Palestine Polytechnic University

College of Engineering and Technology
Civil & architecture Engineering Department

Graduation project

Biogas Generation from Biowaste

'Case Study: Al- Arroub Farm Complex Biogas Station

Project Team

Abed Alrazak Abu Rahma Rami Daraghmah

Project supervisors

Dr. Taleb Al - Harthi
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Hebron – Palestine

June, 2004

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Abed Alrazak Abu Rahma **Rami Daraghmah**

**A project report submitted in partial fulfillment of requirements for the degree of
Bachelor of Engineering in
Civil & Architectural Engineering Department**

Project supervisors
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<u>CERTIFICATION</u>

PALESTINIAN POLYTECHNIC UNIVERSITY
(PPU)

Hebron – Palestine

The Senior Project Entitled

BIOGAS GENERATION FROM BIOWASTE
"CASE STUDY: AL ARROUB FARM COMPLEX
BIOGAS STATION"

Prepared by:

ABED AL-RAZAK ABU RAHMA   RAMI DARAGHMAH

In accordance with recommendations of the project supervisors, and the acceptance of all examining committee members, this project has been submitted to the Department of Civil and Architectural Engineering in the College of Engineering and Technology in partial fulfillment of the requirements of Department for the degree of Bachelor of Science in Engineering.

Project Supervisors Signature:

…….............   ……….........

Examining Committee Signature:

…………...........   ……………………

Department Chairman Signature:

…………..............

إهــــداء

إلى الأم الحنـــونة والأب الغـــالي

إلى الصديق والأخ الغالي ماجـــد أبو شـــرخ وأسرة الكريمة

إلى الصديق والأخ الغالي عماد الزغل وأسرة الكريمة

إلى صناع المجد لهذه الأمة

إلى أحـــبائنا الذين تتـــوق أنفســـهم للتفوق والنجاح

إلى أعـــزائنا الذين تهفو قلـــوبهم للـــسمو وتشـــرئب أعناقهم للمعـــالي

إلى الذيـــن يجعلـــون الاجـــتهاد هدفهم والجد دأبهم

إلى كل الراغبين بالاستزادة من العلم والمعرفة

إلى كل هؤلاء نهدي هذا الجهد المتواضع

عبدالرزاق أبو رحمه

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ABSTRACT

Biogas generation from biowaste

“Case study: Al Arroub from complex biogas station

By:

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Civil and Architectural Engineering Department

College of Engineering and Technology_ PPU

Supervisors: Dr. Majed Abu-Sharkh **Dr. Taleb Al-Harithy**

This research represents a 9 months period of research and investigative study carried on 4 small bio-digesters, all of batch type, installed in the laboratory of the Environment Quality Authority (EQA) of Palestine in Hebron, and one major field bio-digester of Indian type installed in Al-Arroub Farm Complex (AFC).

The study includes measurements of feedstock's quantity and quality, initial total solids percentage (TS%), initial volatile solids percentage (VS%), pH changes/fluctuations versus time, and many other essential analyses like ash ratios, moisture content (MC%), the initial total dissolved oxygen (TDO) in mg/l, electric conductivity (EC) in micro siemens per cm and the salinity in gm/l. All these experiments and measurements were run under ambient temperature conditions.

Conclusions and recommendations are shown in the last chapter (CH 8), they include the lab and field results as well as the scientific discussion concerning what they really mean.

From the study, it was found that the annual net profit (revenue) from AFC plant (as biogas + slurry) reaches approx. 858 $ in the first year of operating the plant and 1458$ every year for the following 14 years of operation. Assuming that the service life period of the plant is 15 years.

And consequently, putting down the suitable related recommendations that coincide with the aims of this study.

CHAPTER ONE

INTRODUCTION

1.1 GENERAL BACKGROUND

1.2 ADVANTAGES AND DISADVANTAGES OF BIOGAS

1.3 PROBLEM IDENTIFICATION

1.4 PROJECT OBJECTIVES

1.5 SCOPE OF THE WORK

1.6 PHASES OF THE PROJECT DEVELOPMENT

CHAPTER ONE
INTRODCTION

1.1 GENERAL BACKGROUND

In recent years, the demand for energy around the world has been increasing, and it is the first interest for decision makers to control the energy sources and look for new recourses to utilize. The combustion of the conventional source of energy (oil) causes pollution for the environment, destroys the ozone layer, deteriorates the green house effect increasing the temperature of the earth, increases acid rain, … etc.

