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Evaluation of Qualitative and Quantitative Efficiency of Small Scale Biogas Units in Palestinian Rural Areas

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Dedication

To the spirit of my mother, who had sacrificed intently for the sake of our Education before she passed away. To my beloved father, wife (Ala'a), brother (Ahmad), sisters (Manal, Afaf, Khitam, Somoud) and to my lovely daughter; Nawal with love.

To everyone who cares about the environment and works to save it Respect.

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Last, but certainly not least, I would like to thank my wife Ala'a for constant love and support that have always given me the confidence and the drive to pursue and realize my dreams.

Mahmood Mansour

الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

Evaluation of Qualitative and Quantitative Efficiency of Small Scale Biogas Units in Palestinian Rural Areas

أقر بأن ما اشتملت عليه هذه الرسالة إنما هي نتاج جهدي الخاص ، باستثناء ما تمت الإشارة إليه حيثما ورد ،وأن هذه الرسالة ككل ، أو أي جزء منها لم يقدم من قبل لنيل أية درجة علمية أو بحث علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى .

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's name:	**اسم الطالب:**
Signature:	**التوقيع :**
Date:	**التاريخ:**

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Abbreviations

CH4	Methane gas
CO2	Carbon dioxide gas
Tm	Melting point [ºC]
Tb	Boiling point [ºC]
Tf	Flash point [ºC]
Ta	Auto ignition temperature [ºC]
S	Water Solubility [mg/L]
ρ	Density [kg/ m^3]
ppm	Part per million
AD	Anaerobic Digestion
pH	Acidity degree value
KVIC	Khaki and Village Industries Commission
PVC	Polyvinyl chloride
GGC	Gobar Gas and agricultural equipment development Company
GI	Galvanized Iron
UASB	Up flow Anaerobic Sludge Blanket
SDD	Sustainable Development Department
FAO	Food and agriculture organization
C/N	Carbon : Nitrogen ratio
TS	Total solids
GC	Gas Chromotography
SPSS	Statistical Package for Social Sciences
SAS	The Statistical Analysis System
MSW	Municipal Solid Waste
PNA	Palestinian National Authority

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Abstract

The importance of the study stems from the increasing demands for the natural gas and the tries to find an alternative for this substances. Therefore, Alternative energy is one of the priorities, which seeks to promote human and developed to replace non-renewable sources of energy, of Biogas technology has the potential to provide an alternative to the current unsustainable energy and provide environmental, social, and economic benefits.

Biogas is generated when bacteria break down organic waste such as manure, crop residues, or food waste in the absence of oxygen, in a process known as anaerobic digestion. Biogas is a complex mixture of several gases, but the majority of the product is methane(CH_4) and carbon dioxide (CO_2).

The main objective of the study is to evaluate the qualitative and quantitative efficiency of small Scale biogas units in Palestinian rural areas. For achieving the study purpose, an experiment on cow manure , food residues, cow manure mixed with food residues and poultry manure mixed with food residues has been conducted, data has been gathered, codified, entered the computer and statistically analyzed by using the Statistical

package of the Social Sciences (SPSS) and the Statistical Analysis System (SAS) program .

The study consists of four chapters. The first one starts with an introduction about the necessity of the energy resources in general and the need for the renewable energy resources for and there advantages. The literature review discuses the biogas as a recourse of energy in the world and its system.

The third chapter presents the study methods included the experimental setup, experimental program, field measurements and lab analysis. A small unit was used to produce biogas size of 1500 L was fed by four types of organic waste: cow dung and food residues and cow dung mixed with the remains of food, poultry manure mixed with the remains of food, and has been studied and assess the effectiveness of the unit in the production of biogas in terms of the amount and quality of the gas output of the four organic waste each separately.

Results obtained from this study showed that all samples produce biogas at ambient temperature. The food residues produce the biggest quantity of biogas comparing with other organic wastes (22.160Kg biogas/ during 14 days), then poultry manure mixed with food residues (20.125Kg biogas/ during 14 days), then cow manure mixed with food residues (16.980Kg biogas/ during 14days),then cow manure (16.600Kg biogas/ during 14 days). The results indicated biogas has a heat value equals half heat value of commercial gas used in our homes. Moreover, results reveal a strong relationship between temperature and (Biogas production from cow manure, food residues, cow manure mixed with food residues and poultry manure mixed with food residues.

According to study results, it can be said that small scale biogas units are not complicated, cheap, robust, easy to operate and maintain, and can be constructed with locally produced materials and suitable for biogas production for Palestinian rural families in order to cover its monthly requirement from natural gas and producing high quality organic fertilizer to improve crop yield.

Therefore, the possibility of making use of biogas as a source of energy in Palestinian rural areas of small scale biogas units is recommended. This what the fourth chapter contained.

According to the study results, several recommendations have been suggested including substituting daily energy requirement of natural gas by biogas in rural areas in order to save the costs, encouraging people to turn to the new recourses of energy, supporting and encouraging biogas technology in order to be used in Palestine by PNA with good cooperation between farmers and related sectors as energy, environment and agricultural sectors to improve and apply digesters in Palestinian rural areas, more researches and practical studies about applying biogas technology in Palestine should be conducted in order to improve biogas plant in Palestine, financial should be provided in this field.

Chapter One

Introduction

1.1 Introduction

Energy is inevitable for human life and a secure and accessible supply of energy is crucial for the sustainability of modern societies. Continuation of the use of fossil fuels is set to face multiple challenges: depletion of fossil fuel reserves, global warming and other environmental concerns, geopolitical and military conflicts and of late, continued and significant fuel price rise. These problems indicate an unsustainable situation. Renewable energy is the solution to the growing energy challenges (Asif, 2005).

Renewable energy resources such as solar energy, wind energy , Hydro energy, Bio energy, Geothermal energy, and Wave and tidal energy. These sources are abundant, inexhaustible and environmentally friendly. Biogas is a kind of renewable energy made from animal and human excreta and food wastes. One way of making it is by collecting the wastes and putting them in containers called digesters and the wastes are converted to gas by an anaerobic process. The process essentially mimics the natural process by which marsh gas is produced at the bottom of stagnant water bodies. The gas is a mixture of methane and carbon dioxide (Asif, 2005).

Since Palestine is a developing country, its access to considerable amounts of energy is essential to achieve economic growth and development. There are many challenges facing Palestine, arising mainly from its energy dependence. Its energy is not provided through domestic means but rather provided through other countries which controls the quantity and quality of energy imported.

With complete dependency on Israel for its energy needs, Palestine is put in a vulnerable position given its complex political and security situation. Such a threat has given rise to the importance of using renewable energy such as solar, wind, biogas and so on (Ibrik, 2009).

Biogas technology is considered suitable technology for rural communities like Palestine , and a good method for reducing the volume of generated wastes that should be disposed off with more positive impacts on our health, economy and our environment in general as well as decrease the energy reliance on the other countries (Ibrik, 2009).

This thesis to share in disseminating this important technology in our rural areas at a family scale which may provide our families and society with many benefits such as:- biogas, organic fertilizer, decreasing the volume of organic wastes that must be disposed off, and improving the environment through evaluating qualitative and quantitative efficiency of small scale biogas units in Palestinian rural areas. This thesis contains four chapters.

The first chapter includes an introduction, research objectives, research motivation, , and research hypothesis.

The second chapter includes literature review ,describes biogas definition and a characteristic, the benefits of biogas technology, the biogas process , and the important factors affecting the digestion process. Then the chapter concerned with biogas system, its types and the main factors influencing the selection of then shows the biogas production in the world, Arab countries and Palestine.

The third chapter presents the experimental setup, experimental program, field measurements ad lab analysis.

The fourth chapter presents the results and discussions, biogas production ,biogas quality, statistical analysis, biogas use and economic analysis.

At the end conclusions, recommendations and appendix.

1.2 Objectives

The study aims to achieve a set of goals and most important of which are the following :

1. Evaluating the biogas production unit by using different types of organic waste.
2. Evaluating the quality and quantity biogas production .
3. Modeling of biogas production as a function of operating parameters (waste type, time and temperature).

1.3 Motivation

My personal motivation to study this topic came from the following reasons:

1. Biogas technology is considered a renewable source of energy and a good method for reducing the volume of generating wastes that should be disposed off with more positive impacts on our health, economy and our environment in general.
2. The vast majority of fossil fuels consumed in the Palestine is imported, with the majority originating in other countries. Using these energy sources may significantly decrease the energy reliance

on other countries and improve the Palestinian population's access to energy.

3. Many Palestinian families are suffering from high prices of commercial gas. Biogas project provides these families a significant portion of the money that spent on gas for cooking and heating.
4. Absence of governmental initiatives and concern for the development of renewable resources.

For the previous reasons biogas technology is considered the most important and suitable technology for rural families, and so it was selected to be the subject of this study.

1.4 Hypothesis

The general hypothesis to the study is:

1. The project is feasible for the rural Palestinian families.
2. The amount of biogas produced from organic wastes by biogas unit sufficient for household uses.
3. Household waste produces biogas enough for household uses such as heating and cooking.
4. There is a relationship between Biogas production from organic waste and the temperature.

Chapter Two

Literature Review

2.1 Biogas

Biogas is generated when bacteria break down organic waste such as manure, crop residues, or food waste in the absence of oxygen, in a process known as anaerobic digestion.

Biogas is a complex mixture of several gases, but the majority of the product is methane and carbon dioxide. Methane, the desired component of biogas, is a colorless, blue burning gas used for cooking, heating, and lighting. Biogas is clean , renewable source of energy, which can be used as a substitute for other fuels in order to save energy in rural areas .

2.1.1 Biogas composition

Werner, Stohr and Hees (1989) state that biogas usually contains about 50 to 70 % CH_4 30 to 40 % CO_2 and other gases, including ammonia, hydrogen sulfide, and other noxious gases. It is also saturated with water vapor. Werner, Stohr and Hees (1989) in their study, indicates that the relative percentage of gases in biogas depends on the feed material and management of the process. Table (2.1) shown Biogas compositions.

Table (2.1) : Biogas compositions (FAO/CMS, 1996)

Substances	**Symbol**	**Percentage**
Methane	CH_4	50 – 70
Carbon Dioxide	CO_2	30-40
Hydrogen	H_2	5- 10
Nitrogen	N_2	1-2
Water vapour	H_2O	0.3
Hydrogen Sulphide	H_2S	Traces

Methane is virtually odorless and is invisible in bright daylight. It burns with a clear blue flame without smoke and is non-toxic. Table (2.2) shown characteristics for CH_4.

Table (2.2) : Characteristics for CH_4

Common synonyms	Marsh gas , fire damp
Formula	$CH4$
Physical properties	Form : colorless , odorless gas . Stability : Stable Melting point [**Tm**]: -182 ºC Boiling point [**Tb**]: -164 ºC Flash point [**Tf**] : -1221 ºC Auto ignition temperature [**Ta**] : 537 ºC Water Solubility [**S**] : slight (25mg/L at 20 ºC) Density [**ρ**] = 0.717 kg/m^3 at 20 ºC
Principal hazards	CH4 is very flammable. CH4 can react violently or explosively with strong oxidizing agents, such as oxygen, halogens or inter halogen compounds. At high concentration methane acts as an asphyxiant .
Safe handling	Wear safety glasses. The primary danger is from fire and explosion, so ensure work in a well-ventilated area, preferably within a fume cupboard, and that there is no source of ignition present.
Emergency	Eye contact : Unlikely to occur. Skin contact : Unlikely to occur. If inhaled : Remove from the source of gas. If the amount inhaled is large or if breathing has ceased call for immediate medical help.
Disposal	Small amounts of CH4 can be allowed to disperse naturally. Be aware that any significant build-up of gas presents a danger or fire or explosion.
Protective equipment	Safety glasses.
Heating value	The heat value of biogas equal 1/2 heat value of butane gas (mahmoud,2007) = 9.5 kWh/Kg biogas (34200 kj /kg).

http://ptcl.chem.ox.ac.uk/~hmc/hsci/chemicals/methane.htm1

Biogas is highly flammable and is produced through the anaerobic (without oxygen) decomposition of organic materials from plants and animals. It is similar in most respect to Natural gas (obtained from fossil fuel) used for heating and cooking at homes and industries. Table (2.4) presents comparison between biogas and natural gas (Bothi, 2007).

Table 2.3 : Comparison of constituents in natural gas and biogas.

Constituents	**Units**	**Natural Gas**	**Biogas**
Methane (CH_4)	Vol%	91	55-70
Ethane (C_2H_6)	Vol%	5.1	0
Propane (C_3H_8)	Vol%	1.8	0
Butane (C_4H_{10})	Vol%	0.9	0
Pentane (C_5H_{12})	Vol%	0.3	0
Carbon Dioxide (CO_2)	Vol%	0.61	30-45
Nitrogen (N_2)	Vol%	0.32	0-2
Volatile Organic Compounds (VOC)	Vol%	0	0
Hydrogen (H_2)	Vol%	0	0
Hydrogen Sulfide (H_2S)	ppm	~1	>500
Ammonia (NH_3)	ppm	0	~100
Carbon Monoxide (CO)	ppm	0	0
Water Dew Point	ºC	<-5	Saturated
Heating Value	BTU/SCF	1031	~600

Source: Jensen and Jensen (2000) referenced in Monnet (2003).

2.1.2 The Benefits of Biogas Technology

According to AgSTAR (2010), several benefits of biogas technology can be achieved:

1. **Energy benefits**
   - Multiple existing biogas end-use applications, including:
     – Heat-only
     – Electric-only
     – Combined heat and power
     _ Transportation fuel
   - Dispatchable energy source (vs. intermittent wind and solar)

- Distributed generation (which means lower transmission / transportation costs and higher reliability) .
- Direct replacement for non-renewable fossil fuels .

2. **Waste treatment benefit**s

AgSTAR (2010) reported the following benefits for the waste treatment:

- Reduces volume of waste for transport, land application (vs. not using digestion).
- Very efficient decomposition.
- Complete biogas capture.
- Nutrient recovery and recycling.

3. **Environmental benefits**

Also AgSTAR (2010) reported the following environmental benefits:

- Dramatic odor reduction.
- Reduced pathogen levels.
- Reduced greenhouse gas emissions.
- Platform for reducing nutrient runoff.
- Increased crop yield by produce High quality fertilizer. In the process of anaerobic digestion, the organic nitrogen in the manure is largely converted to ammonium. Ammonium is the primary constituent of commercial fertilizer, which is readily available and utilized by plants.

4. **Economic benefits**

AgSTAR (2010) reported the following economic benefits:

- Jobs (temporary /construction and permanent) .

- Turns cost item (i.e., waste treatment) into revenue-generating opportunity.
- Can operate in conjunction with composting operations.
- Improves rural infrastructure and diversifies rural income streams

2.1.3 Environmental impacts of biogas technology in Palestine

Using organic wastes (animals dung, plants waste, domestic organic waste, waste water) as a substrate for the biogas plants considered one of the most important ways for wastes management. The following main impacts could be achieved if this technology successfully applied:

1- Reducing the volume of wastes that to be disposed of by other disposal ways as incineration, landfill, direct burning or bad accumulation which eliminate negative impacts associated with these ways as: smoke, dust, leachate forming and gases emissions. Biogas technology decreases air, soil, ground and surface water pollution.

2- Reducing uses of fossil fuels, charcoal, firewood and direct burning of animals dung for getting energy which decrease air pollutants, save frosts, decreasing soil erosion and saving time and efforts for gathering firewood.

3- Reducing pathogens and the following statement emphasize that “Anaerobic digester systems can reduce fecal coli form bacteria in manure by more than 99 percent, virtually eliminating a major source of water pollution” (Oregon Office of Energy, 2002).

4- Using of digested organics as crops fertilizer reduces using of chemical and manufactured fertilizers return positively on consumer health.

5- The odor of digested wastes is much less than that of undigested.

6- Eliminating or reducing accumulated wastes decreases the distribution of rodents, insects, flies and other disease victors in addition to enhancing area aesthetic sight.

2.2 Biogas Generation

According to Demirer and Chen(2004) biogas can be generated from the following digestions:

2.2.1 Anaerobic Digestion

Anaerobic digestion is a microbiological process that produces biogas, consisting primarily of methane (CH_4) and carbon dioxide (CO_2) in the absence of oxygen. The digestion process occurs in four steps as shown in figure (2.1).

