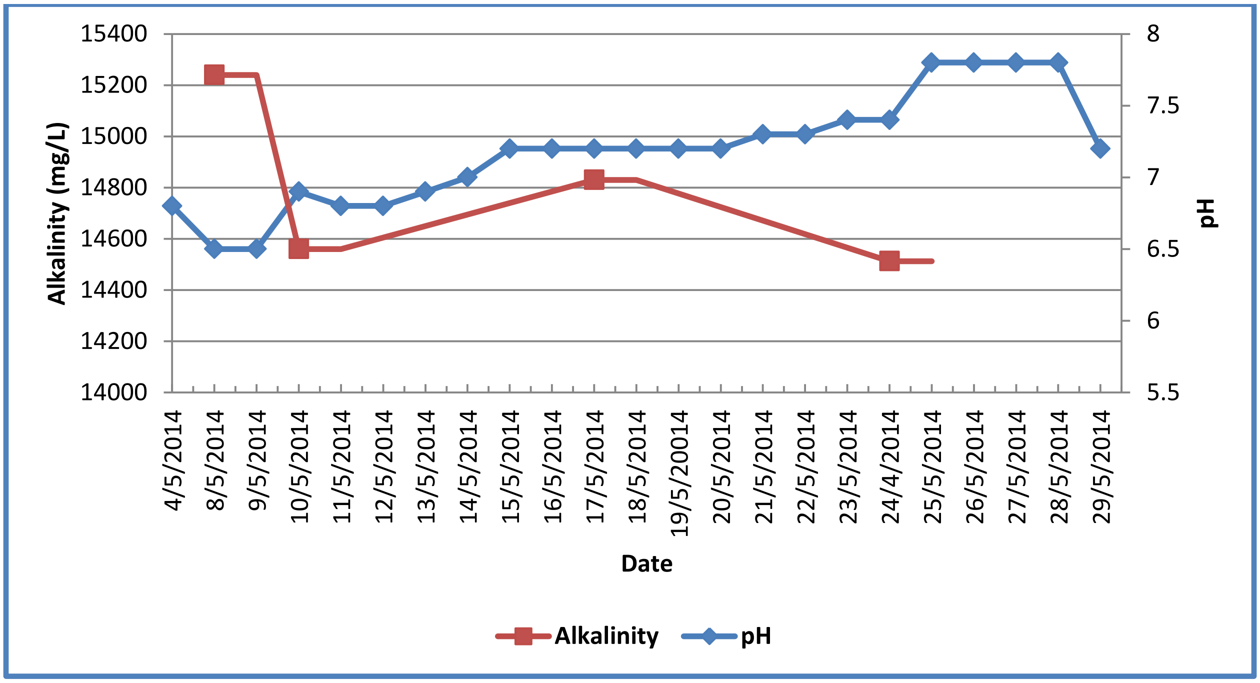

Figure 4-2: Variation between pH and alkalinity acids

Figure 4-3, shows the variation of pH and VFA concentration which were in the same period of star-up. The highest concentration of VFA was with the lowest pH of 6.5. After that, pH of slurry was stabilized in the small range between 7 and 7.8. While VFA concentration was increased at the first few days then dropped gradually and thereafter remains constant in the range 800 mg/L as the indication of the balance condition of the anaerobic system (Table 4-2).