Methane gas molecule contains one atom of carbon and four atoms of hydrogen (CH_4). It is "like the natural gas in its characteristics" used in many houses for cooking and heating. It is odorless and colorless gas, and yields about 1,000 British Thermal Units (Btu) [252 kilocalories (kcal)] of heat energy per cubic foot (28 litter) when burned [5]. Natural gas is a fossil fuel that was created years ago by the anaerobic decomposition of organic materials. It is often found in association with oil and coal.

The same types of anaerobic bacteria that produced natural gas also produce methane gas today. Anaerobic bacteria are some of the oldest forms of life on earth, they appeared first on the earth surface approx. 3.8 billion years ago. They evolved before the photosynthesis of green plants released large quantities of oxygen into the atmosphere. Anaerobic bacteria break down or "digest" organic material in the absence of oxygen and produce 'biogas" as a waste product. Aerobic decomposition, or composting, requires large amounts of oxygen and produces heat. Anaerobic decomposition occurs naturally in swamps, waterlogged soils and rice fields, deep bodies of water, and in the digestive systems of termites and large animals.

Anaerobic processes can be managed in a "digester" (an airtight tank) or a covered lagoon (a pond used to store manure) for waste treatment. The primary benefits of anaerobic digestion are nutrient recycling, waste treatment, and odor control. Except in very large systems, biogas production is a highly useful but secondary benefit.

Biogas produced in anaerobic digesters consists of methane (50%-80%), carbon dioxide (50%-20%), and trace levels of other gases such as hydrogen, carbon monoxide, nitrogen, oxygen, and hydrogen sulfide. The relative percentage of these gases in biogas depends on the feed material and management of the process. When burned, a cubic foot (28 litter) of biogas yields about 1000 Btu (252 kcal) of heat energy per percentage of methane composition. For example, biogas composed of 65% methane yields 650 Btu per cubic foot (5.857 kcal/ litter) [5].

1.2 ADVANTAGES AND DISADVANTAGES OF BIOGAS

1.2.1 Advantages of Biogas

Extracting energy from biosolids is considered one of the most significant approaches in energy technologies around the world because of many advantages:

1. Surplus to the total economy, it helps conserve foreign exchange through reducing demand for kerosene, gas and commercial fertilizers.
2. Environmentally friendly, this will follow as individual families and enterprises practice an efficient waste disposal system.
3. Increasing animal backyard, with biogas production animal raising home lots can now be undertaken without the usual undesirable smell and other sanitation problems.
4. Reduce deforestation; in the long run biogas would reduce demand for firewood as primary source of fuel in the rural areas.

5. Forms electricity source for rural or areas that are located far from the electric sources supply.
6. The material drawn from the digester is called sludge, or effluent. It is rich in nutrients (ammonia, phosphorus, potassium, and more than a dozen of trace elements) and is an excellent soil conditioner.
7. Digesters are very good utilities for killing the microbes in pathogenic residue.

1.2.2 Disadvantages of Biogas

1. Optimal reactor temperature is 20^o C and above; (the lower limit of currently applied anaerobic technology in developing countries is influent temperatures above 12^o C).
2. Longer startup time because of the slow growth rate of anaerobic bacteria.
3. Methanogenic activity may be inhibited from the toxic effects of high concentrations of heavy metals, toxic organics, free ammonia NH_3 (> 50 mg/l) and free H_2S (> 250 mg/l).[4]
4. Chemical buffering may be required to maintain alkalinity in reactor.
5. Corrosion resistant materials, such as plastics and masonry coatings are required for the reactor vessel and pipes.

1.3 PROBLEM IDENTIFICATION

Nowadays the demand for energy around the world is increasing, and the controlling of energy sources, should be the first aim for the decision makers. Extracting energy from biosolids is nowadays considered one of the most significant approaches in energy technologies around the world because of its benefit as clean energy, friend to atmosphere, cheap, helps to treat biosolids and for its economical benefits.

Energy can be directly generated from dry biosolids by burning them using thermo turbines while from wet biosolids by fermenting them anaerobically in what is technically called a biodigester to generate methane (CH_4) rich biogas.