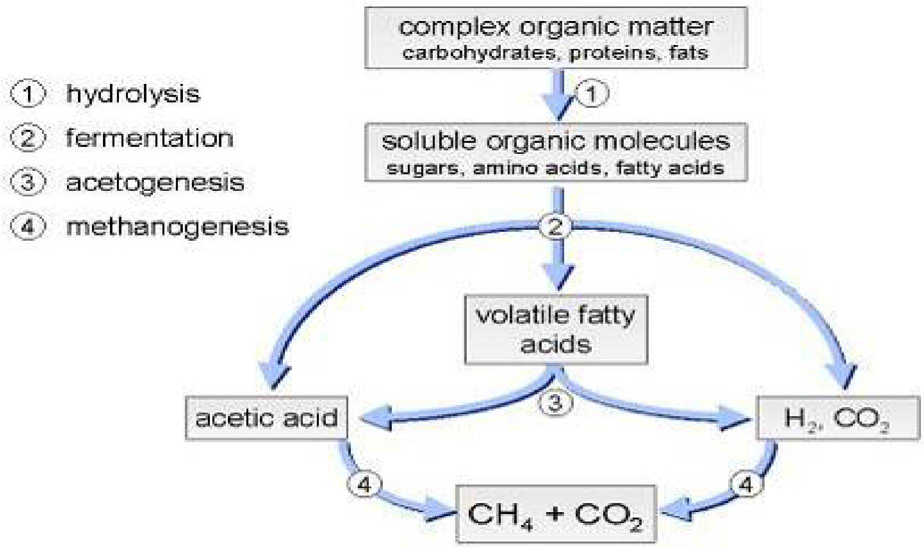

Figure (2.1): Anaerobic process microbiology consists of four steps http://water.me.vccs.edu/courses/ENV149/lesson4b.htm

- **Step1: Hydrolysis**

  Hydrolysis is an enzyme mediated conversion of complex organic compounds (carbohydrates, proteins, and lipids) to simple organics (sugar, amino acids, and peptides) for use as an energy source and cell carbon.

  Hydrolysis and liquefaction of complex and insoluble organics are necessary to convert these materials to a size and form that can pass through bacterial cell walls for use as energy or nutrient sources.

- **Step2: Fermentation or Acidogenesis**

  Acidogenesis is the process in which bacterial fermentation (by the acidogens) of the hydroylsis products results in the formation of volatile acids. The hydrogen-producing acetogens convert the volatile acids (longer than two carbons) to acetate and hydrogen.These microorganisms are related and can tolerate a wide range of environmental conditions. Under standard conditions, the presence of hydrogen in solution inhibits oxidation, so that hydrogen bacteria are required to ensure the conversion of all acids.

- **Step3:Acetogenesis**

  The simple molecules from acidogenesis are further digested by bacteria called acetogens to produce CO_2, hydrogen and mainly acetic acid.

- **Step4: Methanogenesis**

  Karki, et al.(2005) added that methanogens convert the acetate and hydrogen to methane and carbon dioxide. Or Methanogenesis - methane, CO_2 and water are produced by bacteria called methanogens.

The primary route is the fermentation of the major product of the acid forming phase, acetic acid, to methane and carbon dioxide. Bacteria that utilize acetic acid are acetoclastic bacteria (acetate splitting bacteria). The overall reaction is:

$$CH_3COOH \longrightarrow CH_4 + CO_2$$

About two-thirds of methane gas is derived from acetate conversion by acetoclastic methanogens. Some methanogens use Hydrogen to reduce Carbon dioxide to Methane (hydrogenophilic methanogens) according to the following overall reaction :

$$4H_2 + CO_2 \longrightarrow CH_4 + 2H_2O$$

Circumstances in treating solid wastes, acetate is a common end product of acidogenesis. This is fortunate because acetate is easily converted to methane in the methanogenic phase. Due to the difficulty of isolating anaerobes and the complexity of the bioconversion processes, much still remains unsolved about anaerobic digestion.

The principle acids produced in Stage 2 are processed by methanogenic bacteria to produce CH_4. The reaction that takes place in the process of CH_4 production is called Methanization and is expressed by the following equations:

$CH_3COOH \longrightarrow CH_4 + CO_2$

Acetic acid Methane Carbon dioxide

$2CH_3CH_2OH + CO_2 \longrightarrow CH_4 + 2CH_3COOH$

Ethanol Carbon dioxide Methane Acetic acid

$CO_2 + 4H_2 \longrightarrow CH_4 + H_2O$

Carbon dioxide Hydrogen Methane Water

The above equations show that many products, by-products and intermediate products are produced in the process of digestion of inputs in an anaerobic condition before the final product CH_4 is produced.

2.2.2 Factors affect the rate of digestion and biogas production

Several parameters within the anaerobic digester affect the physical environment and therefore the efficiency of digestion and biogas production potential. AD facility operators must monitor the following parameters within acceptable ranges: pH, temperature, retention time, organic loading rate, nutrient content, toxicants and mixing. The optimum ranges and importance of these critical factors are described below.

1.pH value :

The pH of the input mixture plays very important role in methane formation. The acidic condition is not favorable for methanogenic process. The optimum biogas production is achieved when the pH value of input mixture in the digester is between 6 and 7 (FAO/CMS, 1996).

2.Temperature :

The enzymatic activity of the bacteria largely depends upon temperature, which is critical factor for methane production. There are mainly three types of microorganisms categorized according to their habit of growth temperature. They are as follows:

- Physophillic bacteria, which grow below I0°C;
- Mesophilic bacteria, which grow between 25°C - 35°C; and
- Thermophylic bacteria, which grow within the range of 45°C - 55°C.

Once metabolism occurs exothermic reaction is helpful for the methane production. In case of mesophilic digestion, temperature range should be maintained between 30 and 40°C. Satisfactory gas production takes place in the mesophilic range, the optimum temperature being 35°C.

Therefore, in cold climate the temperature of fermenting substances in the digester needs to be raised up to 35°C. Biogas production can be augmented significantly by increasing the temperature up to 55°C beyond which the production falls because of destruction of bacterial enzyme by elevated temperature. Thus, in case of thermophylic digestion, it should be between 45 and 55°C. On the other hand, when the ambient temperature goes down to 10°C, gas production virtually stops. Gas production can be increased in the cold climate by means of proper insulation of digester (Verma, 2002).

3. Organic Loading Rate :

Lagrange(1979) in his study stated that loading rate is the amount of raw materials fed per unit volume of digester capacity per day. If the plant is overfed, acids will accumulate and methane production will be inhibited. Similarly, if the loading rate is lower, there will be less gas.

4.Retention Time :

Retention time (also known as detention time) is the average period that a given quantity of input remains in the digester to be reacted, time is calculated by dividing the total volume of the digester by the volume of inputs added daily. Time is also dependent on the temperature and up to 35°C, when the time become higher the temperature get lower (Lagrange, 1979).

5.Toxicity :

In terms of toxicity, Chengdu (1989) mentioned in his study that mineral ions, heavy metals and the detergents are some of the toxic materials that inhibit the normal growth of pathogens in the digester. Small quantity of mineral ions (e.g. sodium, potassium, calcium, magnesium, ammonium and sulphur) also stimulates the growth of bacteria, while very heavy concentration of these ions will have toxic effect. For example, presence of NH_4 from 50 to 200 mg/L stimulates the growth of microbes, whereas its concentration above 1,500 mg/L produces toxicity. This depends on PH.

Similarly, heavy metals such as copper, nickel, chromium, zinc, lead, etc. in small quantities are essential for the growth of bacteria but their higher concentration has toxic effects. Likewise, detergents including soap, antibiotics, organic solvents, etc. inhibit the activities of methane producing bacteria and addition of these substances in the digester should be avoided.

6. Slurry :

Lagrange (1979) states that this is the residue of inputs that comes out from the outlet after the substrate is acted upon by the methanogenic bacteria in an anaerobic condition inside the digester. After extraction of biogas (energy), the slurry(also known as effluent) comes out of digester as by-product of the anaerobic digestion system. There is less separation in the slurry if the feed materials are homogenous. Appropriate ratio of urine, water and excrement and intensive mixing before feeding the digester leads to homogeneous slurry.

7. Mixing:

Al Sadi (2010) in his study states that this parameter is primarily a function of the hydraulic regime (mixing) in the reactors. Mixing of the substrate in the digester helps to distribute organisms uniformly throughout the mixture and to transfer heat .The importance of adequate mixing is considered to encourage distribution of enzymes and microorganisms throughout the digester where MSW decomposition is carried out. Furthermore, agitation aids in particle size reduction as digestion progresses and in removal of gas from the mixture.

The material inside any digester may be further mixed through mechanical or gas mixers that keep the solids in suspension. Often biogas is bubbled through the digester as an inexpensive way to promote movement .Mechanical mixers inside digesters are less common because maintenance is somewhat difficult.

Mixing can also be achieved through the recirculation of waste. After digested waste is removed from the reactor at the end of its retention time ,a percentage of it is fed into the stream of incoming fresh waste. This serves to contact the fresh waste with bacterial mass and increase movement in the digester, which prevents the buildup of a scum layer.

2.2.3 Biogas plants types

The biodigester is a physical structure, commonly known as the biogas plant. Since various chemical and microbiological reactions take place in the biodigester, it is also known as bio-reactor or anaerobic reactor .The main function of this structure is to provide anaerobic condition within it. As a chamber, it should be air and water tight. It can be made of various construction materials and in different shape and size.

2.2.3.1 Size types

1- The family – size units

   These units seem to be the most promising sizes. For these units organic wastes of three or more equivalent animal units plus the human waste and kitchen waste of an eight person family can be fed. This waste is enough to produce biogas to supply the household with its cooking gas needs.

2- The community – type units

   These units are to be shared by neighbors, usually relatives. These units will be fed by combined feed stock of human and animal wastes. Also, these units can be used in public latrines in schools, factories, hospitals. It is expected that these units will face problems in their operation and maintenance as a result of the social structure.

3- The large- scale systems

Al Jaber (1992) showed in his study that there are a large number of animal farms; these farms are suitable for large mechanized biogas plants. This includes installation of modified biogas fueled internal combustion engine driving electric generator for lighting and operating small household electrical appliances in the village. The situation in many villages is such that the Palestinian villages do not have electricity or even running water. In these cases the community indicated that their urgent need is supplying them with electricity from biogas .

2.2.3.2 Continuity types

Hassan (2004) indicates that Biogas plants can be classified according to the rate of substrate loading into three types which are:

1. continuous,
2. semi-continuous
3. and batch.

In the continuous plants, there is a daily (or regular) introducing of the substrates into the digester with getting out the same quantity of digested materials. While in the case of batch plants, all of required amount of substrates to fill the digester are added once at the beginning of the digestion process and removed all from the digester after completing substrate digestion. In semi-continuous plants, fast or reasonable digested substrates are added into and removed from the digester in a regular manner.

Continuous plants provide the farmer or the investor with stable and high biogas production, in addition to daily disposal of wastes, which avoid from the bad odor that resulted from accumulation of these wastes. These plants require fluid and homogenous substrate and they are so sensitive toward substrate characteristics (especially pH and total solids) and ambient conditions, therefore it requires monitoring .

2.2.3.3 Design types

1-Floating drum digester

In 1956 Jashu Bhai J Patel developed a design of floating drum biogas plant popularly known as Gobar Gas Plant . In 1962, the Khadi and Village Industries Commission (KVIC) of India approved Patel's design and this design soon became popular in India and the world. The design of KVIC plant is shown in Figure 2.2 (Singh. Myles and Dhussa, 1987).

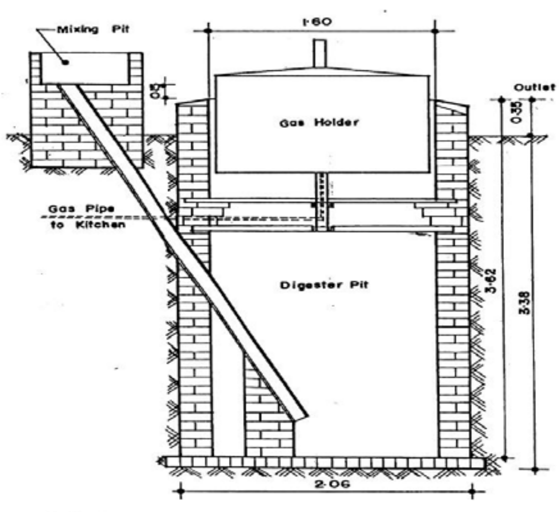

Figure (2.2): KVIC Floating gas holder system

In this design, the digester chamber is made of brick masonry in cement mortar. A mild steel drum is placed on top of the digester to collect the biogas produced from the digester. Thus, there are two separate structures for gas production and collection.

2- Fixed dome digester (Drumless Digester)

This type of digester was built in China as early as 1936. It consists of an underground brick masonry compartment (fermentation chamber)with a dome on the top for gas storage. In this design, the fermentation chamber and gas holder are combined as one unit. This design eliminates the use of costlier mild steel gas holder which is susceptible to corrosion . Its sketch is given in figure (2.3) (Singh. Myles and Dhussa, 1987).

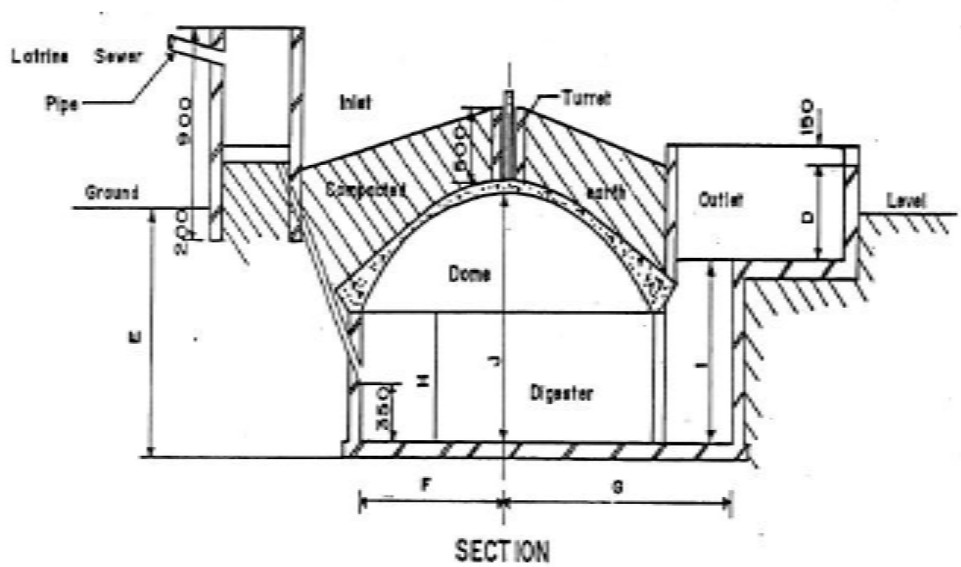

Figure (2.3): Concrete model biogas plant

3- Deenbandhu model

Deenbandhu plants are made entirely of brick and work with a spherical shaped gas holder at the top and a concave bottom, this model proved 30%cheaper than Janata model (also developed in India) which is the first fixed dome plant based on Chinese technology. It also proved to be about 45%cheaper than a KVIC plant of comparable size. A typical design of Deenbandhu plant is shown in figure (2.4**)** (Singh. Myles and Dhussa, 1987).