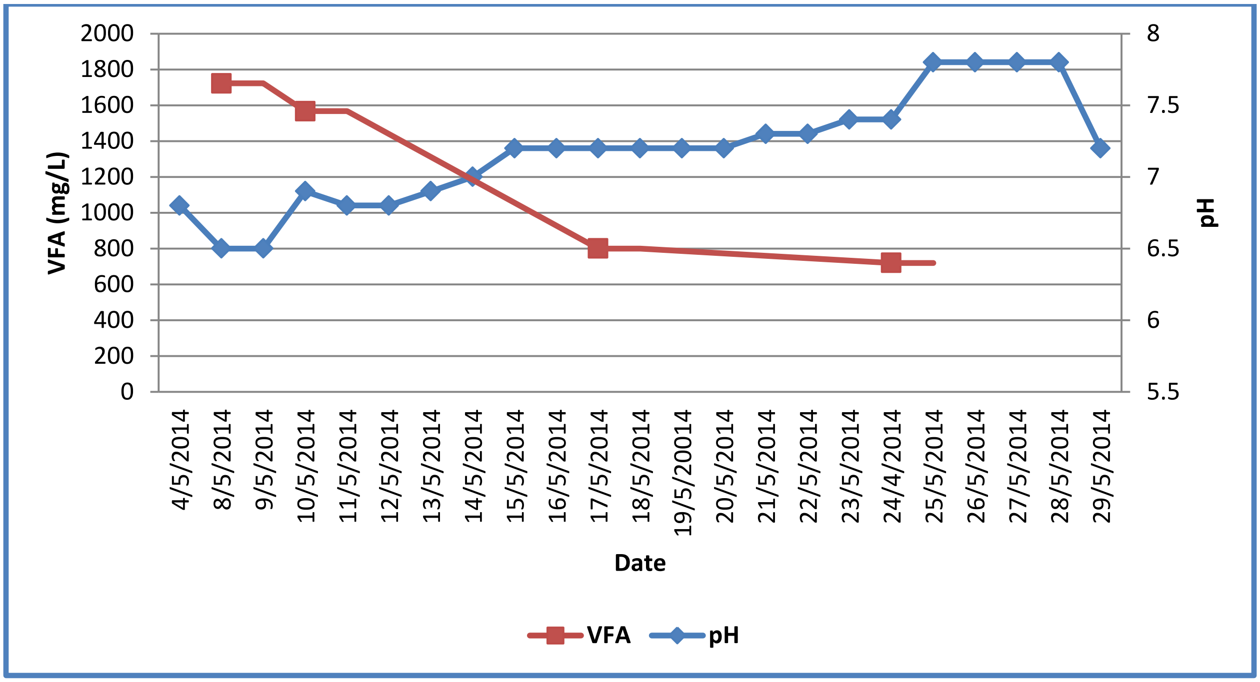

Figure 4-3: Variation between pH and volatile fatty acids

4.4 Continuous feeding

Through the digester operation, a continuous feeding was applied with loading rate of 2.5 kg VS/ (m^3day), however calculations of loading rate and volume of the digester are describe in chapter three. According to (VDI 4630 standard) loading rate was gradually increased by 0.5 kg VS/(m^3day). The loading rate was initiated at an organic loading rate (OLR) of 2.5 kg VS/(m^3day) on 20 June after 28 days (retention time) from beginning of biogas production then OLR was increased by 0.5 kg VS/(m^3day) to be 3 kg VS/(m^3day) after 10 days. After that, the OLR was increased by steps of 0.5 kg VS/ (m^3day) every 10 days (Figure 4-4). In October and November the increasing by 0.5 kg VS/ (m^3day) of in loading rate stopped, due to decreasing in temperature and decreasing in degradation rate.

The reactor is started at an OLR of 0.5 kg VS/ (m^3day) and the biogas production was measured every day. It was shown that after every increase in OLR, the biogas volume was decreased that may due to VFA accumulation; then it was increased again, which shows the adaptation resulting with a stabilized process during the August and September.

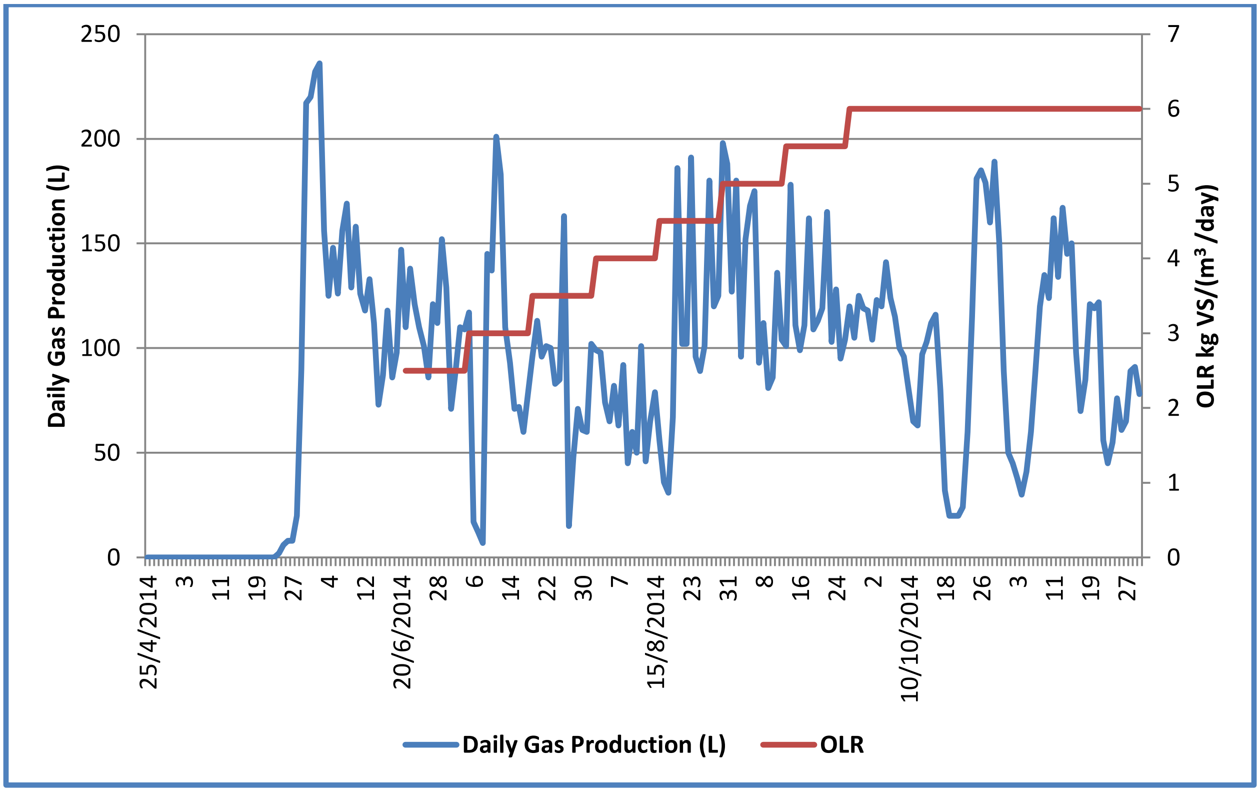

Figure 4-4: Daily gas production per m^3 reactor volume considering organic loading rate (OLR)

4.5 Bio-chemical Methane Potential (BMP)

As mentioned in previous section BMP test procedure was according to (DIN 38 414 (S8)), the setup was used in this study to determine the methane potential from chicken manure samples .at mesophillic condition (35°C) for 30 day. Depending on the daily gas production, a degradation curve was drawn (Figure 4-5) which represents the methane potential of feedstock sample together with blank batch.