At the time being, biogas driven vehicles (e.g. public buses, lorries, vans...etc) and in machines are widely used in developed countries like U.S.A, European Union and Japan. Biogas is also being used extensively for household purposes in many parts of the developing countries like China, India, African and Asian countries.

In Palestine where energy prices are considered the highest in the world and the energy sector is fully controlled by Israel and the Palestinian people are suffering the daily violence committed by the Israeli occupation forces and as Palestine is a fertile land " Craddle of Honey & Milk " where biological (especially the agricultural) residues exist in large quantities, biogas generation opportunities must be grasped and applied to sustain the standstiffness of the Palestinian people on their own homeland soil.

1.4 PROJECT OBJECTIVES

The main objectives of the present study are to:

1. Study the processes of converting cow manure into gas fuel and other beneficial products like soil fertilizer.
2. Design and construct a pilot biogas plant at Al Arroub Farm Complex (AFC).
3. Run and monitor the biogas generation plant in AFC.
4. Determine the efficiency and performance of the constructed biogas plant.
5. Identify the type quantity and concentration of feedstock material needed to reach the optimum biogas output for the plant, as well as to identify the chemicals added to reach that.
6. Define the most suitable design for a biogas reactor (digester) and the plant as well as the factors affecting it.

1.5 SCOPE OF THE WORK

In order to achieve the aforementioned objectives, the following steps were carried out:

1. Carrying out several field visits to the plant area to investigate the environmental situation in-situ.
2. Collecting the data and information related to the proposed project such as maps, designs, drafts, climatic and weather condition,... etc, from the concerned institutions along with the technical and illustrative details that show the topography and the nature of the area of study.
3. A comprehensive literature review with respect to biogas generation from quantity and quality biowaste.
4. Design a gas generation plant to produce biogas and organic fertilizer.
5. Biogas plant had been built at al Arroub farm. The operation of the system was monitored during the research work.
6. Sampling and measurement of the gas fraction and other parameters that affect gas generation in order to assess the performance of the system.
7. Putting down suitable scenarios to develop and optimally run the biogas generation plant.
8. Come up with appropriate recommendations to further building up more biogas generation plants, taking in consideration the local prevailing climatic, environmental, demographic, economic, and other circumstance.
9. Finally to write down the final report of the project. The report will include all collected data, methodology and results of the analyses, conclusions and recommendations.

1.6 PHASES OF THE PROJECT DEVELOPMENT

This project is being implemented in four phases and is proposed to be completed in accordance with time schedule shown in Table (1.1).

Table 1.1 Time Schedule to Implement the Study.

Phase No.	Title	Duration								
		2003			2004					
		10	11	12	1	2	3	4	5	6
One	Introduction and literature review.									
Two	Design and construction of Biogas Plants									
Three	Field and lab. work and analyses									
Four	Report writing									

The description of each phase of the project and the task involved are discussed at next:

1.6.1 Phase One: Introduction and literature review:

During this phase the available data and information about biogas generation from biowastes and about AFC plant, are collected from different sources. As well as, visits to the plant site were carried out. To undertake this phase the following tasks are being included:

1. A comprehensive literature review with respect to generated biogas from biowaste.
2. Collecting all information related to Al Arroub Farm Complex (AFC) such as location, topography, geology, existing facilities, activities run, … etc.

3. Studying the environmental health risks and solid waste management parameters in Al Arroub farm complex.
4. Studying the biogas plants in Palestine and the benefits to apply this technology for the Palestinian society.

1.6.2 Phase Two: Design and Construction of Biogas Plants:

To undertake this phase the following tasks are going to be included:

1. Types of biogas plants, Biogas characteristics, how does a biogas plant work, the Anaerobic Digestion Process and parts of biogas plant.
2. Design a gas generation plant to produce biogas and organic fertilizer.
3. Building up one pilot biogas generation plant at Al Arroub farm complex.
4. Operate, monitor and maintain the system.

1.6.3 Phase Three: Field and Lab. Work and Analyses:

To undertake this phase the following tasks are going to be included:

1. Feed the Biogas digester with cow manure of different concentrations in order to assess the performance of the digester with regard to most suitable concentration.
2. Running four small bio-digesters in the laboratory of the Environment Quality Authority (EQA) of Palestine in Hebron in order to study the feasibility of producing biogas from cow manure and the parameters affecting the process.
3. After running the needed studies, the most suitable design of the plant was suggested.