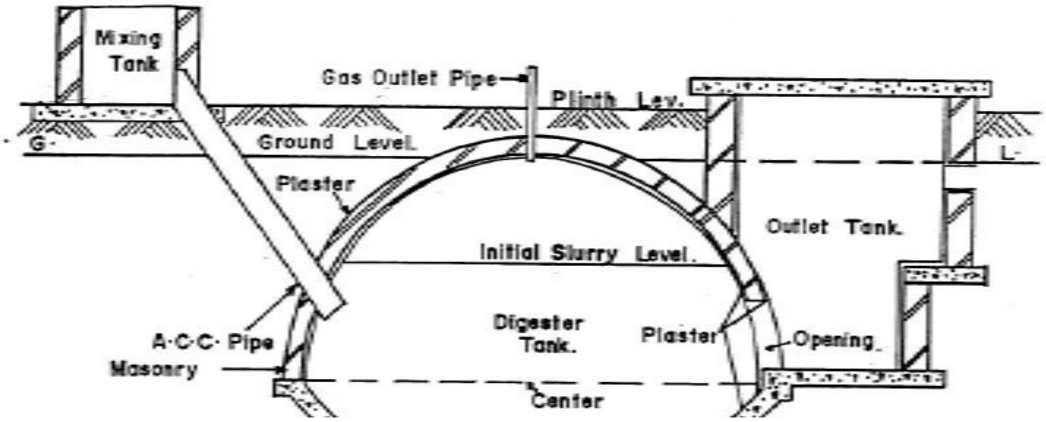

Figure (2.4): Deenbandhu biogas plant (3 m^3 gas production per day)

4-Bag digester

This design was developed in 1960s in Taiwan. It consists of a long cylinder made of PVC or red mud plastic figure 2.5. The bag digester was developed to solve the problems experienced with brick and metal digesters. A PVC bag digester was also tested in Nepal by GGC at Butwal from April to June 1986. The study concluded that the plastic bag biodigester could be successful only if PVC bag is easily available, pressure inside the digester is increased and welding facilities are easily available. Such conditions are difficult to meet in most of the rural areas in developing countries (Singh. Myles and Dhussa, 1987).

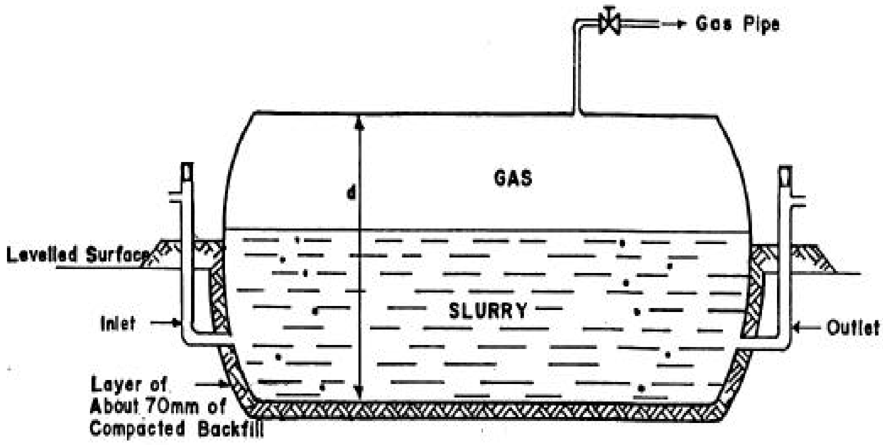

Figure (2.5): Bag digester

5- Plug flow digester

The plug flow digester is similar to the bag digester. It consists of a trench (trench length has to be considerably greater than the width and depth) lined with, concrete or an impermeable membrane.

The reactor is covered with either a flexible cover gas holder anchored to the ground, concrete or GI top. The first documented use of this type of design was in South Africa in 1957. Figure 2.6 shows a sketch of such a reactor (Singh. Myles and Dhussa, 1987).

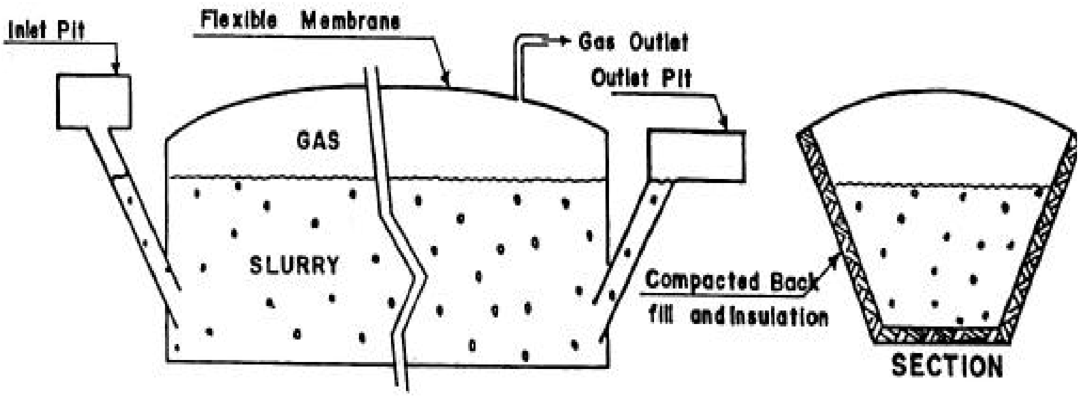

Figure (2.6): Plug flow digester

6- Anaerobic filter

This type of digester was developed in the 1950's to use relatively dilute and soluble waste water with low level of suspended solids. It is one of the earliest and simplest types of design developed to reduce the reactor volume. It consists of a column filled with a packing medium. It has a variety of non-biodegradable materials that have been used as packing media for anaerobic filter reactors such as stones, plastic, coral, mussel shells, reeds, and bamboo rings. The methane forming bacteria form a film on the large surface of the packing medium and are not earned out of the digester with the effluent. For this reason, these reactors are also known as "fixed film" or "retained film" digesters. Figure 2.7 presents a sketch of the anaerobic filter. This design is best suited for treating industrial, chemical and brewery wastes (Singh. Myles and Dhussa, 1987).

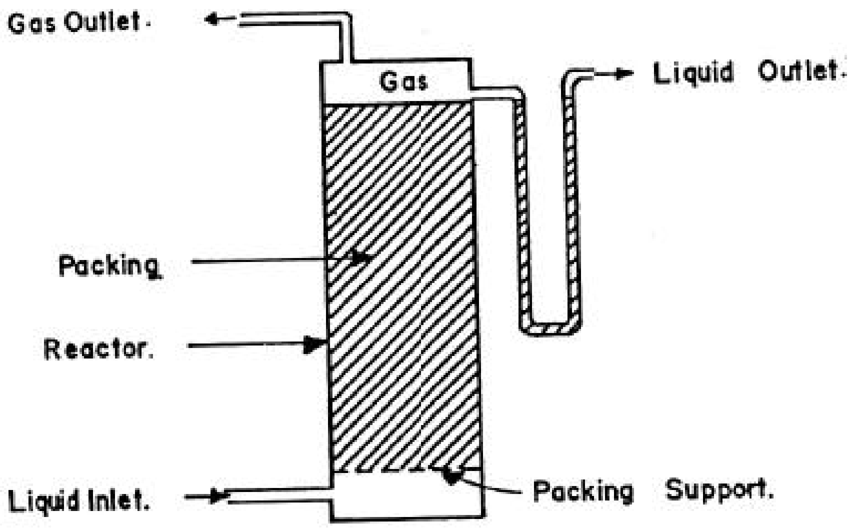

Figure (2.7): Anaerobic filter

7- Up flow anaerobic sludge blanket

This UASB design was developed in 1980 in the Netherlands. It is similar to the anaerobic filter in that it involves a high concentration of immobilized bacteria in the reactor. However, the UASB reactors contain no packing medium; instead, the CH_4 forming bacteria are concentrated in the dense granules of sludge blanket which covers the lower part of the reactor.

The feed liquid enters from the bottom of the reactor and biogas is produced while liquid flows up through the sludge blanket(Figure 2.8). Many full-scale UASB plants are in operation in Europe using waste water from sugar beet processing and other dilute wastes that contain mainly soluble carbohydrates. (Singh. Myles and Dhussa, 1987).

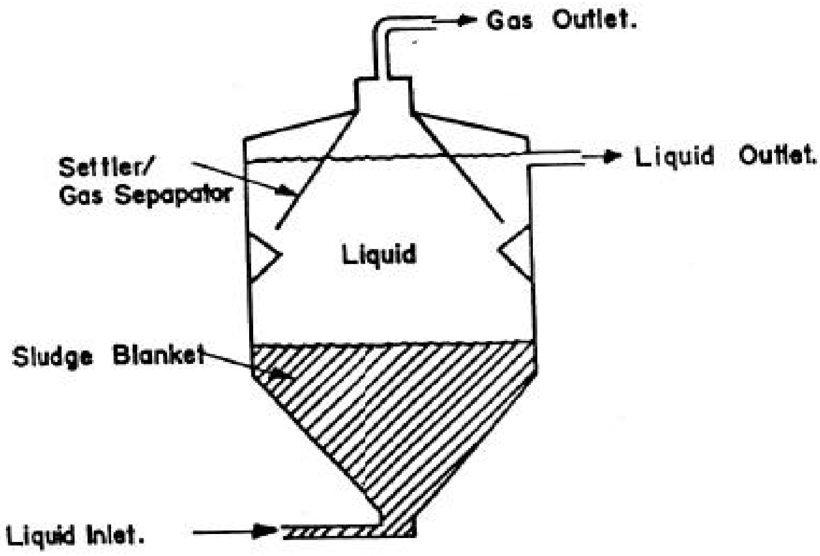

Figure (2.8): Up flow anaerobic sludge blanket (UASB)

2.2.4 Main factors influencing the selection of biogas design

The main factors that influence the selection of a particular design or model of a biogas plant according to Sustainable Development Department (SDD), FAO(1997) are as follows (Al Seadi, 2008).

1.Economic

An ideal plant should be as low cost as possible in terms of the production cost per unit volume of biogas both to the user of the biogas as well as to the society which use the substance . At present, with subsidy, the cost of a plant to the society is higher than to an individual user.

2.Simple design

The design should be simple for construction operation and maintenance.

3.Utilization of local materials

Use of easily available local materials should be emphasized in the construction of a biogas plant. This is an important consideration.

4. Durability

Construction of a biogas plant requires certain degree of specialized skill which may not be easily available. A plant of short life could also be cost effective. Especially in situation where people are yet to be motivated for the adoption of this technology and the necessary skill and materials are not readily available, it is necessary to construct plants that are more durable although this may require a higher initial investment.

4. Suitable design for the type of inputs

The design should be compatible with the type of inputs that would be used. If plant materials such as rice straw, maize straw or similar agricultural wastes are to be used then the batch feeding design or discontinuous system should be used instead of a design for continuous or semi continuous feeding.

6. Frequency of using inputs and outputs:

selection of a particular design and size of its various components also depend on how frequently the user can feed the system and utilize the gas.

2.2.5 Inputs and their characteristics

Since different organic materials have different bio-chemical characteristics their potential for gas production also varies. Two or more of such materials can be used together provided that some basic requirements for gas production or for normal growth of methanogens are met. Some characteristics of these inputs which have significant impact on the level of gas production are described below (Karki, 1994).

1- C/N Ratio:

Karki (1994) says that the relationship between the amount of carbon and nitrogen present in organic materials is expressed in terms of C/N ratio. A C/N ratio ranging from 20 to 30 is considered optimum for anaerobic digestion. If the C/N ratio is very high, the nitrogen will be consumed rapidly by methanogens for meeting their protein requirements and will no longer react on the left over carbon content of the material.

Karki (1994) continues : as a result, gas production will be low. On the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of ammonia (NH4), NH4 will increase the pH value of the content in the digester. A pH higher than 8.5 will start showing toxic effect on methanogen population.

Animal waste, particularly cattle dung, has an average C/N ratio of about 24. The plant materials such as straw and sawdust contain a higher percentage of carbon. The human excreta have a C/N ratio as low as 8. C/N ratios of some of the commonly used materials are presented in Table 2.8.

Table (2.4): C/N ratio of some organic materials

Sample	Raw Materials	C/N Ratio
1.	Duck dung	8
2.	Human excreta	8
3.	Chicken dung	10
4.	Goat dung	12
5.	Pig dung	18
6.	Sheep dung	19
7.	Cow dung/ Buffalo dung	24
8.	Water hyacinth	25
9.	Elephant dung	43
10.	Straw (maize)	60
11.	Straw (rice)	70
12.	Straw (wheat)	90
13.	Saw dust	above 200

Source: (Karki. and Dixit 1984).

Materials with high C/N ratio could be mixed with those of low C/N ratio to bring the average ratio of the composite input to a desirable level.

2- Dilution and consistency of inputs

Before feeding the digester, the excreta such as fresh cattle dung has to be mixed thoroughly with water. For proper solubilization of organic materials, the ratio between solid and water should be 1:1 on unit volume basis (i.e. same volume of water for a given volume of solid) when the domestic wastes are used. However, if the dung is in dry form (that has to be crushed before putting into the digester), the quantity of water has to be increased accordingly to arrive at the desired consistency of the inputs (e.g. ratio could vary from 1:1.25 to even 1:2). The dilution should be made to maintain the total solids (TS) from 5 to 10 percent in order to facilitate its decomposition throughout the bacteria . If the slurry mixture is too diluted, the solid particles can precipitate at the bottom of the digester and if it too thick, the flow of gas can be impeded. In both cases, gas production will be less than optimum. Generally the users have the tendency to over dilute the slurry. For thorough mixing of the cow dung and water (slurry), a Slurry Mixture Machine can be fitted in the inlet of a digester (Karki, 1994).

3- volatile solids:

Sathianathan (1975) clarifies that the weight of organic burned off when heated to about 538 °C is defined as volatile solids. The biogas production potential to different organic material can be calculated on the basis of their volatile solid content. The higher the volatile solid content in unit volume of fresh dung, the higher the biogas production.

2.3 Biogas technology in the world

Historical evidence indicates that the AD process is one of the oldest technologies. Biogas was used for heating bath water in Assyria during the 10th century BC and in Persia during the 16th century. AD advanced with scientific research and, in the 17th century, Jan Baptista Van Helmont established that flammable gases evolved from decaying organic matter. Also, Count Alessandro Volta in 1776 showed that there was a relationship between the amount of decaying organic matter and the amount of flammable gas produced. In 1808, Sir Humphry Davy demonstrated the production of methane by the anaerobic digestion of cattle manure (Lusk, 1997).

The industrialization of AD began in 1859 with the first digestion plant in Bombay, India. By 1895, AD had made in roads into England where biogas was recovered from a well-designed sewage treatment facility and fueled street lamps in Exeter. Further AD advances were due to the development of microbiology. Research led by Buswell and others in the 1930s identified anaerobic bacteria and the conditions that promote methane production (Lusk, 1997).

Barker in the mid 20 century was able to isolate and perform biochemical studies on a large number of the bacteria involved in anaerobic digestion.

Today there is a desire for development of large scale bio digesters in numerous applications. Four main reasons why bio digestion is being pursued currently are according to Marchaim (1992):

1. Improvement of sanitation for treatment of high organic solid, high nutrient, and high biological wastes and waste waters,
2. Reduction in unpleasant aroma associated with animal waste,
3. Production of energy,
4. Production of high quality fertilizers.

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. In Egypt there were 18 family biogas plants and 2 farm plants built till 1998**,** also two family biogas plants were built in Keraeda and Um-Jar villages of Sudan in the period between 19/1 and 16/2/2001. There were two constructed plants for producing biogas from liquid wastes in Jordan, one in Ain-Ghazal and the other in the central station of Irbid. The number of biogas plants in Arab countries is very small if it is compared with the numbers in other countries (Hassan, 2004).

2.4 Potential of Biogas Production in Palestine

The climate in Palestine changes from region to region despite the small area. The rainfall in the high regions reaches 510 mm with high humidity and mild temperatures with a mean temperature of 18.5 ºC. While the Jordan Valley has tropical climate and high evaporation rate, the mean temperature in the Jordan Valley reaches 23.6 ºC and this is the highest mean in the Palestine. At present all of the Palestinian energy needs are met by importing oil products from Israeli companies. The prices are very high and usually not affected by the international market price especially when the international prices drop (Adwi,2008).

The problems facing rural families in disposing their animals waste, plants residues, wastewater and domestic wastes are summarized in the following points:

1. Transporting wastes after cleaning animal's farm along distance between family home and wastes containers or disposing place.
2. Difficulty of farms wastes removing in winter season.
3. Lack of wastes collecting truck which cause over filling of wastes containers (accumulation of wastes) and so distribution of bad odors and insects.
4. Unavailability of enough number from waste containers.
5. Unavailability of wastewater disposing net.
6. Some families complain from unavailability of vacuum tank when
7. cesspit filled and form bad odors distributed when the cesspit contents empty.
8. Some rural families complain from neighbor animal farms (odors, distribution of rats and flies)

Above problems indicates the suffering of rural Palestinian families in disposing off wastes and this emphasized the opinion about negative impacts of wastes on rural families life. The suitable solution to these problems is building biogas digester at least for each Palestinian farm. The number of animals during the years 2005-2006 appeared in the table (3.1). (Adwi,2008).