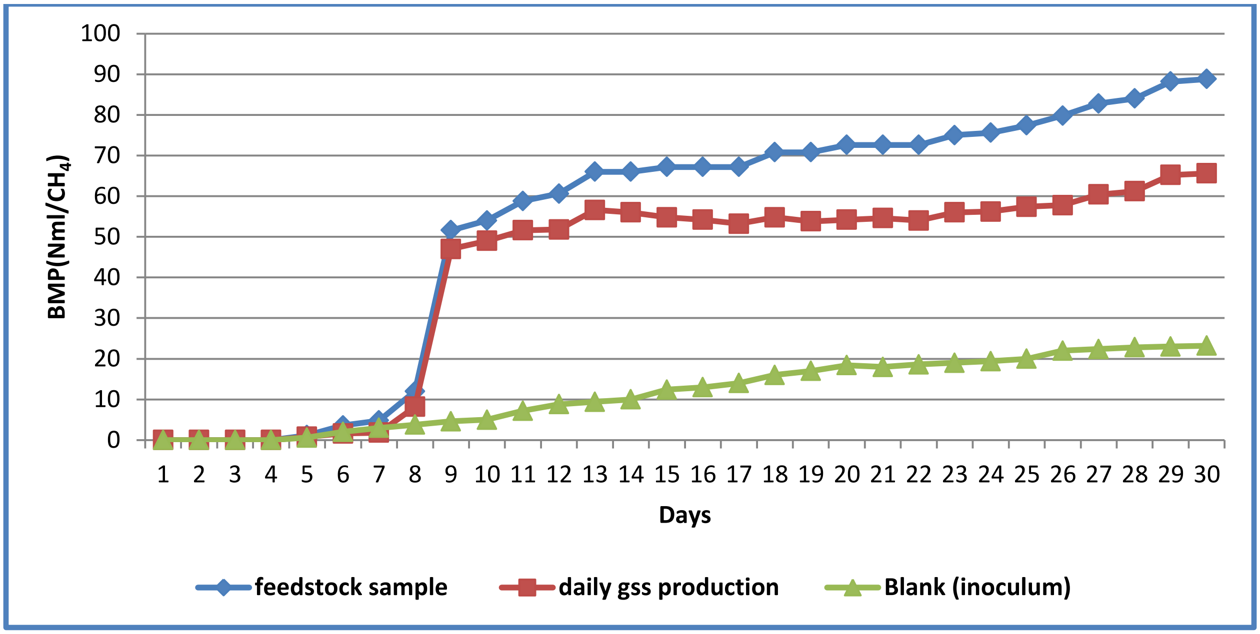

Figure 4-5: Methane potential of feedstock sample together with blank batch

As shown in (Figure 4-5) daily gas production was obtained by subtracting the gas production of the blanks from the daily gas production of the tests with samples; likewise production form inoculum does not exceed 20% of methane production from feed stock according to (VDI 4630) comparing with BMP degradation curves (adapted from VDI 4630 and DIN 38 414 (S8)). Depending on the daily gas production carves and according to the steepness of the graph there was a delay in degradation which may due to microorganism's adaptation.

4.6 Biogas plant output

In this study two main products are result from biogas plant, the biogas and the spent slurry, biogas is directly used for farm heating proposes as substitute of natural gas , the amount of heat that generated from the biogas was 185,787 Kcal which equivalent to 777MJ. The effluent released from the biogas is also an excellent fertilizer. Figure 4-6 shows the farm heated by biogas burning and the spent slurry as an excellent fertilizer.

a. Biogas using for farm heating

b. Bio fertilizers as a product from the biogas plant.

Figure 4-6: The biogas plant output.

As shown in (Figure 4-6) the farm heating by biogas , where the biogas flame has a blue color which means that the biogas quality is very high, on the other side the biofertilizers have a dark brown color without any odors, which trends to improve the soil properties and increase the crops yields. The benefits for both biogas and biofertilizers will be discussed in more details in next chapter.

4.6.1 Biogas production and composition

Biogas production was monitored daily by gas flow meter to measure the volume and the quantity of the biogas but it was not indicate the quality of the gas; therefore composition of the biogas was measured. The volume and the composition of the biogas is an important factor in fermentation process performance.

The results showed the fluctuation of daily biogas volume during anaerobic digestion process, as presented in (Figure 4-1). A very close range of biogas produced was observed in August and September, with approximately average of 108 L/day. However, cumulative of biogas was obtained in the straight pattern indication of biogas remain generated daily.

Methane concentration in biogas and composition of the biogas produced in terms of methane and carbon dioxide content was observed five times in the first days of September; and it was range between 46 to 60% of biogas produced (Table 4-3). It was shown the amount of Carbon dioxide is fluctuated and some time was closed to the mount of methane, on the other hand the amount of oxygen was high of the first two tests of the analysis.

Table 4-3: The composition of the biogas

Test	% CH_4	%CO_2	%O_2
1	46.7	33	2.7
2	46	34	2.1
3	56	25	1.0
4	60.7	21.0	1.5
5	66.2	25	1.6

This problem was occurred during the biogas sample transportation from Ramallah to Amman for one day before the analysis take place. Transportation of the sample was caused a chance of air to go inside the biogas test balloon; although it was made from air tight materials to be operated under anaerobic condition. Which confirms the existence of this problem is that the percentage of methane has risen in the last two tests, while the percent of carbon dioxide and oxygen were decreased (Table 4-3).

On the other hand, average of the methane was approximately 60%, where it is within the acceptable value according to (Khoiyangbam *et al*., 2011).