1.6.4 Phase Four: Report Writing:

Upon the completion of the work, a final report will be written. The report will include all collected data and results of analyses carried out as well as the conclusions, and recommendations reached.

CHAPTER TWO
LITERATURE REVIEW

2.1 INTRODUCTION

2.2 HISTORICAL BACKGROUND

2.3 PRESENT INTEREST IN BIOGAS

2.4 GENERAL OVERVIEW

2.5 ENERGY STATUS IN PALESTINE

CHAPTER TWO
LITERATURE REVIEW

2.1 INTRODUCTION

In recent years the conversion of biomass materials to methane for use as an energy source has excited great interest throughout the world. This conversion is accomplished by anaerobic digestion, the biological process by which the organic material or feed stock is degraded-in the absence of oxygen- to produce a combustible gas [methane (CH_4) and carbon dioxide (CO_2)] is often called "fermentation" and the energy source produced is called "biogas".

Other benefits of digestion include reduction or elimination of pathogens, depending upon temperature, and production of a stable, generally environmentally acceptable slurry or sludge which can be used as a fertilizer and/or soil conditioner.

2.2 HISTORICAL BACKGROUND

In 1630 Van Helmont recorded the emanation of a gas from decaying organic matter. In 1667 Shirley described this gas more precisely, and is sometimes considered to be its discoverer. However, Volta is generally recognized as putting methane digestion on a scientific footing. From a number of observations he concluded in 1776 that:

a- The amount of gas that evolves is a function of the amount of decaying vegetation in the sediments from which the gas emerges.

b- Certain proportions of the gas are obtained form an explosive mixture with air.

In 1804 Dalton established the chemical composition of methane, and in 1806 Henry confirmed that town gas was very similar to Volta's "marsh gas." In 1808 Davy established that methane was produced from decomposing cattle manure, which may be the first time to mention that organic wastes were recognized as a source of energy [2].

It was not until towards the end of the 19th century that methanogenesis was found to be connected to microbial activity. In 1868 Bechamp, a student of Pasteur named the "organism" responsible for methane production from ethanol. This organism was apparently a mixed population since Bechamp was able to show that depending on the substrate, different fermentation products were formed. Popoff, in 1875, was the first to systematically investigate the formation of methane using different complex substrates, and he found that with cellulose the end products were methane, carbon dioxide and some hydrogen, while with acetate no methane was produced. However, in 1876 Herter, in cooperation with Hoppe-Seyler, reported that acetate in sewage sludge was converted stoichiometrically to equal amounts of methane and carbon dioxide [2].

In 1884 Gayon, another student of Pasteur, fermented manure at 35°C, obtaining 100 liters of methane per cubic meter of manure. It was concluded that the fermentation could be a source of gas for heating and lighting, and the "Compagnie des Omnibus" in Paris requested that Gayon design an installation in which the manure of their many horses could be digested to methane to be used for street lighting. Gayon declined, however, saying that his work was only preliminary. As early as 1896 gas from sewage was used for lighting streets in Exeter, England, and gas from human wastes in the Matinga Leper Asylum in Bombay, India was used to provide lighting in 1897 [4].

In 1906 Sohngen was able to enrich for two distinct acetate utilizing bacteria, and he found that format, and hydrogen plus carbon dioxide could act as precursors for methane. This remained the major breakthrough in the microbiology of methane bacteria for thirty years. On the applied side, Buswell began studies of anaerobic digestion in the late 1920s and developed a solid base of information on such issues, as the fate of nitrogen in anaerobic digestion, the stoichiometry of reaction, the production of energy from farm wastes and the use of the process for industrial wastes [5].

Barker's studies contributed significantly to our knowledge of methane bacteria, and his enrichment cultures enabled him to perform many of the common biochemical studies. Schnellen was the first worker to isolate two methane bacteria in 1947, *Methanosarcina barkeri* and *Methanobacterium formicium*. Much of this work is still relevant today, and those who are developing biogas as an energy source would gain much from review of this earlier work [4].