Table (2.5): Livestock numbers by type in Palestine, 2005/2006

Chicken x 103		Goat	Sheep	Cows
Layers	Broilers			
3,372	31,533	387,123	793,874	36,284

Palestinian Agricultural relief Committees (PARC) (http://www.palarc.org/)

Considering the number of animals mentioned above, and estimating the human and other organic wastes in the Palestinian rural community, the yearly amounts of dry organic wastes can be estimated as in the table (3.2).

Table (2.6): Types of wastes in the West Bank and Gaza Strip

Waste type	Yearly amount
Animal wastes	22,000tons
Chicken waste	17,000 tons
Goats and sheep wastes	105,000 tons
Kitchen wastes	8,000 tons

Prospects for Biogas Technology in the Palestinian Occupied Territories, November 1992

Based on the amount of organic wastes presented in table (3.2) the theoretical amounts of the production of biogas in Palestine can be calculated. At this point, it should be mentioned that 60% of goats and sheep are raised in the mountains and their waste cannot be used, the 40% left is raised in sheds and spend the day outside the shed, so only 50% of its waste can be used. Then the yearly amount that considered as useful wastes was 21,000tons/year out of the 105,000tons/year. This means that the estimated amounts of biogas production to be presented are achievable. The production is estimated to be 32 million m3/year of biogas. This is equivalents 46.08 million NIS, which accounts 13% of Palestine spending on oil products (Adwi,2008).

According to the findings and surveys from (Palestinian Centre for Statistics) the animal ownership can be presented as follows: an average of 60% of the families in rural areas own animals and an average of 46% of them owns one animal, 26 % of them own between 2-5 animals and 26% of them own more than 6 animals (Adwi,2008). Unfortunately biogas production is still under investigation and few demonstration projects are existing in Palestine.

2.4 Previous studies

From the experimental studies about biogas in Palestine:

1. **Ayoub Eshraideh,2002,Palestine: An Educational Biogas Prospect in Tolkarm.**

   This digester was constructed in the middle of 2000 with 14 m^3 digester volume and 3 m^3 holder volume that could store 60% from daily biogas production, it was floating drum type digester fabricated locally by PARC, it was located near the cows farm which belongs to agricultural college of An-Najah National University. The fresh cow dung was obtained from cow's farm which had 14 cows .The result when addition rate of slurry added on daily basis was 50 L/day, the amount of biogas produced is 0.685 m^3, the average pH is 7.91 and the average ambient air temperature is 34.5 ºC while for the 100 L/day rate , the amount of biogas produced was 1.610 m^3,the average pH is 7.96,and the average ambient air temperature is 34 ºC .In both cases the slurry temperature was 27 ºC.

2. Medyan Hassan , 2004 , Palestine : The Feasibility of Biogas Production from Mixed Organic Wastes in Palestinian Rural areas.

The research concerned with studying the feasibility of family biogas production from mixed organic wastes in Palestinian rural areas by field survey and experiment. This experiment was applied over ground in the most agricultural governorate (Jenin) of Palestine. Moreover; the biogas production for 20 samples of mixed organic wastes (cow dung, sheep and goat dung, chicken waste, food residues and wheat straw) were tested at the same time and in two different digester volumes 18 barrels each of 240 liter capacity, and 2 large steel digesters each of 1500 Liter capacity. The experiment data show all samples produce biogas at ambient temperature with an average biogas weight (51.9g) per kilogram of mixed organic wastes, and reach their maximum biogas production within a time interval of (24 to 36) days from the beginning of the experiment which continue for 60 days. The biogas production enhanced by increasing sample water content and with stirring for the digester content. Also the results indicate the Palestinian rural family will save monthly (23.07 JD) as a result of using biogas (instead natural gas) and using digested organic material as an organic fertilizer, if this family construct a $9m^3$ biogas plant with daily loading for (30.83 Kg) of organic wastes into the digester.

3. Mansour-Al Sadi, 2010,Palestine: Design and Building of Biogas Digester for Organic Materials Gained From Solid Waste.

This thesis discusses the biogas production technology from organic waste using two types of digestion: Batch fed digesters are filled all at once, sealed, and emptied when the raw material has stopped producing gas, an experimental work in Nablus Industrial School, where a batch digester type with 100 liter capacity and he fill the digester by 30 kg of organic waste and 30 liter of water (total mix as liquid 60 liter). The results indicate produced 4.98 kg of bio gas over 30 days, as result he can say each one kg of organic waste can produce 0.166 kg of bio gas. Another experimental work done on continuous-load digesters which feed a little, regularly, so this gas and fertilizer are produced continuously. A two drum digester continuous-load digesters with total volume of 240 L. he used about 100 kg of waste and 100 liter of water, with a daily supply of 5 L mixed over a period of 40 days. The Results indicate 11.125 kg of biogas during 40 days = 15.89 m^3 had been produce can say each kg of organic waste can produce 0.11 kg of biogas.

2.5. Summary

There are many technologies available today to deal with the problem of excessive use of biomass for household energy consumption in rural areas of developing countries. These can include solar, wind, hydro power etc. Many of these technologies are well suited in specific areas based on the natural resources available there. However, a common problem for the majority of these technologies are that they are often associated with very high initial capital costs and a dependency on foreign financing and expertise. One solution that has proven itself to be very useful in most rural areas in developing countries is the use of biogas.

The biogas energy is considered one of the best alternative energy resources in the Palestine especially in rural areas. The rural areas are considered an excellent environment to construct biogas systems.

Hence, previous studies indicated that 60% of Palestinian villages have their own animals, which their wastes can be used for the generation of the biogas**.** Compared to other countries in the world, the use of biogas technology in Palestine is still under investigation and few demonstration projects are existing in Palestine .

By reviewing the previous literatures, it has been cleared that the process of generating biogas from organic waste could be technically clear, efficient and simple operation and feasible in terms of cost, and meeting the demands of renewable energy in Palestine.

From previous studies, it could be concluded that biogas technology contribute to the sustainable development of Palestinian rural areas by providing them with a wide variety of socioeconomic benefits, including personal or household impacts, health impacts, social, economic and environmental impacts.

Public support is very important in the promotion of biogas. If the rural communities don't have confidence in investing in biogas they will continue to use firewood and other biomass that are already available. Spreading information about biogas and it's positive effects is important.

One approach is for the government to implement pilot biogas projects in Palestinian rural areas to showcase the benefits of biogas technology. It is important to build up a local knowledge base to ensure that there is long term competence in the building and maintaining of biogas plants.

One major objective of the study is to explain the benefits of biogas technology and to encourage the use of this technology in Palestinian rural areas through providing small scale biogas unit for each Palestinian rural families in order to encourage them to utilize this digester and other designs of digesters.

Chapter Three

Methodology

This chapter includes the following information; the experimental setup; the experimental program Field measurements and Lab analysis.

3.1 Experimental setup

3.1.1 Materials and equipments

The used materials and equipments are:

1. Biogas Unit (Digester) : used for anaerobic digesting of introducing organic waste sample.

The biogas unit consists of the following major parts:

a. Digester tank (outer tank): Plastic tank cylindrical external diameter of 125 cm and a height of 128 cm. It is the main part where the biological processes take place.

b. Gas storage tank (inner tank): Plastic tank cylindrical internal diameter of 106 cm and a height of 128 cm. to collect the biogas produced, and when the amount of biogas is increasing the volume of floating tank is proportionally increased.

c. Base square-shaped : made from iron (125 cm in diameter and height of 25 cm)

d. The inlet with a Blender for feeding the Digester tank where water is mixed with waste to form slurry directed through plastic pipe to the digester tank .

e. The outlet, which is prepared for getting rid of the residue water (sludge) that could be used in agricultural irrigation and fertilizer because of many useful minerals in it.

f. Valves : gas valve to withdraw biogas and slurry valves to get out slurry and clean. Figure (3.1) shows the Schematic diagram of digester.

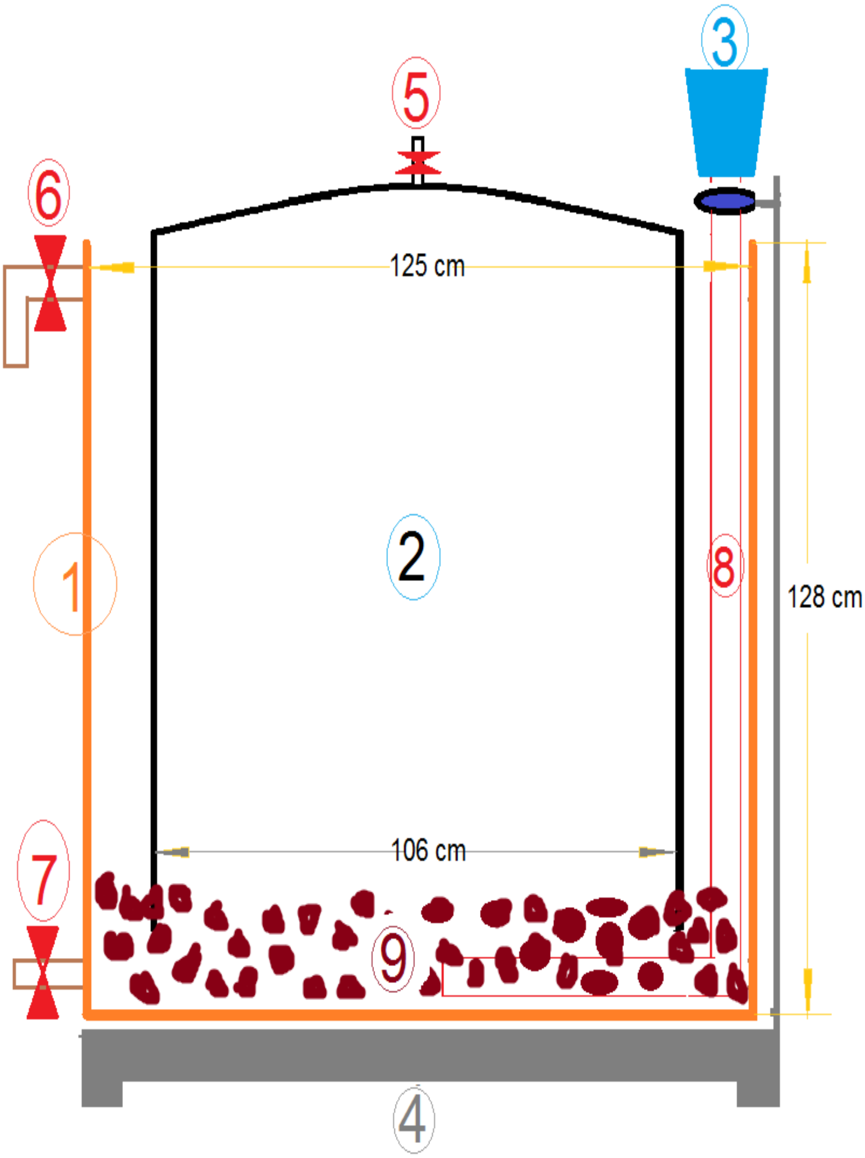

Figure 3.1: Schematic diagram of Biogas Unit

1. Digester tank 2. Gas storage tank 3. Blender 4. Base 5. Gas valve 6. Slurry valve7. Cleaning valve 8. Inlet pipe 9. Gravel

Photo 3.1 : Biogas Unit

2. Air compressor to withdraw biogas from the digester.

3. Electronic balance used for weighing organic waste sample and used to weigh produced biogas that withdrawn from the digesters .

4. Gas cylinder for collecting biogas from the digesters .

5. Thermometer to record temperatures .

6. Plastic vessel for measuring wastes and water volumes.

7. Steel funnels for simplifying substrate introducing into the digesters .

8. plastic vessel for wastes mixing .

9. PVC pipes of different lengths and connectors for connection purposes.

The following photos shows some these materials.

Photo 3.2 : Some of the used materials

3.1.2 Preparing Biogas Unit (Digester)

1.Cut the top off the outer tank (Digester tank).

2.Cut holes in the top of inner tank(Gas storage tank).

3. Work necessary extensions (Gas outlet , compost outlet, Cleaning outlet and enter the organic waste with Blender).

4. Put the outer tank (Digester tank**)** on the base metal.

5. Put small stones at bottom of outer tank (Digester tank) as homes for bacteria, but do not block or go higher than the output of the feeding pipe (White, et al., 1995).

6.Place the inner tank(Gas storage tank) in the outer tank (Digester tank**).**

7. Fill half outer tank (Digester tank) with fresh cow manure , has to be mixed with water at the ratio of 1:1 on a unit weigh basis (i.e. same weigh of water in a given weigh of manure) .

fresh cow manure is the most suitable material for biogas plants because of the methane producing bacteria already contained in the stomach of ruminants .

8. Wait three weeks or so with valve closed until the inner tank(Gas storage tank) starts to rise. Release all gas to the air and let it rise again in order to evacuate the (CO2) -which is more than the Methane - resulted from the first amount of production so the bacteria activate again and produce the required gas .

9. Try to light gas coming out. If it doesn't light it has too much CO_2 in it. Release it and let it rise again. then start feeding.

3.2 Experimental Program

3.2.1 Wastes Collection and Preparation

The used organic wastes in this experiment are:-

1. cow manure .
2. food residues.
3. cow manure mixed with food residues.
4. poultry manure mixed with food residues.

- Cow manure and poultry manure which were collected from neighboring farms .
- Food residues were separated from local community domestic solid waste disposal containers.

3.2.2 Samples Compositions

Four samples of organic wastes were introduced in biogas unit and the composition of each sample with ratio of each organic waste type and water dilution factor are found in table (3.1).

Table 3.1: Samples Compositions.

No sample	Sample Composition Waste added (kg)			Water Dilution Factor (kg)	Time added (day)
	cow	Organic food residues	poultry		
1.	12	0	0	12	14
2.	0	12	0	12	14
3.	6	6	0	12	14
4.	0	6	6	12	14

3.2.3 Sample preparing and introducing

For each sample, the required waste weight was weighted by Electronic balance and drained in the mixing steel vessel were mixed with required amount of water at the ratio of 1:1 on a unit kg (same kg of organic wastes for a given kg of water) . The organic food residues were grounded by a blender in order to transfer this substance into small pieces , then the slurry was introduced into the digester. Each sample from waste is added daily to the digester for 14 days . The use of this period of time is to accomplish the experiment in an suitable time.

The main aim of preparing these samples is studying the effect of each waste type on the samples productivity for biogas of the anaerobic digestion of mixed organic wastes ,to evaluate efficiency of Biogas Units in Palestinian rural areas. The air temperatures at the experiment location were recorded every day by using a thermometer .

The following photos explain Sample preparing and introducing samples.

Photo 3.3: Mixing samples

Photo 3.4: Introducing sample into the digester

3.3 Biogas withdrawing and weighting

The air compressor was weighted by the electronic balance before taking the biogas , then the compressor was connected to the gas valve of the biogas unit, gas valve opened to the air compressor, as a result the biogas flow into an air compressor .When the air compressor stops, gas valve was disconnected from the biogas unit, weighted again. The difference in weight between air compressor before and after biogas withdrawing is the weight of biogas which recorded.

Biogas is withdrawn from the digester every day for 14 days for each sample of the previous four residues. The following photo explain Biogas withdrawing and weighting.The operation was repeated three times a day and the produced quantities were calculated .

Photo 3.5: Withdrawing biogas from digester into air compressor

3.4. Lab analysis

To evaluate quality biogas, will be measured the methane (CH_4) ratio in the produced biogas for different waste mixtures, by using Gas Chromotography (GC) present at An-Najah National University.

Photo 3.6: Gas Chromotography (GC)

Unfortunately, it is showed that the university Gas Chromotography (GC) does not work as it should. So, a simple experiment to compare the biogas and commercial gas was conducted .

Instead, simple experiment aimed at comparing the biogas and commercial gas used in our homes by lighting 1 kg biogas and 1 kg of commercial gas, then monitoring it's time for all types was conducted. Moreover, identifying the quality of biogas resulting from biogas unit was a goal of the experiment.

Chapter Four

Results & Discussion

This chapter consists of three sections; data collection , data analysis and economic analysis .