4.6.2 Biofertilizer quality

The digested effluent of the biogas production process can have values as fertilizer or soil amendment. Due to the removal of carbon during anaerobic digestion process results in organic materials that are rich in nitrogen and phosphorus. The digestate quality depends on the quality of the feedstock that enters the digester, the retention time which this feedstock spends in the digester and the temperature inside the digester.

In this study the chemical parameter were measured for dry digestate samples and compared with the fresh slurry samples (Table 4-4), which illustrates the nitrogen, phosphorus, potassium, carbon/ nitrogen ratio and pH value in digestate samples during the first four months of plants operation. As shown these analysis results as obtained, the anaerobic digestion and sun drying reduced the nitrogen content in feedstock.

Likewise, the increasing the phosphorus and potassium was found. A decrease of nitrogen concentration in the digestate was due to bio-conversion to ammonia gas, which is volatilizing during the sun drying. For potassium and phosphorus, were higher due to the fact that some solid have been converted to biogas, resulting in higher nutrient concentration. The chemical parameter values were compared with (FAO) guideline to be used as organic fertilizer.

Table 4-4: The characteristics of digestate slurry

Samples	**N%**	**P_2O_5%**	**K_2O%**	**C:N**	**pH**
Fresh sample (First of June)	2.86	1.03	1.87	30	7.95
Sample 1 (First of June)	2.31	2.35	2.31	23	7.84
Sample 2 (First of July)	2.12	3.02	3.51	22	7.46
Sample 3 (First of August)	1.90	2.82	2.52	24	7.32
Standard (FAO, 2013)	1.4-1.8%	1.0-2.0%	0.8-1.2%		

Another important criterion is pathogen concentration in the digestate. The feedstock may have pathogens, which can cause diseases for both animals and humans. Anaerobic digestion is able to kill most of common pathogens present in the feedstock mixture inside the digester; the activation of pathogens depends on temperature and retention times of feedstock inside the digester. Drying of the slurry after digestion process is also kills most of pathogens and reducing odors.

In this study, E. coli, Streptococcus faecalis, and Total coliform were selected as indicator organisms in order to represent the efficiency of AD process, those microorganisms have a high heat tolerances and resistance. A reduction of the amount of FS per gram biomass of 3–4 log 10 units is an indicator that the temperature and retention time in the digester able to destroy most of the pathogens such as Salmonella sp. and Pestivirus and other parasites such as Ascaris (Biosantech *et al*., 2013).

Three samples were taken respectively at the first three months from plants operation, these samples were taken after drying of the slurry under the sun light (Table 4-5), on the other hand fresh slurry sample was also taken to measure the reduction of indicator microorganism through the anaerobic digestion process at mesophilic temperature.

Table 4-5: The biological characteristics of the digestate slurry

Samples	**Total coliform(CFU/g)**	**E.coli**	**Streptococcus faecalis (CFU/g)**
Fresh sample (first of June)	32000	4700	144000
Sample 1 (first of June)	Nil	Nil	44000
Sample 2 (first of July)	Nil	Nil	3100
Sample 3 (first of August)	Nil	Nil	830

As shown in (Table 4-5) the sun drying was able to destroyed all cells of E.coli and total coliform within the different retention time of the samples, where SF was more resistance to heat and sun light, the drying was reduced it from 144000 to 830 CFU/g; that means the anaerobic digestion with mesophilic temperature and sun drying can be able to kill the pathogens from the digestate improving the human health and minerals values. This is attributes make the anaerobic digestion slurry and effluent to be more accessible for plant utilization and an excellent fertilizers.

4.7 Impact of the temperature on the anaerobic digestion

The temperature of the digester was daily monitored along the study period of the plant operation. In order to observe the effect of the solar system on the digester temperature and biogas production; two months were taken into account October and November, where the ambient temperatures and solar radiation started to decrease; in these two months solar system was put in use in order to increase the temperature of the digester and to enhance the anaerobic process.

The daily changes in the temperatures of the digester are shown in (Figure 4-7). Fluctuations in the temperature of the digester were small at summer season (from May to September), which although visible fluctuation was notice in October and November. The highest temperature in summer was 50 °C in June and the lowest was 30°C in September. While, the lowest temperature of the digester in October and November was 20°C (rainy day), and the highest temperature was 45°C (sunny day). The annual average temperature of digester in the summer was 40°C, while in November an October was 33°C.