2.3 PRESENT INTEREST IN BIOGAS

The technology of anaerobic digestion has not yet realized its full potential for energy production. In industrialized countries biogas programs are often hindered by operational difficulties, a lack of basic understanding of the fundamentals involved, and little engineering innovation. In some developing countries, on the other hand, development of biogas programs has lacked urgency because of readily available and inexpensive noncommercial fuels such as firewood.

Biogas technology is also potentially useful in the recycle of nutrients back to the soil. Burning of noncommercial fuel sources such as dung and agricultural residues leads to a severe ecological imbalance since the nutrients (nitrogen, phosphorus and micronutrients) are essentially lost from the ecosystem. Biogas production from organic materials not only produces energy, but preserves the nutrients, which can be recycled back to the land in the form of slurry. The organic content also acts as a soil conditioner by contributing humus. Fertilizing and conditioning of soil can be achieved by simply using other fuel sources and recycling the waste back to the land without burning it. However, while data are sparse, Chinese workers report that digested biomass increases agricultural productivity by as much as 30% over farmyard manure on an equivalent basis [2]. This is due in part to the biochemical processes occurring during digestion which cause the nitrogen in the digested slurry to be more accessible for plant utilization, and to the fact that less nitrogen is lost during digestion than in storage or composting. This aspect of biogas technology may, in fact, be more important than the gas produced [6].

In the area of public health and pollution control, biogas technology can solve another major problem, that of disposal of sanitary wastes. Digestion of these wastes can reduce the parasite and pathogenic bacterial counts by over 90%. Breaking the vicious circle of reinfection via drinking water, which in many rural areas is untreated? Industrial waste treatment using anaerobic digestion is also possible and rather recommended [4].

During anaerobic digestion of cow manure at 15 ^oC in continuous stirred reactors, methanogenesis could be achieved at a retention time of 100 days , while it can not at 50 days. Zeeman found the % hydrolysis at 125 days batch digestion of cow manure is 12, 14, 18, 27 , and 45% at process temperatures of 5 , 10 , 15 , 25 and 30 ^oC respectively. However, the reduction in temperature significantly affects the sludge metabolic activities and hence, affects both the hydrolytic and methanogenic activities of the sludge and consequently the optimum solids retention time [2].

The rate limiting–step be defined as "that step which will cause process failure to occur under imposed conditions of kinetic stress ".The hydrolysis of retained particles is in general considered as the rate-limiting step of the overall digestion process and is highly influenced by process temperature and solids retention time [5].

2.4 GENERAL OVERVIEW

2.4.1 Technical Status

Three basic designs of biogas plants, fixed dome (Chinese), floating covers (Indian), and bag (membrane) has been used in a number of countries for many years. The designs reflect modest optimization for reduced capital costs and increased volumetric gas yields (volumes of gas per volume of digester per day), although more can be done in this area. Application of other recent designs such as the up flow anaerobic sludge blanket (UASB) digester, anaerobic filter, and anaerobic baffled reactor should also be explored. These show promise in treating a wide variety of feedstock at low capital investment with high volumetric gas yields. Performance can also be increased by selective use of heating, pre-treating (e.g. grit and stones isolation, straw removal, size reduction, screening …etc) and mixing [7].

Lack of technical expertise can be a significant problem to widespread acceptance of biogas programs. Many digesters fall into disuse within months because of such problems as gas leaks or faulty construction of gas holders. Some designs are not "user friendly". Plants that is extremely labor intensive, for instance requiring manual handling of feedstock and/or digested slurry are soon abandoned. Cost is also a major factor. Process design should eliminate unnecessary and expensive equipment in favor of simple, low maintenance systems or cost effective major capital items. Fixed wall digesters, for example, should be sized for high loading rates and low retention times. Alternatively, inexpensive pits can be optimized by taking advantage of longer retention times for negligible cost, allowing lower temperatures, less mixing and less concern with daily maintenance and control.

Careful consideration of plant goals must precede design. Not all end uses are consistent with the same size or type of digester. Initial feedstock should be as fresh as possible if the goal is high gas yield, as large portions of volatile solids are consumed aerobically over time. Pathogen destruction requires higher temperatures and longer retention times, as do many industrial or toxic wastes. Proper handling for nitrogen conservation enhances slurry use as a soil conditioner.

Integrated resource recovery systems can improve the financial viability of biogas plants, and help combine several goals into effective programs. The private sector should be encouraged to incorporate biogas technology into commercial and industrial applications.