4.1 Biogas production

The experiment started on 14/7/2012 ; finished on 17/9/2012, that is, the retention time was 60 days. The daily temperatures were recorded and the weights of produced biogas (for 14 days) from each sample were also measured. The transition period between the samples was three days . The following tables show the results.

4.1.1 Biogas production from cow manure sample

Biogas production from cow manure sample has been calculated . The results are shown in the following table :

Table 4.1: Biogas production from cow manure sample

No	Day	Biogas mass (g)	Air Temperature (ºC)
1.	14-July	1200	33
2.	15- July	1220	33.5
3.	16- July	1200	32.5
4.	17- July	1170	31
5.	18- July	1070	30
6.	19- July	1075	30
7.	20- July	1075	31
8.	21- July	1175	31.5
9.	22- July	1220	32.5
10.	23- July	1200	32.5
11.	24- July	1285	33.5
12.	25- July	1265	33.5
13.	26- July	1220	32.5
14.	27- July	1225	32.5
	Total	**16600**	

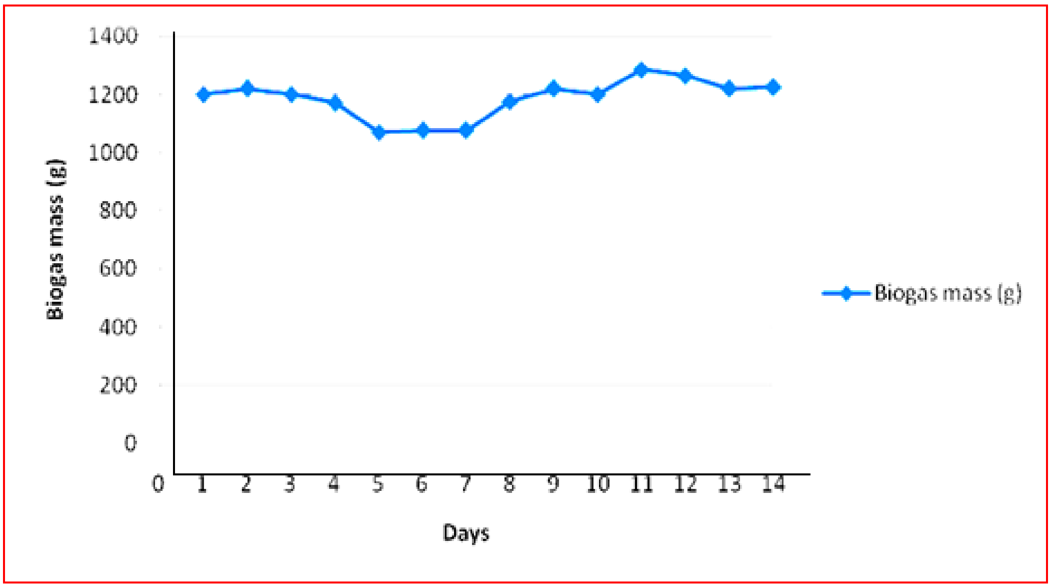

Figure 4.1: Biogas production with time for cow manure sample.

Table (4.1) shows that biogas production from cow manure sample ranged between (1070 g) on the 18 th of July to with a temperature of (30 ºC) which is the lowest degree to (1285 g) on the 24th of the same month with a temperature of (33.5 ºC) which is the highest degree of the temperature at the same month. Also, during the fourteenth days, the total amount of the biogas production from cow manure reached 16600 g.

From the previous table , it can be concluded that Biogas production from cow manure sample continue to increase due to the increasing in the temperature . The lowest amount of the biogas(g) matches the lowest in the temperature (ºC).Similarly, the highest one matches the highest temperature degree. This result could be an indicator for a relationship which will be clarified in the second section. Moreover, it indicates the importance of the temperature degree in the biogas process.

4.1.2 Biogas production from cow manure mixed with food residues

Biogas production from cow manure mixed with food residues sample has been calculated . The results are shown in the following table :

Table 4.2 Biogas production from cow manure mixed with food residues

No	Day	Biogas mass (g)	Air Temperature (ºC)
1.	31- July	1200	33
2.	1-Aug	1150	32
3.	2- Aug	1200	32.5
4.	3- Aug	1170	32
5.	4- Aug	1150	32
6.	5- Aug	1150	31.5
7.	6- Aug	1200	32
8.	7- Aug	1200	33
9.	8- Aug	1150	31.5
10.	9- Aug	1200	31.5
11.	10- Aug	1250	32
12.	11- Aug	1300	32.5
13.	12- Aug	1330	33
14.	13- Aug	1330	33
	Total	**16980**	

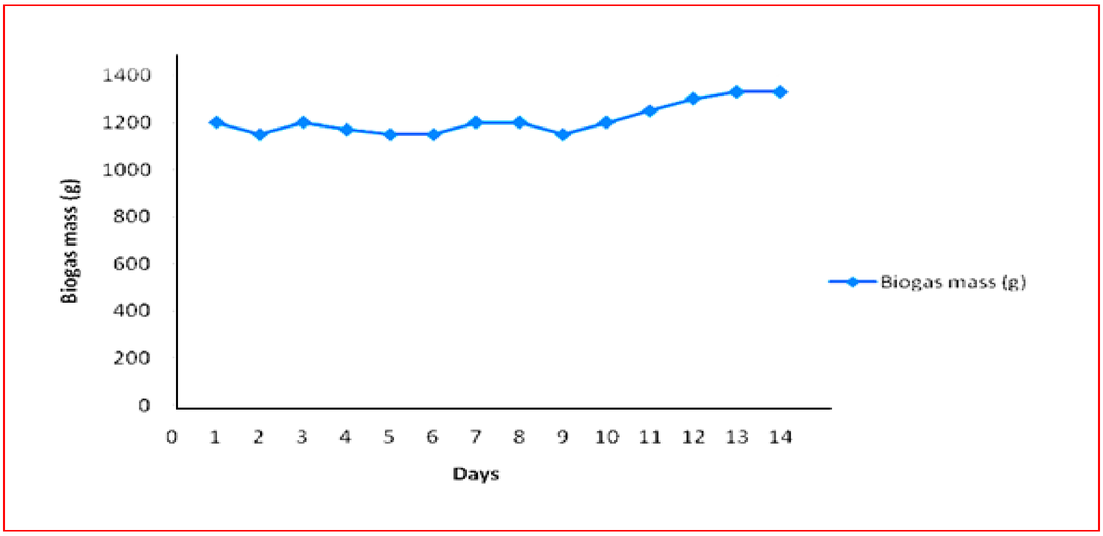

Figure 4.2: Biogas production with time for cow manure mixed with food residues

Table (4.2) shows that biogas production from cow manure mixed with food residues sample in the month ranges from (1150 g) on the first ,4,5and 8th of August to with a temperature of (31.5 ºC – 32 ºC) which is the lowest degrees to (1330 g) on the 12 and the 13 of the same month with a temperature of (33 ºC) which is the highest degree of the temperature at the same month. Also, during the fourteenth days , the total amount of the biogas production from cow manure reached 16980 g.

The behavior of the curve can be explained by two stages, the first one shows nearly a steady amount of biogas production in the first ten days of the month where the temperature ranged from(31.5) to (33.0) . This duration of the production contains the lowest amount (per gram) which is (1150 g) in the second fifth and sixth days of the duration of the experiment. The second stage started at eleventh day of the experience , the biogas production starts to continue its increasing from (1250 g) on the eleventh day of the month with temperature degree of (32.0) to reach (1330 g) on the fourteenth day with a temperature of (33.0) which is the maximum during the experiment days.

Also, it can be concluded as in the case of cow manure mixed with food residues sample, this result could be an indicator for a relationship which will be clarified in the second section. Moreover, it indicates the importance of the temperature degree in the biogas process.

4.1.3 Biogas production from poultry manure mixed with food residues

Biogas production from poultry manure mixed with food residues sample has been calculated . The results are shown in the following table :

Table 4.3: Biogas production from poultry manure mixed with food residues sample

No	Day	Biogas mass (g)	Air Temperature (ºC)
1.	17- Aug	1500	34
2.	18- Aug	1450	33
3.	19- Aug	1375	32.5
4.	20- Aug	1250	32
5.	21- Aug	1375	32.5
6.	22- Aug	1425	33
7.	23- Aug	1450	33.5
8.	24- Aug	1435	33
9.	25- Aug	1380	33.5
10	26- Aug	1410	33
11.	27- Aug	1450	34
12.	28- Aug	1500	33.5
13.	29- Aug	1550	33
14.	30- Aug	1575	33.5
	Total	**20125**	

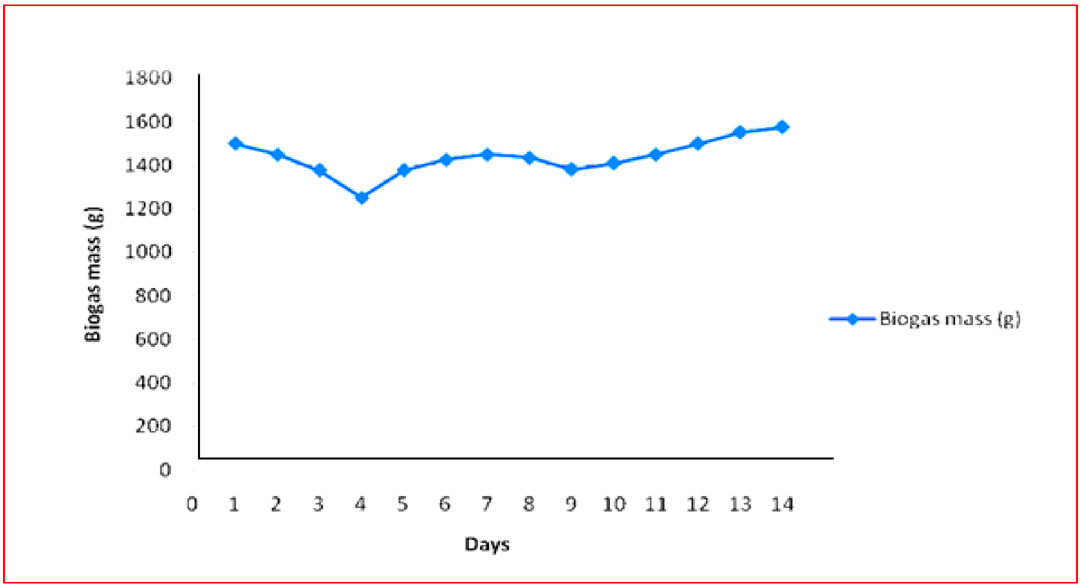

Figure 4.3: Biogas production with time for poultry manure mixed with food residues sample

Table (4.3) shows that biogas production from poultry manure mixed with food residues ranges from (1250 g) on the 20th of August to with a temperature of (32 ºC) which is the lowest degree to (1575 g) on the 30th of the same month with a temperature of (33.5 ºC) which is the highest degree of the temperature at the same month. Also, during the fourteenth days , the total amount of the biogas production from poultry manure mixed with food residues reached 20125 g.

4.1.4 Biogas production from food residues

Biogas production from food residues sample has been calculated . The results are shown in the following table :

Table 4.4: Biogas production from food residues sample

No	Day	Biogas mass (g)	Air Temperature (ºC)
1.	4- Sep	1375	33.5
2.	5- Sep	1375	33
3.	6- Sep	1375	33.5
4.	7- Sep	1500	34
5.	8- Sep	1375	31.5
6	9- Sep	1450	32
7.	10- Sep	1500	33.5
8.	11- Sep	1500	33
9.	12- Sep	1750	34.5
10.	13- Sep	1625	34.5
11.	14- Sep	1750	34
12.	15- Sep	1750	33.5
13.	16- Sep	1875	35
14.	17- Sep	1960	35.5
	Total	**22160**	

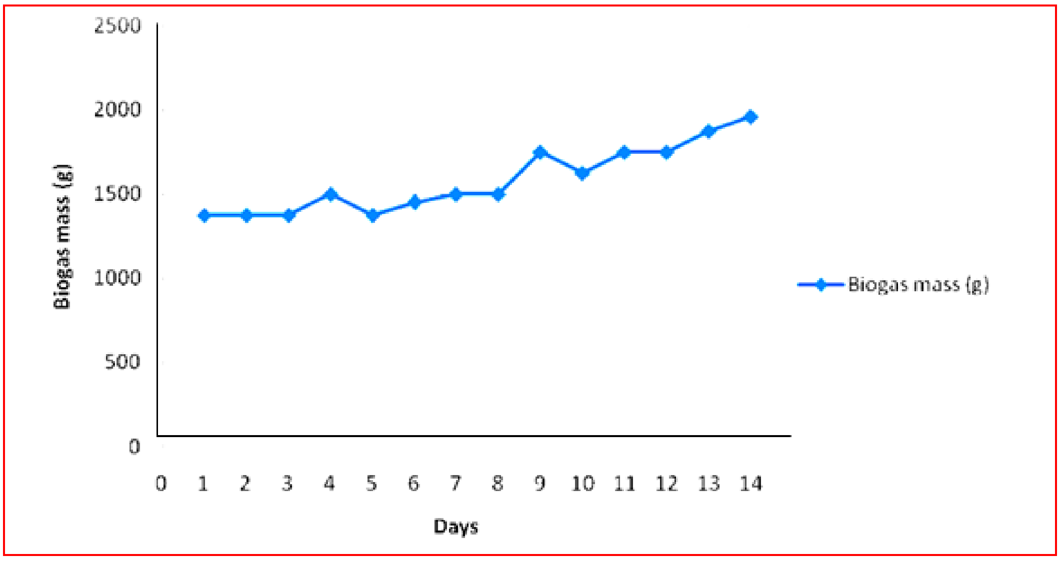

Figure 4.4: Biogas production with time for food residues sample

Table (4.4) shows that biogas production from food residues sample ranges from (1375 g) on the 4,5,6 of September with a temperature of (33 ºC - 35.5 ºC) which are the lowest degrees to (1960 g) on the 17th of the same month with a temperature of (35 ºC) which is the highest degree of the temperature at the same month. Also, during the fourteenth days , the total amount of the biogas production from food residues sample reached 22160 g. The results from the previous tables show that there is an effect of the temperature on the biogas production from its three resources which give an indicator for conducting the statistical analyses in order to clarify the results precisely. These results will be discussed widely in section (4.2.Statistical analysis).

In general, the finding of the previous tables and figures seem to indicates that there is a relationship between biogas production in all cases and the temperature.

Table 4.5: Biogas production during 14 days from organic wastes

N0.	Sample	Biogas production (Kg)
1.	Cow manure	16.600
2.	Cow manure mixed with food residues	16.980
3.	Poultry manure mixed with food residues	20.125
4.	Food residues	22.160

By comparing the results in the previous tables and figures for samples of the four resources of the biogas production : cow manure, cow manure mixed with food residues, Poultry manure mixed with food residues and food residues; the data of the tables show that the sample of food residues produces was the highest biogas production weights (22.160 Kg biogas). In the second place , the sample of Poultry manure mixed with food residues weights (20.125 Kg biogas), the sample of cow manure mixed with food residues produces (16.980Kg biogas). Finally, the sample of cow manure produces (16.600 Kg biogas).

The monthly average for Palestinian rural families consumption from commercial gas is two gas cylinder of butane (24 kg) which is used for cooking , heating , bread making and other purposes .The monthly weight of biogas required for Palestinian rural family to cover its monthly requirement from commercial gas is (48) Kg based on calorific value of butane.

The small scale biogas unit which used in the study experiments is continuous-load digester require a daily addition of organic waste, so that biogas is produced continuously. Therefore, the amount of biogas production from the small scale biogas unit may be adequate for one home consumption per a month.

4.2 Statistical analysis

In order to clarify the relationship between biogas production from its four major resources and the temperature statistically, the Statistical Package for Social Sciences (SPSS) program, which is the most famous statistical program used for evaluation and calculations of data in social sciences studies, was used in the study for the experimental data evaluation and calculations.