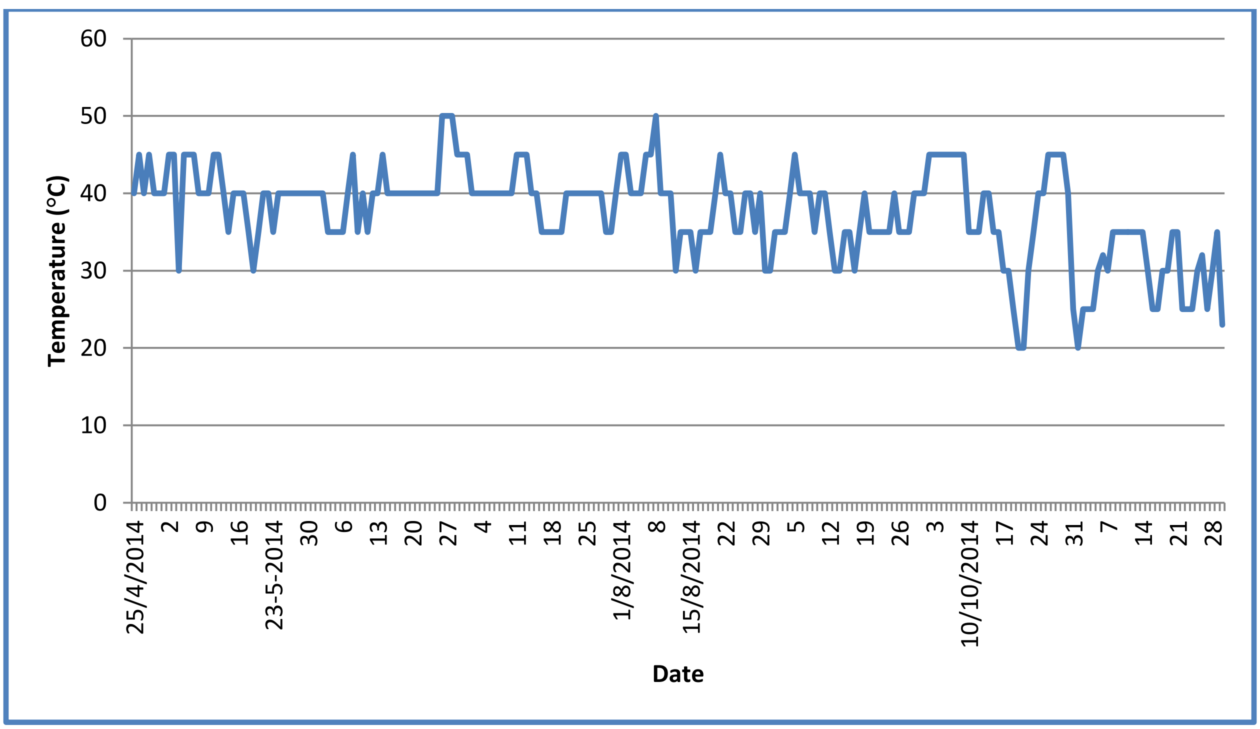

Figure 4-7: Daily changes in the temperatures of the digester.

The biogas volume was measured by flow rate meter at the same time every day during the digester operation; the average of biogas production in summer was 108 L per day, while in October and November decrease to 96 L per a day. Figure 4-8 shows the temperature and the biogas production through the two months of October and November.

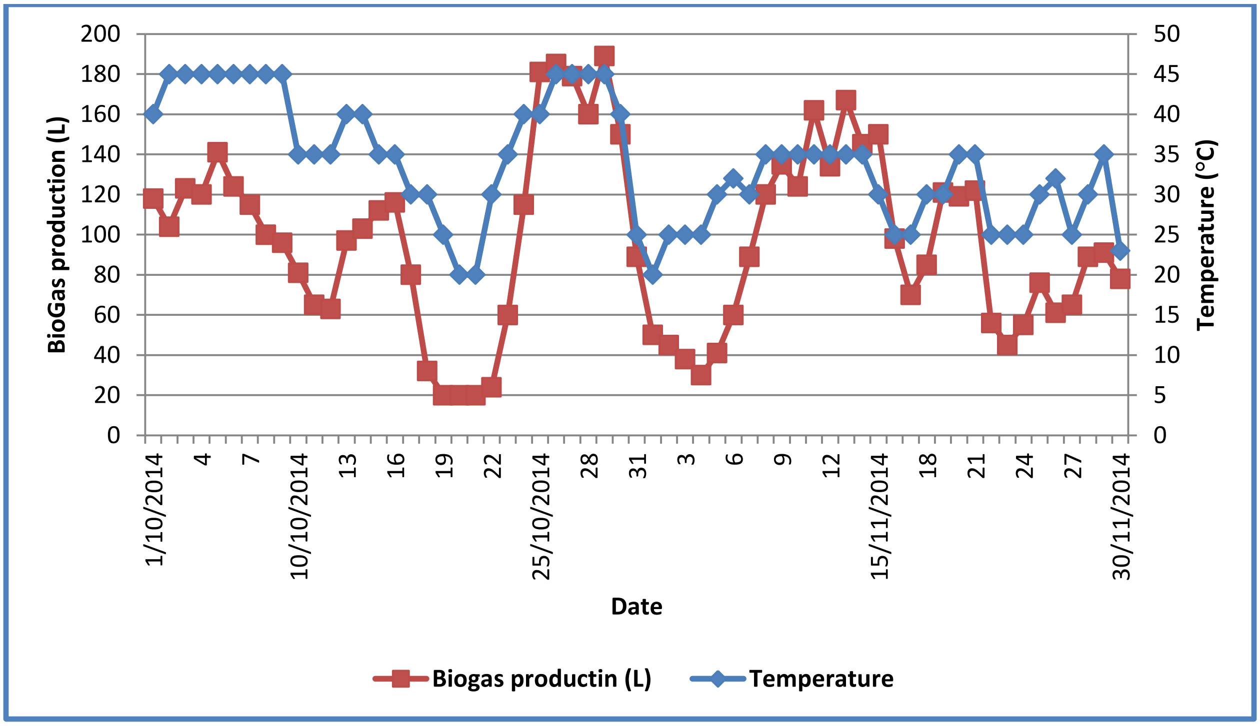

Figure 4-8: Relationship between the biogas production and the digester temperature.

As shown in (Figure 4-8); it is obvious that the gas production in correlated to the change in temperature where the production rate rise after the increase in digester temperature where the largest volume of the biogas produced was 189 L at temperature of 45°C, on the other hand the production decreased to 20 L when temperature declined to 20°C.

October and November of 2014 had 38 sunny days, the average temperature of the digester in these days was 37°C with total average of the biogas production 117 L per a day, while the rainy days were 23 with an average of the biogas production was 62 L per a day at average temperature 27°C.

Hence, the impact of solar system on the biogas production rate was observed. Concluding that the average temperature and average amount of the biogas produced in the sunny days and using the solar system increased by 37% and 88% respectively compared to the rainy days along of the two months.

Chapter Five

Biogas plant financial analysis

5.1 Introduction

One of the most challenges that facing farmers is to provide alternative energy sources to complement traditional sources and mitigate the current energy crisis under the rising in the price of fuel and electricity price, at the same time reduce the amount of the waste that produced from their farm. Therefore, this lead to design and select of the most cost effective sustainable systems. Biogas technology is one of most options that can meet the growing energy demand of rural areas in developing countries. Biogas technology is a source of energy, which can be meet end uses including farm heating, lighting, and the spent slurry can be used as bio fertilizers.

In this study, the full-scale of biogas plant is based on the built design with 10 years lifetime. The digester volume was 500L with capacity volume equal 300L. The gas is used directly for heating by burning it directly from the storage balloon which is connected to heat stove. The plant is operated with the chicken manure from the study farm. The retention time of the substrate was 28 days and then the digestate was drying by sun light to obtain biofertilizer. Table (5-1) gives an overview of the most important characteristics of the biogas plants.

Table 5-1: Summary of engineering design of biogas project for farms heating.

Parameter	**Types/Dimensions**
Digester Size	500 L
Digester Capacity	300 L
Substrate	Chicken manure
Fresh manure	18 kg/day
Retention time	28 day
Life time	10 year
The source of energy used usually for farms heating	Natural gas

This chapter deals with the financial evaluation of biogas system at small scale application, attempting to take into account the costs and benefits accruing to the overall biogas energy production system.

5.2 Costs of biogas plants

The most detailed and the outputs of biogas plant in this study were evaluated to involve the cost; the cost of biogas plant depends on the specific type and size of the digester (Adeoti *et al*., 2000). These include capital and installation costs and operating and maintenance costs.

5.2.1 Capital and installation costs

Capital costs included the cost of construction of the digester plant (thanks, steel and iron bars, pipes, solar system, storage balloon, agitators, workers for plant construction) and site preparation for installation. In order to reduce the capital cost in this study, the plant was built with a local construction materials , and constructed by local experts , the cost of these material was according market price and it was in dollars($). In the contrast, this study has excluded the cost of land, opportunity costs of land, and the interest on financing of plant. This is because the biogas plant was often sited on farm land, and was funded by BZU. The total cost of the plant was 2560$, the cost and the lifespan for each component is presented in Table (5-2), where all the components were valued at their market price to arrive at the final capital and installation costs.

Table 5-2: The full scale cost of biogas plant

Equipment	Cost ($)	Lifespan (year)
Tanks	143	10
Valves, pipes, and connection	702	10
Solar system(solar unit, heat exchanger …)	226	10
Waste collection Tub	100	10
Pump	157	5
Agitators	69	10
Storage balloon	129	5
Sensors (thermometer ,pressure meter, and biogas flow meter)	194	5
Structure (miscellaneous)	580	10
Workers expert construction	346	
Site preparation	43	
Total	2560	

The life time is the expected life time of each part. Some parts need a regular replacement. Then these lifetime values are used to calculate the annually replacement cost.

5.2.2 Operation and maintenance costs

The operation and maintenance costs of the biogas plant includes the cost of various inputs such as raw materials for the substrate, and water consumption for mixing materials or other plant requires; as well as the cost of labors required to operate it (Walekhwa *et al*., 2014). The substrate cost includes substrate price, collection, and transportation. These costs didn’t considered because the substrate of chicken manure was readily available to biogas plant from the study farm along the time of plant operation, and no need for purchasing it. For the workers the cost include separation of the waste, loading of the feedstock, managing the system, drying of the digested material and maintaining the plant; but these cost didn’t considered assuming that the farmer can do his own work as the biogas plant is in a small scale application.

Further costs are water consumption which needed for mixing the substrate for daily feeding; assuming water consumption per was calculated based on the market price of cubic meter of water at 1.4$ per cubic meter, according to Equation (5-1).

$$C_{water} = (365V\, m^3/day)P_{water} \qquad (5-1)$$

The other annual operation and maintenance costs of the biogas plants were repair, maintenance and replacement costs. The main repair and maintenance requirement of a digester is consist of the cost of maintenance and replacement of plant biogas parts like gas valves, pump, solar system, storage balloon, and fixing gas leakage points. The replacement cost was calculated according (Equation 5-2), taking into account the lifespan for each parts of the biogas system.

$$R_{yearly} = \sum_{i=0}^{n} \left\{ \left(\frac{T_{plant}}{T_{part}} - 1 \right) \times \frac{C_{part}}{T_{plant}} \right\} \qquad (5-2)$$

Where R_{yearly} is the yearly cost of replacement, C_{part} is the cost of replacement for each parts, T_{plant} the plant life and; T_{part} is the lifespan of the parts.

The annual operation and maintenance of the biogas plat are shown in (Table 5-3), total water consumption cost was 26.1$ per year. On the other hand the replacement cost for the full scale was calculated according to (Equation 5-2) and it was 48$ per a year.