In order to identify the relationship between biogas mass and manure, (Linear Regression Test) has been used and the following results has been found:

4.2.1 The Relationship between Biogas production from cow manure and the temperature :

The following tables show the results :

Table (4.6): Model Summary

	R	Adjusted R Square	Std. Error of the Estimate
Model	0.855	0.708	36.74045

Table (4.7): ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	43894.532	1	43894.532	32.518	*0.000
Residual	16198.326	12	1349.860		
Total	60092.857	13			

Table (4.8) : Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
Model	B	Std. Error	Beta	t	Sig.
(Constant)	-211.285	245.179		-0.862-	0.406
Temperature	43.754	7.673	0.855	5.702	*0.000

Table (4.6) shows that R is (0.855) which means a strong relationship between the independent variable (Temperature) and the dependant one (Biogas production from cow manure) . P value (0.000) which is less than (0.05) as indicated in table (4.7) . Also, the equation as in table (4.8) is:

Y(Biogas production from cow manure) = -211.285 + 43.754 X(Temperature)

4.2.2 The Relationship between Biogas production from cow manure mixed with food residues and the temperature :

The following tables show the results :

Table (4.9) : Model Summary

Model	R	Adjusted R Square	Std. Error of the Estimate
	0.643	0.364	51.80550

Table (4.10) : ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	22680.000	1	22680.000	8.451	*0.013
Residual	32205.714	12	2683.810		
Total	54885.714	13			

Table(4.11) : Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-1109.143-	798.880		-1.388-	0.190
Temperature	72.000	24.768	0.643	2.907	*0.013

Table (4.9) shows that R is (0.643) which means a strong relationship between the independent variable (Temperature) and the dependant one (Biogas production from cow manure mixed with food residues) . P value (0.013) which is less than (0.05) as indicated in table (4.10)

.Also, the equation as in (4.11) is:

Y (Biogas production from cow manure mixed with food residues)

= -1109.143+ 72X(Temperature)

4.2.3 The Relationship between Biogas production from poultry manure mixed with food residues and the temperature :

The following tables show the results :

Table (4.12) : Model Summary

Model	R	Adjusted R Square	Std. Error of the Estimate
	0.665	0.395	63.63656

Table (4.13) : ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	38442.161	1	38442.161	9.493	*0.010
	Residual	48595.339	12	4049.612		
	Total	87037.500	13			

Table (4.14) : Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-1727.924-	1027.529		-1.682-	0.118
Temperature	95.508	30.999	0.665	3.081	*0.010

Table (4.12) shows that R is (0.665) which means a strong relationship between the independent variable (Temperature) and the dependant one (Biogas production from poultry manure mixed with food residues) . P value (0.013) which is less than (0.05) as indicated in table (4.13)

.Also, the equation as in table (4.14) is

Y (Biogas production from poultry manure mixed with food residues)

= -1727.924+ 95.508X (Temperature)

4.2.4 The Relationship between Biogas production from food residues and the temperature :

The following tables show the results :

Table (4.15) Model Summary

Model	R	Adjusted R Square	Std. Error of the Estimate
	0.795	0.601	126.82875

Table (4.16) ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	331209.330	1	331209.330	20.591	*0.001
	Residual	193026.384	12	16085.532		
	Total	524235.714	13			

Table (4.17) Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-3292.734-	1075.003		-3.063-	*0.010
Temperature	144.768	31.904	0.795	4.538	*0.001

Table (4.15) shows that R is (0.795) which means a strong relationship between the independent variable (Temperature) and the dependant one (Biogas production from food residues) . P value (0.001) which is less than (0.05) as indicated in table (4.16) .Also, the equation as in table (4.17) is :

Y(Biogas production from food residues) = -3292.734+ 144.768X (Temperature)

The results in the previous tables show a strong relationship between temperature and biogas production from organic wastes . The temperature is one of the most important physical factors used to improve the anaerobic digestion of organic materials. The study reveals that anaerobic digestion can occur in the mesophilic range between 30 to 35 °C and biogas production affected positively with temperature changes and so the quantity of the produced biogas because the methanogens are inactive in extreme high and low temperatures. The optimum temperature for satisfactory gas production is said to be 30-35°C. Doing the experiment in warm months will enhance samples production for biogas with decreasing the retention time. Proper insulation of digester helps to increase gas production in the cold season.

4.2.5 The Relationship between variables (biogas production , time and temperature) for four waste type

In order to identify the relationship between Biogas mass , waste type , time and temperature, nonlinear procedure of the Statistical Analysis System (SAS) has been used and the following summary of results has been found:

4.2.5.1 Summary of results from ANOVA analyses:

ANCOVA test was used to estimate the least squares means (adjusted means) of gas production from four waste types. Table 4.18 shows the results.

Table 4.18 : ANCOVA test results

Waste type	Least squares means (LSMEANS)
TRT1	$1239.1^{c,*}$
TRT2	1252.7^{c}
TRT3	1431.6^{b}
TRT4	1495.5^{a}

In Table 4.18 the means that are in the same column with different superscripts are significantly different ($P < 0.05$) using Tukey-Kramer adjustment for multiple comparisons. The results indicate that there is statistically significant differences at the significance level ($\alpha = 0.05$) in biogas production for the different waste mixtures.

Table 4.19: Measured and predicted values of gas emission based on the ANCOVA analysis model

Obs	TRT	Y_measured	Y_Predicted	residual
1	1	1200	1156.14	43.857
2	1	1220	1203.71	16.289
3	1	1200	1154.97	45.030
4	1	1170	1120.32	49.680
5	1	1070	1062.92	7.083
6	1	1075	1073.87	1.132
7	1	1075	1084.82	-9.818
8	1	1175	1164.12	10.876
9	1	1220	1192.10	27.898
10	1	1200	1231.63	-31.627
11	1	1285	1242.58	42.422
12	1	1265	1313.22	-48.220
13	1	1220	1324.17	-104.171
14	1	1225	1275.43	-50.430
15	2	1200	1169.74	30.257
16	2	1150	1142.33	7.675
17	2	1200	1168.57	31.429
18	2	1170	1164.23	5.773
19	2	1150	1175.18	-25.178
20	2	1150	1172.85	-22.850
21	2	1200	1197.08	2.920
22	2	1200	1246.40	-46.399
23	2	1150	1205.70	-55.703
24	2	1200	1216.65	-16.653
25	2	1250	1240.88	9.117
26	2	1300	1267.13	32.871
27	2	1330	1301.15	28.846
28	2	1330	1312.10	17.895
29	3	1500	1441.22	58.784
30	3	1450	1359.62	90.375
31	3	1375	1347.50	27.499
32	3	1250	1343.16	-93.158

33	3	1375	1369.40	5.597
34	3	1425	1403.43	21.572
35	3	1450	1451.00	-0.996
36	3	1435	1425.33	9.670
37	3	1380	1472.90	-92.898
38	3	1410	1447.23	-37.232
39	3	1450	1550.72	-100.725
40	3	1500	1505.75	-5.751
41	3	1550	1480.08	69.916
42	3	1575	1527.65	47.347
43	4	1375	1449.10	-74.096
44	4	1375	1423.43	-48.429
45	4	1375	1471.00	-95.997
46	4	1500	1537.87	-37.873
47	4	1375	1404.63	-29.634
48	4	1450	1428.86	21.136
49	4	1500	1514.80	-14.801
50	4	1500	1489.13	10.866
51	4	1750	1673.62	76.377
52	4	1625	1684.57	-59.574
53	4	1750	1695.52	54.475
54	4	1750	1569.56	180.444
55	4	1875	1829.26	45.743
56	4	1960	1988.64	-28.637

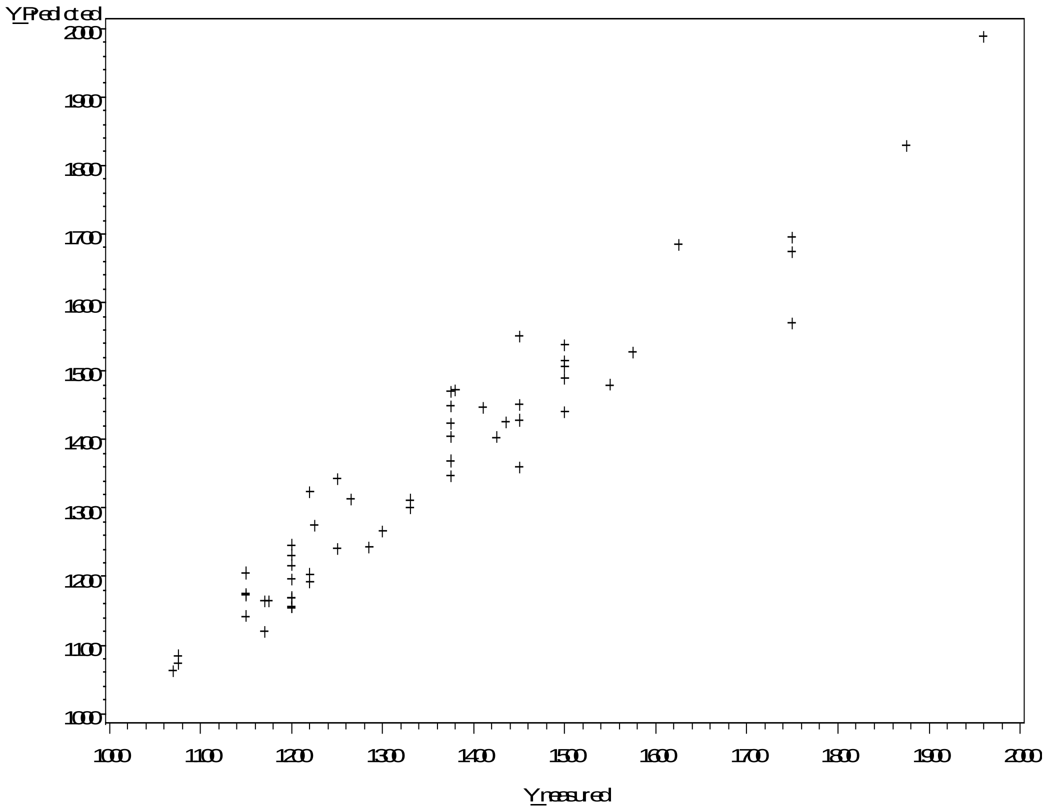

Figure 4.5 : Plot of predicted gas emission vs. measured gas values (ANOVA analysis model)

4.2.5.2 Summary of results from nonlinear procedure of SAS (PROC NLIN):

In order to clarify the relationship between biogas production from the four mixtures and the temperature and time statistically, nonlinear procedure of SAS was used. The nonlinear analyses were based on the following model:

$Y = C^*(\text{Time})^{X1} * (\text{Temp})^{X2}$, where Y is biogas emission

Table 4.20: Nonlinear analyses results

	C		X1		X2	
	Estimate	**SE**	**Estimate**	**SE**	**Estimate**	**SE**
TRT1	19.14	13.10	0.0164	0.0102	1.1827	0.1971
TRT2	1.1339	1.6673	0.0416	0.00999	1.9863	0.4231
TRT3	0.9107	2.3563	0.0140	0.0160	2.0962	0.7397
TRT4	0.9991	1.4573	0.0997	0.0190	2.0423	0.4194
Average	5.545925	4.645225	0.042925	0.0137975	1.826875	0.444825

Biogas predicted:

$$\mathbf{Y = 5.545925 * (Time)^{1.826875} * (Temp)^{0.042925}}$$

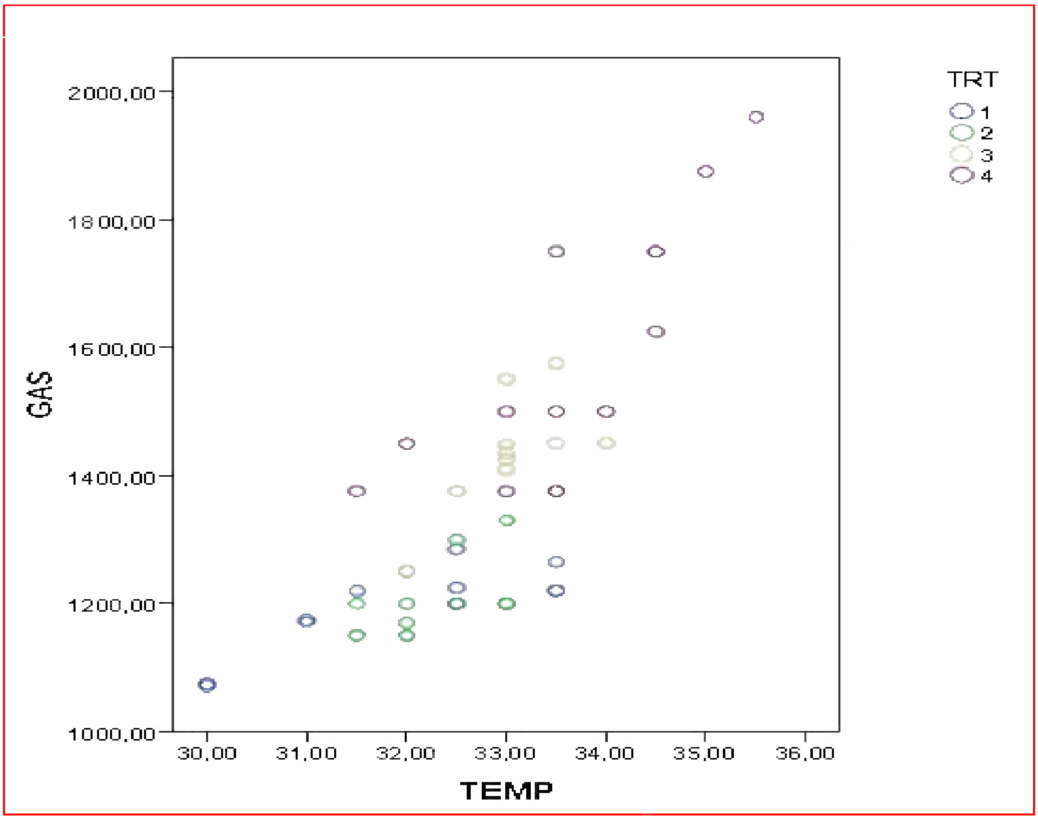

Figure 4.6: Relationship of biogas emission with temperature

Figure 4.5 clearly indicates that the production of biogas is dependent upon temperature. Temperature factor is critical value in the beginning of methane formation. One of the inherent limitations or constraints of biogas technology is that the production of biogas by anaerobic digestion process through methanogenic bacteria is greatly influenced by temperature. The optimum temperature for satisfactory biogas production is said to be 30-35°C.

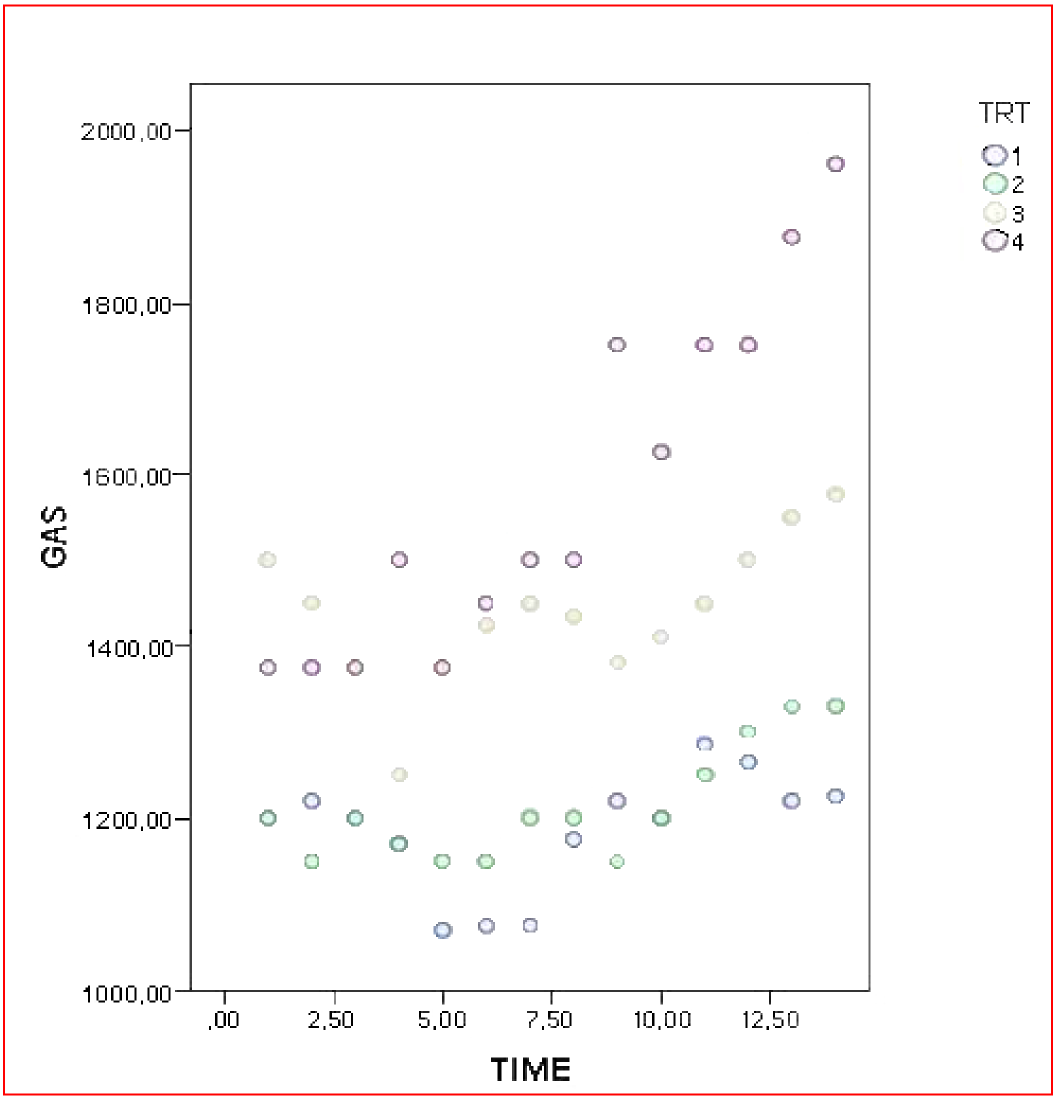

Figure 4.7: Relationship of biogas emission with time

As in all other microbial processes, the rate of metabolism increases along with the temperature. The digester temperature is of interest primarily in connection with the time required for complete fermentation, i.e. the retention time: the higher the temperature, the shorter the retention time.

Table 4.21: Measured and predicted values of gas emission based on the NLIN analysis model

Obs	TRT	Y_measured	Y_Predicted	RESIDUAL
1	1	1200	1289.54	-89.539
2	1	1220	1394.87	-174.872
3	1	1200	1276.21	-76.206
4	1	1170	1096.37	73.626
5	1	1070	987.60	82.404
6	1	1075	994.55	80.454
7	1	1075	1000.46	74.540
8	1	1175	1126.00	49.003
9	1	1220	1195.27	24.726
10	1	1200	1336.70	-136.695
11	1	1285	1341.60	-56.604
12	1	1265	1494.39	-229.391
13	1	1220	1499.00	-278.999
14	1	1225	1354.11	-129.107
15	2	1200	1289.54	-89.539
16	2	1150	1191.05	-41.045
17	2	1200	1276.21	-76.206
18	2	1170	1223.23	-53.226
19	2	1150	1233.77	-83.770
20	2	1150	1176.78	-26.778
21	2	1200	1249.84	-49.841
22	2	1200	1396.92	-196.915
23	2	1150	1195.27	-45.274
24	2	1200	1200.13	-0.128
25	2	1250	1271.76	-21.759
26	2	1300	1346.10	-46.102
27	2	1330	1423.25	-93.246
28	2	1330	1427.31	-97.309
29	3	1500	1429.37	70.634
30	3	1450	1324.38	125.619
31	3	1375	1276.21	98.794
32	3	1250	1223.23	26.774
33	3	1375	1301.53	73.471

34	3	1425	1381.54	43.457
35	3	1450	1463.73	-13.729
36	3	1435	1396.92	38.085
37	3	1380	1477.95	-97.946
38	3	1410	1408.96	1.044
39	3	1450	1567.47	-117.467
40	3	1500	1494.39	5.609
41	3	1550	1423.25	126.754
42	3	1575	1503.28	71.722
43	4	1375	1358.18	16.825
44	4	1375	1324.38	50.619
45	4	1375	1416.80	-41.796
46	4	1500	1507.65	-7.649
47	4	1375	1168.55	206.446
48	4	1450	1242.45	207.548
49	4	1500	1463.73	36.271
50	4	1500	1396.92	103.085
51	4	1750	1635.72	114.276
52	4	1625	1642.37	-17.366
53	4	1750	1648.40	101.602
54	4	1750	1494.39	255.609
55	4	1875	1743.42	131.582
56	4	1960	1836.04	123.957

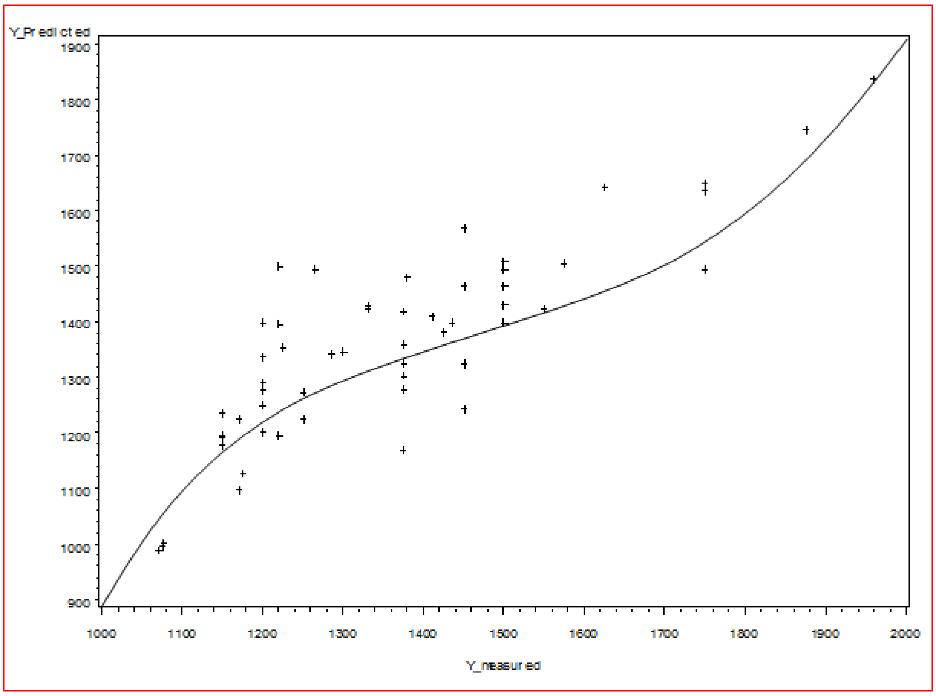

Figure 4.8 : Plot of predicted gas emission vs. measured gas values(NLIN analysis model)

4.3 Biogas quality

Methane concentration were determined by collecting samples of biogas in small gas cylinders and transporting the samples to the An-Najah National University laboratory. Biogas samples were taken with a pressure lock syringe and their methane content was measured with gas chromatographs (GC).

Gas chromatography (GC) is a popular instrument and has several advantages such as high resolution, high speed, high sensitivity and good quantitative results (B. Kolb, L. S. Ettre, 2006).

The following table shown results (GC) analysis

Table (4.22) : (GC) analysis

Sample	**Methane content**
Cow manure	30.9 %
Food residues	33.9 %
Cow manure + food residues	32.9 %
Poultry manure + food residues	31.2 %

The (GC) analysis are necessary for more confidence in evaluating the objectives of the study, but unfortunately the results are not accurate for two reasons: the first because the gas chromatography device at An-Najah National University laboratory is inefficient for analyzing gases ; the later there are no technical persons who are experienced with gas analysis. These two reasons were obstacles for achieving this study purpose.

To overcome the possibility of a defect in the Gas chromatography (GC) device , a simple experiment was conducted in order to compare the biogas and commercial gas used in Palestinian homes, 1 kg biogas and 1 kg of commercial gas were ignited , the time it takes for all types has been monitored in order to identify the quality of biogas resulting from biogas unit. The following table shows the results.

Table (4.23) : Time consume for biogas and Commercial gas burned

Gas type	Time (Hour)
Commercial gas	5
Biogas	2.20

The experimentally produced biogas burned with a flame similar to the natural gas and nearly Biogas has a heat value which is equal to the half of commercial gas by comparing 1 (kg) of both gasses on the same flow rate. The result of the experiment indicates a good biogas quality.

4.4 Biogas use

Small scale biogas unit has several advantages of not complicated, cheap, robust, easy to operate and maintain, low construction cost and that it could be operated and repaired by the family itself. Moreover, it can be constructed with locally produced materials and suitable to biogas production for Palestinian rural family for covering its monthly requirements of natural gas . It can produce high quality of organic fertilizer used to improve crops yield.

Another advantage of a small biogas unit is that Biogas technology has the potential for providing an alternative to the current unsustainable energy and provide environmental, social, and economic benefits ,as well as decreasing the energy reliance on Israel. This technology is a vital component of the alternative rural energy in Palestine.

One major objective of the study is to explain the benefits of biogas technology and to encourage the use of this technology in Palestinian rural areas through providing small scale biogas unit for each Palestinian rural families in order to encourage them to utilize this digester .

Biogas produce from small scale biogas unit can be used to:

1. Direct combustion and heat utilization instead of natural gas such as:
   - Cooking
   - Heating home
   - Bread making
   - Heating greenhouses to avoid the risk of frost in winter, and
   - Heating poultry farms
2. Lighting and Power Generation
   - Biogas from the digesters could be to a combustion engine in order to convert it into electrical and mechanical energy. Biogas requires a liquid fuel to start ignition. Diesel fuel can also be combined with biogas for power generation(Bond, T.; Templeton,2011).
   - Biogas can be used to power engines when mixed with petrol or diesel . Also, it helps in pumping water for irrigation.
   - Biogas conversion into electricity using fuel cells is a hot research topic nowadays. However, it is not commercially affordable due to the requirement of clean gas and the cost of fuel cells(Bond, T.; Templeton,2011).
   - Providing electricity for houses by biogas lamps , Biogas lamps are more efficient than the kerosene powered lamps, but the

efficiency is quite low compared to electric-powered lamps (Laichena,1997).

3. Biogas Can be used to drive refrigeration processes. e.g. for cooling food storage or for air conditioning.
4. A biogas plant is not only a supplier of energy, but also, the digested substrate, usually named digestate, is a valuable soil fertilizer, which is rich of nitrogen, phosphorus, potassium and micronutrients. These substances can be applied on soils with the usual equipment for application of liquid manure.

4.5 Financial analysis

The costs for constructing the proposed design of the small scale biogas unit may be estimated as follows:

Table (4.24): Requirements and costs for constructing biogas unit

Requirements	Cost (NIS)
Plastic tank 1500L	500
Plastic tank 1000L	400
Base iron	150
Steel funnel	30
Blender	1200
PVC pipes	30
Gas valve and connectors	30
Slurry valves	60
Miscellaneous	100
Total	2500

As shown in the previous table, the initial investment to construct a floating tank biogas unit is 2500 NIS.

4.5.1 Running cost

The Annual running cost for operating the biogas plant may come from replacing some of the used gas transporting pipes or replacing some valves. In addition to that, the price of using water in the digester in the case of using clean water instead of waste water .

1- Annual running cost to operate the digester

=15 % of digester cost + water cost (Al Sadi,2010)

= 375 NIS + 22 NIS

= 397 NIS /Year

The water needed to operate the biogas unit in similar waste addition rate as this study is 12 kg/day; that is 0.012 m^3/day. According to Palestinian Central Bureau of Statistics PCBS, the price of 1 m^3 of water is 4-5 NIS. (PCBS, 2013)

(22NIS) water cost/year = 0.012 m^3/day x 365 day/year = 4.38 m^3/Y

4.38 m^3/Y x 5NIS/m^3 = 21.9 NIS approximately 22 NIS

4.5.2 Biogas profit

Based on the experiment results, the biogas produced is sufficient to provide for the family needs of cooking fuel; this means it is sufficient to replace the commercial gas that is usually used for cooking. An average Palestinian family needs one 12 kg-bottle of commercial gas per month. The price of commercial gas in West Bank- Palestine fluctuates due to some political reasons. But on average the price of 12kg bottle is 65 NIS.

So, the biogas profit = 65 NIS/month.

Profit of produced biogas =

NIS / two butane bottle /month) x 12 month/Year =1560 NIS /Year.

4.5.3 Fertilizer Profit

The biogas unit produces organic fertilizer. The fertilizer produced can save the family the cost of buying fertilizers from the market for their farm or garden and can sell the surplus to neighboring farmers.

Price of 1 ton fertilizer 1000 NIS/Ton

Yearly fertilizer produced = 200kg /30day x 365 day /year

= 2433.33 kg/year

= 2.43 ton/year

Yearly fertilizer profit = 2.43 ton x 1000 NIS

= 2430NIS/year

- **Total income/Year = biogas profit+ Fertilizer profit**

  Total income/Year = 1560+ 2430

  Total income/Year = 3990 NIS/year

- **The profit /year = income profit – running cost** (Al Sadi, 2010)

  The profit /year = 3990 – 397

  The profit /year =3593 NIS / year

- **The Simple payback Period = capital cost /annual profit**

  = 2500 / 3593=0.6957 year = 8.3 month

This means, the rural family will get back the capital cost within a time period 8 month which is very a reasonable period.

Conclusions

According to the study results several conclusions can be suggested, included the following :

1. Biogas is usually generated when bacteria break down organic waste such as manure, crop residues, or food waste in the absence of oxygen. This process known as anaerobic digestion . Biogas contains about 50-70 % CH_4, 30 - 40% CO_2, and other gases .
2. Biogas is a clean, efficient, and renewable source of energy, which can be used as a substitute for other fuels in order to save energy in rural areas.
3. Biogas technology contributes to the sustainable development of Palestinian rural areas by providing them with a wide variety of socioeconomic benefits, including personal or household impacts, health impacts, social, economic and environmental impacts .
4. Small scale biogas unit is not complicated, cheap, robust, easy to operate and maintain, low construction cost and that could be operated and repaired by the family itself and can be constructed with locally produced materials and suitable to biogas production for Palestinian rural family to cover its monthly requirement from natural gas and production high quality organic fertilizer to improve crops yield.
5. The food residues (alone) produce the biggest quantity of biogas comparing with other organic waste.
6. Biogas has a heat value equals half heat value of butane gas.

7. The success of the experiment indicates to the possibility for technical application feasibility for biogas technology in the in Palestinian rural areas.
8. Small scale biogas unit is a suitable family digester type. This will make a benefit of 3593NIS/year and the simple payback period of it is less than one year.
9. The digested slurry removed from the biogas plant is visibly different than the pre-digested kitchen waste fed into the plant. The pre-digested kitchen waste has a smell of rotten vegetables, takes the color of the input material used , the type of vegetables , and fruits can still be identified in the mix. The digested slurry is practically odorless and blackish in color; the parent materials (as well as any solids) are no longer visible. It is being used as organic fertilizer in the kitchen garden.
10. The gas is practically odorless and burns with a blue flame. A slight hissing sound can be heard during the initial opening of the valve at the gas burner. This is due to the fact of accumulation of condensed water in the pipe, which needs to be drained out from time to time.
11. It is possible to design a large anaerobic digesters in order to process organic wastes in municipal wastes as an alternative to landfill disposal. The digested effluent could also be used as fertilizers rather than occupying space in the landfill.

Recommendations

Several recommendations have been suggested:

1. Constructing small scale biogas unit with continuous loading for organic wastes will cover the daily energy requirements (instead of natural gas) for rural family and provide it with organic fertilizer for improving crops yield and so could be used instead of manufactured fertilizers.
2. Informing and encouraging people about the benefits of biogas at a young age, and providing school material about the importance of the environment and the benefits of biogas is a necessity. This will enable them to make sensible choices when they grow older.
3. Supporting and encouraging biogas technology in order to be used in Palestine by Palestinian National Authority PNA with good cooperation between farmers and related sectors as energy, environment and agricultural sectors to improve and apply digesters in Palestinian rural areas.
4. More researches and practical studies about applying biogas technology in Palestine should be conducted in order to improve biogas plant in Palestine.
5. Financial help (from government or non governmental organizations -NGO´s-) should be provided for rural families in order to help them in constructing biogas plants.