Table 5-3: Operation and maintenance cost per year

Type	Cost ($/ year)
Substrate cost	0
Water consumption	26.1
Electricity	0
Plant worker	0
Replacement	48
Total	**74.1**

The total operation and maintenance costs are 74.1$ for the full scale plant. That's because working days are not included in the annual running costs.

5.3 Benefits of biogas plants

The benefits from establishing and running a biogas system includes monetary and environmental. The monetary benefits are saving cost from using other energy source such as fuel or electricity, and on fertilizer costs substituted by digester slurry. Environmental benefits include several other indirect benefits such as mitigation of air and water pollution.

The total benefit of biogas system is listed in (Table 5-4), taken into account the benefit from saving by using the biogas as alternative of natural gas, spent slurry, and the mount from the excess biogas, excluding the environmental benefit because it is difficulty to evaluate. The benefit from the biogas production and spent slurry will be discussed in more details in next sections.

Table 5-4: Market value and total benefit of biogas plant considering biogas and slurry value.

Name of component	**Annual Quantity**	**Unit price ($)**	**Annual benefit ($/year)**
Saving from using biogas as alternative of natural gas	0.252 m^3	1.6 $ per/L	420
Biogas production	39.42 m^3		
Amount of the Biogas equivalent to natural gas	17.09 m^3		
Surplus of the biogas after using	16.39m^3	1.5 $ per m3	24.58
Spent slurry (biofertilizers)	10.7 kg/ day	0.11$ per Kg	429.61
Environmental and waste management	0	0	0
Total			**874.19**

Thus the total annual benefits, TAB, due to the installation of a biogas plant was calculated as the sum of benefit from using biogas, saving from using biogas as alternative of natural gas, as well as the benefit from the spent slurry, where the TAB was 874.19 $. The benefits from using the solar system are already included within the amount of the biogas produced.

5.3.1.1 Valuation of biogas

In this study, biogas is mainly used for farm heating purposes. Therefore, the value of biogas based on the quantity of natural gas that the biogas replaced it for heating. The total annual amount of the biogas was 39.42 m^3; according to (Khoiyangbam *et al*., 2011) one cubic meter of biogas with 60% methane is equivalent to 0.433 cubic meter of natural gas. Therefore, the net mount of the biogas would be 17.09 m^3; this amount covers the needed from the natural gas with surplus 16.39m^3 of biogas. The benefit from the excess biogas mount was calculated according to biogas price from the literature which is 1.5$ per cubic meter (Khoiyangbam *et al*., 2011). The annual benefits of the biogas project are shown in (Table 5-4).

5.3.1.2 Valuation of biofertilizer

The chicken manure used in feeding of biogas plant is a source of income to farmers. The digestate slurry has a nutrition value (NPK), and it can use as a biofertlizers and soil amendment. Not only because it contains a nutrient like N, P and K, but also because such nutrients are readily available as crop nutrients.

This study used market prices of organic fertilizers to calculate the benefit of the biofertilizers from the biogas plant. Since the organic fertilizers are used in the most of Palestinian agriculture; these organic fertilizers are purchasing from Israel's companies. Values of the digestate slurry (S_b) were calculated from the (Equation 5-3):

$$S_b = 365 \times W \times P \qquad (5-3)$$

Where S_b is the total annual benefit from the spent slurry, W is the mount of biofertlizers produced per a day in kg (considered as 10.7 kg), and P is the market price of organic fertilizers (considered as 0.11$/kg). In the result, the total benefit of the biofertilizers was 429.61$ per a year (Table 5-4); Hence, the total benefit of the biogas plant would be the sum of benefit of biogas production and the benefit of biofertilizers.

5.4 Cost – Benefit analysis

Cost – benefit analysis play an important role in the valuation of biogas system. In cost benefit analysis, both paid price and unpaid price are taken into account. The cost-benefit analysis of this study is presented in (Table 5-5):

Table 5-5: cost-benefit analysis of biogas plant

Parameters	Amount ($)
a. Capital cost	
Tanks	143
Valves, pipes, and connection	702
Solar system(solar unit, heat exchanger …)	226
Waste collection Tub	100
Pump	157
Atgitors	69
Storage balloon	129
Sensors (thermometer ,pressure meter, and biogas flow meter)	194
miscellaneous	580
Workers expert construction	346
Site preparation	43
Total	**2560**
b. Annual cost	
Water consumption (1.4$/m^3	26.1
Depreciation on biogas storage balloon at 10%	15.7
Depreciation on pump at 10%	12.9
Depreciation on sensors at 10%	19.4
Total	74.1
c. Annual income	
Saving from using biogas as alternative of natural gas	420
Income from biogas production (1.5$/m^3)	24.58
Income from biofertilizers (10.7kg/a day at 0.11$/kg)	429.61
Total	874.19
d. Net annual income (c - b)	**800.09**

The net annual income of 800.09$ of the capital cost 2,560$ can be recouped in about 3.2 years

5.5 Economic viability of biogas production

After quantification and valuation of the costs and benefits of the biogas systems, four criteria were used in the analysis of the financial viability, namely, payback period (PBP), net present value (NPV), cost benefit ratio (BCR), and internal rate of return (IRR). The economic life of the biogas plant is 10 years. Results of financial assessment are shown in Table (5-6):

Table 5-6: Results of financial assessment of biogas plant.