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Appendix(1)

Statistical Analysis

The SAS System

Obs	TRT	gas	temp	time
1	1	1200	33.0	1
2	1	1220	33.5	2
3	1	1200	32.5	3
4	1	1170	31.0	4
5	1	1070	30.0	5
6	1	1075	30.0	6
7	1	1075	30.0	7
8	1	1175	31.0	8
9	1	1220	31.5	9
10	1	1200	32.5	10
11	1	1285	32.5	11
12	1	1265	33.5	12
13	1	1220	33.5	13
14	1	1225	32.5	14
15	2	1200	33.0	1
16	2	1150	32.0	2
17	2	1200	32.5	3
18	2	1170	32.0	4
19	2	1150	32.0	5
20	2	1150	31.5	6
21	2	1200	32.0	7
22	2	1200	33.0	8
23	2	1150	31.5	9
24	2	1200	31.5	10
25	2	1250	32.0	11
26	2	1300	32.5	12
27	2	1330	33.0	13
28	2	1330	33.0	14
29	3	1500	34.0	1
30	3	1450	33.0	2
31	3	1375	32.5	3
32	3	1250	32.0	4
33	3	1375	32.5	5
34	3	1425	33.0	6
35	3	1450	33.5	7
36	3	1435	33.0	8
37	3	1380	33.5	9
38	3	1410	33.0	10
39	3	1450	34.0	11
40	3	1500	33.5	12
41	3	1550	33.0	13
42	3	1575	33.5	14
43	4	1375	33.5	1
44	4	1375	33.0	2
45	4	1375	33.5	3
46	4	1500	34.0	4
47	4	1375	31.5	5
48	4	1450	32.0	6
49	4	1500	33.5	7
50	4	1500	33.0	8
51	4	1750	34.5	9
52	4	1625	34.5	10
53	4	1750	34.5	11
54	4	1750	33.5	12
55	4	1875	35.0	13
56	4	1960	35.5	14

The GLM Procedure

Dependent Variable: gas

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	2078269.133	296895.590	92.42	<.0001
Error	48	154201.849	3212.539		
Corrected Total	55	2232470.982			

R-Square	Coeff Var	Root MSE	gas Mean
0.930928	4.183798	56.67926	1354.732

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	1506219.196	502073.065	156.29	<.0001
time	1	304365.721	304365.721	94.74	<.0001
temp	1	182749.024	182749.024	56.89	<.0001
temp*temp	1	56976.030	56976.030	17.74	0.0001
temp*temp*temp	1	27959.162	27959.162	8.70	0.0049

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	410968.2802	136989.4267	42.64	<.0001
time	1	92101.1156	92101.1156	28.67	<.0001
temp	1	25411.5544	25411.5544	7.91	0.0071
temp*temp	1	26597.6115	26597.6115	8.28	0.0060
temp*temp*temp	1	27959.1615	27959.1615	8.70	0.0049

Parameter		Estimate		Standard Error	t Value	Pr > |t|
Intercept		-247188.2673	B	90213.95361	-2.74	0.0086
TRT	1	-256.3353	B	26.77595	-9.57	<.0001
TRT	2	-242.7350	B	27.10775	-8.95	<.0001
TRT	3	-63.8045	B	23.75915	-2.69	0.0099
TRT	4	0.0000	B	.	.	.
time		10.9509		2.04523	5.35	<.0001
temp		23377.3907		8311.98194	2.81	0.0071
temp*temp		-733.7418		255.00348	-2.88	0.0060
temp*temp*temp		7.6851		2.60504	2.95	0.0049

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

TRT	gas LSMEAN	LSMEAN Number
1	1239.11553	1
2	1252.71582	2
3	1431.64636	3
4	1495.45086	4

Least Squares Means for effect TRT
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: gas

i/j	1	2	3	4
1		0.9394	<.0001	<.0001
2	0.9394		<.0001	<.0001
3	<.0001	<.0001		0.0472
4	<.0001	<.0001	0.0472	

The NONLINEAR analyses were based on the following model:

$$Y = C*(Time)^{X1} * (Temp)^{X2}$$ **, where Y is gas emission**

The NLIN Procedure (ALL TRTS)
Dependent Variable gas
Method: Gauss-Newton

Iterative Phase

Iter	c	X1	X2	Sum of Squares
0	10.0000	2.0000	2.0000	6.322E13
1	-0.0232	1.9966	2.0033	7.4546E8
2	-0.0232	3.4522	0.5653	1.9159E8
3	0.0104	7.8714	-2.5830	82421031
4	0.0125	7.6865	-2.5010	82293852
5	0.0154	7.4631	-2.4003	82171867
6	0.0197	7.1946	-2.2765	82059228
7	0.0258	6.8744	-2.1247	81951647
8	0.0347	6.4959	-1.9390	81823438
9	0.0477	6.0539	-1.7124	81605606
10	0.0656	5.5471	-1.4380	81156411
11	0.1109	4.4160	-0.7821	80445541
12	0.2145	0.0419	2.2569	32501955
13	0.1759	0.0417	2.3168	31936260
14	0.1417	0.0415	2.3821	31338215
15	0.1125	0.0413	2.4518	30676234
16	0.0886	0.0411	2.5246	29904526
17	0.0696	0.0408	2.5989	28971431
18	0.0549	0.0406	2.6732	27831501
19	0.0437	0.0404	2.7461	26457330
20	0.0268	0.0400	2.8865	26297339
21	0.0200	0.0397	2.9854	23552222
22	0.0127	0.0392	3.1368	19944441
23	0.00498	0.0384	3.4334	14843336
24	0.00723	0.0385	3.4538	661866
25	0.00747	0.0385	3.4486	639640
26	0.00748	0.0385	3.4484	639619

NOTE: Convergence criterion met.

Estimation Summary

Method	Gauss-Newton
Iterations	26
Subiterations	42
Average Subiterations	1.615385
R	7.135E-6
PPC(c)	0.000026
RPC(c)	0.001012
Object	0.000032
Objective	639619.5
Observations Read	56
Observations Used	56
Observations Missing	0

The NLIN Procedure

NOTE: An intercept was not specified for this model.

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	3	1.0437E8	34789869	2882.75	<.0001
Error	53	639619	12068.3		
Uncorrected Total	56	1.0501E8			

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
c	**0.00748**	**0.00835**	**-0.00927**	**0.0242**
X1	**0.0385**	**0.0145**	**0.00940**	**0.0675**
X2	**3.4484**	**0.3205**	**2.8057**	**4.0912**

Approximate Correlation Matrix

	c	X1	X2
c	1.0000000	0.1454809	-0.9996686
X1	0.1454809	1.0000000	-0.1690656
X2	-0.9996686	-0.1690656	1.0000000

-- TRT=1 --

The NLIN Procedure
Dependent Variable gas
Method: Gauss-Newton

Iterative Phase

Iter	c	X1	X2	Sum of Squares
0	20.0000	0	2.0000	5.2146E9
1	4.4813	0.000915	1.9516	1.0217E8
2	5.0570	0.00548	1.7119	7674111
3	8.8821	0.0120	1.3798	169512
4	10.7688	0.0132	1.3249	154805
5	12.9685	0.0143	1.2740	121501
6	17.0904	0.0160	1.1988	77075.5
7	19.0474	0.0164	1.1822	14063.1
8	19.1421	0.0164	1.1828	13167.1
9	19.1428	0.0164	1.1827	13167.1

NOTE: Convergence criterion met.

Estimation Summary

Method	Gauss-Newton
Iterations	9
Subiterations	3
Average Subiterations	0.333333
R	2.429E-7
PPC(c)	5.417E-7

RPC(c)	0.000036
Object	3.48E-10
Objective	13167.13
Observations Read	14
Observations Used	14
Observations Missing	0

NOTE: An intercept was not specified for this model.

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	3	19729783	6576594	5494.18	<.0001
Error	11	13167.1	1197.0		
Uncorrected Total	14	19742950			

The NLIN Procedure

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
c	19.1428	13.0954	-9.6801	47.9657
X1	0.0164	0.0102	-0.00606	0.0389
X2	1.1827	0.1971	0.7490	1.6165

Approximate Correlation Matrix

	c	X1	X2
c	1.0000000	-0.0595314	-0.9995681
X1	-0.0595314	1.0000000	0.0324680
X2	-0.9995681	0.0324680	1.0000000

--------------------------------------- TRT=2 ---------------------------------------

The NLIN Procedure
Dependent Variable gas
Method: Gauss-Newton

Iterative Phase

Iter	c	X1	X2	Sum of Squares
0	20.0000	0	2.0000	5.3818E9
1	1.0488	0.00235	2.0005	216342
2	1.0578	0.0445	2.0064	13143.5
3	1.1321	0.0416	1.9861	12483.6
4	1.1340	0.0416	1.9863	12371.3
5	1.1339	0.0416	1.9863	12371.3

NOTE: Convergence criterion met.

Estimation Summary

Method	Gauss-Newton
Iterations	5
R	2.74E-7

PPC(X1)	2.153E-7
RPC(c)	0.000018
Object	3.482E-9
Objective	12371.28
Observations Read	14
Observations Used	14
Observations Missing	0

NOTE: An intercept was not specified for this model.

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	3	20636829	6878943	6116.46	<.0001
Error	11	12371.3	1124.7		
Uncorrected Total	14	20649200			

Parameter	**Estimate**	Approx **Std Error**	**Approximate 95% Confidence Limits**	
c	1.1339	1.6673	-2.5357	4.8036
X1	0.0416	0.00999	0.0196	0.0636
X2	1.9863	0.4231	1.0551	2.9175

Approximate Correlation Matrix

	c	X1	X2
c	1.0000000	-0.0257935	-0.9999090
X1	-0.0257935	1.0000000	0.0132713
X2	-0.9999090	0.0132713	1.0000000

The SAS System 11

-- TRT=3 --

The NLIN Procedure
Dependent Variable gas
Method: Gauss-Newton

Iterative Phase

Iter	c	X1	X2	Sum of Squares
0	20.0000	0	2.0000	5.9114E9
1	0.7777	0.000896	2.0071	4447591
2	0.7951	0.0219	2.1722	749256
3	0.8956	0.0152	2.1011	46197.5
4	0.9131	0.0140	2.0954	45976.5
5	0.9107	0.0140	2.0962	45975.5
6	0.9107	0.0140	2.0962	45975.5

NOTE: Convergence criterion met.

Estimation Summary

Method	Gauss-Newton
Iterations	6
R	2.7E-7

PPC(c)	1.582E-6
RPC(X1)	0.000044
Object	7.436E-9
Objective	45975.53
Observations Read	14
Observations Used	14
Observations Missing	0

NOTE: An intercept was not specified for this model.

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	3	28970749	9656916	2310.49	<.0001
Error	11	45975.5	4179.6		
Uncorrected Total	14	29016725			

Parameter	**Estimate**	Approx **Std Error**	**Approximate 95% Confidence Limits**	
c	**0.9107**	**2.3563**	**-4.2754**	**6.0969**
X1	**0.0140**	**0.0160**	**-0.0212**	**0.0493**
X2	**2.0962**	0.7397	**0.4683**	3.7242

Approximate Correlation Matrix

	c	X1	X2
c	1.0000000	0.0934382	-0.9999264
X1	0.0934382	1.0000000	-0.1045969
X2	-0.9999264	-0.1045969	1.0000000

The SAS System 13

--------------------------------------- TRT=4 --

The NLIN Procedure
Dependent Variable gas
Method: Gauss-Newton

Iterative Phase

Iter	c	X1	X2	Sum of Squares
0	20.0000	0	2.0000	6.2702E9
1	0.6135	0.00644	2.0078	10661872
2	0.6781	0.1958	2.2166	9848482
3	0.7400	0.1307	2.1309	271648
4	0.9360	0.1022	2.0518	75019.6
5	0.9986	0.0997	2.0419	49576.4
6	0.9991	0.0997	2.0423	49465.2
7	0.9991	0.0997	2.0423	49465.2

NOTE: Convergence criterion met.

Estimation Summary

Method	Gauss-Newton
Iterations	7

R	8.06E-8
PPC(c)	2.668E-7
RPC(c)	0.000019
Object	1.486E-9
Objective	49465.2
Observations Read	14
Observations Used	14
Observations Missing	0

NOTE: An intercept was not specified for this model.

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	3	35550885	11850295	2635.25	<.0001
Error	11	49465.2	4496.8		
Uncorrected Total	14	35600350			

Parameter	**Estimate**	**Approx Std Error**	**Approximate 95% Confidence Limits**	
c	**0.9991**	**1.4573**	**-2.2083**	**4.2065**
X1	0.0997	**0.0190**	**0.0578**	**0.1416**
X2	2.0423	**0.4194**	**1.1193**	**2.9653**

Approximate Correlation Matrix

	c	X1	X2
c	1.0000000	0.4948859	-0.9997328
X1	0.4948859	1.0000000	-0.5137188
X2	-0.9997328	-0.5137188	1.0000000

جامعة النجاح الوطنية

كلية الدراسات العليا

تقييم الكفاءة النوعية والكمية لوحدات صغيرة لإنتاج الغاز الحيوي في الريف الفلسطيني

إعداد

محمود رشاد راشد منصور

إشراف

أ. د. مروان حداد

قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في العلوم البيئية بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس ، فلسطين .

2014

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الملخص

تعتبر الطاقة البديلة من الأولويات التي تسعى البشرية للارتقاء بها وتطويرها لتحل محل مصادر الطاقة غير المتجددة ، وتعتبر تقنية إنتاج الغاز الحيوي من البدائل المناسبة لكثير من أنواع الوقود غير المتجددة وهي ذات فوائد بيئية واقتصادية متعددة .

ينتج الغاز الحيوي عن تحلل المواد العضوية الصلبة مثل مخلفات الحيوانات والمحاصيل وبقايا الطعام بواسطة البكتيريا تحت ظروف حرارية مناسبة وبمعزل عن الأكسجين ، ويتكون الغاز الحيوي في غالبه من غازي الميثان (CH_4) وثاني أكسيد الكربون (CO_2) بالإضافة إلى غازات أخرى .

في هذه الدراسة قمنا بتصميم وحدة صغيرة لإنتاج الغاز الحيوي بحجم 1500 لتر وتم تغذيتها بأربعة أنواع من المخلفات العضوية وهي: روث الأبقار وبقايا الطعام وروث الأبقار مخلوطا ببقايا الطعام ، وروث الدجاج مخلوطا ببقايا الطعام ،وتمت دراسة وتقييم مدى فعالية الوحدة في إنتاج الغاز الحيوي من حيث كمية الغاز الناتج ونوعيته من المخلفات العضوية الأربعة كل على حدا .

النتائج التي تم الحصول عليها من هذه الدراسة أظهرت أن جميع المخلفات العضوية أنتجت الغاز الحيوي في درجات الحرارة السائدة .وبحسب النتائج أيضا فإن بقايا الطعام أنتجت أكبر كمية من الغاز(22.160 كغم خلال 14 يوم) ثم روث الدواجن المخلوط ببقايا الطعام (20.125 كغم خلال 14 يوم) ثم روث الأبقار المخلوط ببقايا الطعام (16.980 كغم خلال 14 يوم) ثم روث الأبقار (16.600 كغم خلال 14 يوم) وأشارت النتائج إلى أن القيمة الحرارية للغاز الحيوي مساوية تقريبا لنصف للقيمة الحرارية للغاز التجاري المستخدم في بيوتنا .

من خلال النتائج يمكننا القول أن تصميم وحدة إنتاج الغاز الحيوي المستخدمة في التجربة ذات فعالية عالية في إنتاج الغاز الحيوي من حيث الكمية والنوعية وهي وحدات بسيطة التركيب ويمكن بناؤها بكل سهولة وقليلة التكاليف وسهلة التشغيل والصيانة وكمية الغاز الناتج ونوعيته كافية لتغطية الاحتياجات الشهرية للأسر الريفية الفلسطينية من الغاز التجاري .

لذلك أوصي باستخدام وحدات الغاز الحيوي في المناطق الريفية الفلسطينية وإجراء المزيد من الدارسات لتزويد أبناء شعبنا في الريف الفلسطيني بمعلومات وخبرات عملية أكثر حول تقنية الغاز الحيوي والعمل على نشر هذه الفكرة .

وفي الختام ، نسأل الله تعالى التوفيق والسداد في الدارين، والحمد لله رب العالمين.