Profitability index (i=4%, n=10 years)	**Financial assessment**
Net Present Value, NPV	3,535
Internal Rate of Return, IRR (%)	26.8%
Benefit–Cost Ratio (BCR)	1.57
Payback Period (years)	3.2

5.5.1 Payback period

Payback period (PBP) refers to the number of years it would take for an investment to return its original cost of investment through the annual net cash revenues it generates (Walekhwa et al. 2014). The PBP was calculated from (Equation 5- 4):

$$PBP = TI/NR \qquad (5-4)$$

Where, TI is the total amount of investment; and NR is the annual net revenue.

While the payback period is 3.2 years, which shows that the project has a good feature of not being a risk, operating costs of the project can be recovered within a short duration of 3.2 years, when compared with the economic life-cycle of the project, 10 years. The financial assessments in (Table 5-6) show that the insulation and application of biogas technology, from the Palestinian farmers has a good economic benefit.

5.5.2 Net present value

Net present value (NPV) is a way of comparing the value of money now with the value of money in the future. To calculate the NPV of the biogas investment (Equation 5-6) was used:

$$NPV = \sum_{t=0}^{n}(B - C)_t \,(1 + i)^{-t} \qquad (5-6)$$

Where is B a cash benefit of the investment, C is a cash cost of the investment, $(B - C)_t$ is a net cash flow in the year (t), n is the calculation period, which is equal to the project life-cycle; and i the discount rate.

The NPV in the economic analysis is 3,535$, which shows that the project has a good economic profitability, since the NPV > 0.

5.5.3 The Benefit–Cost Ratio

The Benefit–Cost Ratio is defined as the ratio of the equivalent worth of benefits to the equivalent worth of costs (Adeoti *et al*., 2000). It's given by equation (3-12):

$$BC_{Ratio} = \frac{\sum_{t=0}^{n} B_t(1+i)^{-t}}{\sum_{t=0}^{n} C_t(1+i)^{-t}} \qquad (5-7)$$

Where is B_t is the benefit in time (t), and C_t is the cost in time (t), If the BCR exceeds one, then the project might be a good candidate for acceptance.

The benefit–cost ratio in this study was 1.57, which was greater than 1.0, shows that the investment opportunity is a worthwhile investment, as it has an excess of revenues over expenses.

5.5.4 Internal rate of return

Internal rate of return (IRR) is a financial analysis tool that estimates the interest rate that would make the present value of a stream of net cash revenues equal to zero. It was calculated as:

$$\sum_{t=0}^{n}(B - C)_t(1 + IRR)^{-t} = 0 \quad (5 - 7)$$

The project IRR which is 26.8 % is greater than the present of discount rate of 4%, which shows that the project is apparently worthy of investment and has a good ability to make a profit.

In conclusion the financial analysis of the biogas plant shows great potential for making profit on the capital investment. The benefit from the biogas production and biofertilizers, the economic profitability of the project is expected to increase, making investment in more worthwhile to farmers, since the substrate available.

Chapter Six

Conclusions and Recommendations

6.1 Conclusions

In this study, small scale of anaerobic digestion with volume 500L was designed and operated under continuous feeding mode; the chicken manure was used as substrate. To optimize the anaerobic process a feeding was done by increasing the loading rate at different digestion time. The conclusions drawn based on results from this study are the following:

- The biogas plant has a simple design which can easily applied in other Palestinian farms; where the raw materials and the feeding substrate of the plant available. The biogas plants also can easily constructed using local materials and skills. And it is environmentally sound with 100% recyclable inputs and zero waste emissions.

- Poultry manure was suitable substrate for biogas system with average production 110 L per a day; the biogas increased with increasing the system temperature; where using of solar system supported the system operation by sustaining the temperature.

- The energy results showed that the quantity of biogas was utilized, where it produced enough heat to meet up the farm energy needs, and the biogas is of high quality which leads to a cleaner farm environment and possibly would aid in reducing maintenance costs for the plant.

- The effluent released from the biogas is also an excellent bio-fertilizer. The anaerobic digester and the sun drying of the slurry were able to destroy most of pathogens that may present.

- The biogas system proved to be economically feasible for the farmers to save money by providing them with another source of energy to heat their farm and biofertilizers to use for agricultural purposes making biogas investment more worthwhile to farmers, since the substrate available.

6.2 Recommendations

With regards to the results of the applied biogas pilot project, the following recommendation is proposed in order to facilitate the replication of the pilot on larger scale for the benefit of the Palestinian farmers, research institutes and the government:

- Investigate the technical, environmental and economic feasibility of production of electricity instead of thermal energy. Further to investigate the potential utilization of both systems in accordance to either use it in the Palestinian farms, or any other use.

- To investigate the feasibility of using different substrates and C: N ratio.

- To investigate the utilization of better quality of construction material for the body and the solar thermal component.

- In order to enhance the plant design with optimal use of the available resources and optimal biogas production. The design of the pilot scale in this study has shown that the valves should be larger to prevent clogging, the plant should be insulated or constructed under the ground to keep the temperature of the digester constant during the rainy days, when the solar system can't be operated. Furthermore, the volume of storage balloon needed to be enlarged to provide storage capacity for longer period, while the amount of the gas exceeded or not using.

- The spent slurry after digestion is rich in nutrients and can be used as fertilizer. However further researches shall be conducted on this spent slurry in order to observe the impact of the bio-fertilizer on selected plants and its or its products growth rate, investigate the environmental impacts of utilizing the slurry. What guidelines shall be developed to regulate the slurry utilization as bio-fertilizers

- Various biodegradable organic materials can be anaerobically digested for biogas production to generate electrical power. It is recommended, that Birzeit University build a large scale biogas system for anaerobic treatment of organic waste produced on campus. Thermal or electrical power can be used to run various University facilities.

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