2.4.2 Economic Feasibility

There are two ways of looking at economic viability of biogas programs and integrated resource recovery. A strictly financial approach involves analysis of monetary benefits such as sale or reuse of products (methane, carbon dioxide and slurry) and the costs of constructing and maintaining facilities. The societal costs of inputs and outputs, including such intangibles as improvements in public health, reduced deforestation and reduced reliance on imported fossil fuels, are added to the equation in a social cost benefit analysis (SCBA). There is no agreed upon methodology for quantifying these social benefits, so rigorous economic comparisons between biogas and other renewable as well as conventional energy sources are difficult.

In assessing the economic viability of biogas programs, it is useful to distinguish between four main areas of application: individual household units, community plants, large scale commercial animal rearing operations, and municipal/industrial projects. In each of these cases, the financial feasibility of individual facilities depends largely on whether outputs in the forms of gas (for cooking, lighting, power) and slurry (for use as fertilizer / soil conditioner, fishpond or animal feed) can substitute for costly fuels, fertilizers or feeds which were previously purchased. For example, a plant has a good chance of being economically viable when the farmers or communities previously paid substantial percentages of their incomes for cooking fuels (e.g., kerosene, coal) and/or fertilizers (e.g. urea). The economics may also be attractive in farming and industry where there is considerable cost involved in disposing of manure or effluent. In these cases the outputs can be sold or used to reduce energy costs, repaying the original capital investment. If outputs/products do not generate income or reduce cash outflow, then the financial viability of a biogas plant decreases; for example, when cooking fuels such as wood or dung can be collected at no financial cost, or where the cost of commercial fuel is so low then the market for biogas is limited.

If the broader SCBA criteria are used to evaluate anaerobic digestion, then determination of viability requires knowledge of real resource or opportunity costs of inputs and outputs. When such outputs, as improved public health, greater rural self-sufficiency, reduced deforestation, and reduced dependence on imported fossil fuels can be incorporated, SCBA analysis usually results in more positive conclusions than strictly financial analysis [7].

2.4.3 Biogas Programs in Developing Countries

Technical, social and economic factors, government support, institutional arrangements, and the general level of commercial activity in the construction of biogas plants and related equipment are highly interrelated. All influence the development of biogas programs. Focusing attention on any one aspect will not bring about successful results.

A large variation exists in the number of digesters installed in developing countries throughout the world, depending on the extent of government interest and support. Three countries China, India and the Republic of Korea have installed large numbers of units, ranging from some seven million plants in China to approximately 30,000 in Korea. Other countries have less than 1, 000 usually less than 200. Egypt has more than 500 units. Most countries rely on two basic designs, the floating cover and the fixed dome digester [2].

The relative poverty of most rural and urban people in developing countries and their concomitant lack of capital are real powerful economic considerations. Socially, program growth will be slow if facilities require a relatively large number of people to cooperate and alter their behaviors simultaneously. Commercial and private sector interest in anaerobic digestion is steadily increasing in conjunction with government tax policies, subsidies which alter prices of competing fossil fuels and fertilizers, and pollution control laws which all affect biogas program growth.

Institutional program infrastructure and government policies are the primary administrative and driving forces behind biogas implementation. With the exception of China, and possibly Brazil and India, the infrastructure to disseminate information on biogas to technical personnel, policy makers and potential users are somewhat fragmented. Both qualitative and quantitative assessments of ongoing activities are needed to improve technology and adapt its use to each specific country. Generally program coordination is relatively tenuous between indigenous research and development projects and implementing agencies. Biogas programs, which have expanded rapidly in the last decades, have had strong governmental support, including subsidized capital costs and tax incentives [2].

2.5 ENERGY STATUS IN PALESTINE

2.5.1 Introduction

Palestine has a proud history, as the cradle of civilization and as the focal point of the world's three monotheistic religions, it has a global influence, which greatly exceeds its small size.

"New" Palestine now consists of the West Bank and Gaza Strip, those two parts of the Historic Palestine were occupied by the Israeli army in 1967. Palestine national authority is today inhabited by almost three million people living in an area of about 6000 km^2. About 60% of the population is living in small rural communities [12].

2.5.2 Energy Sources

The energy sources in Palestine are very limited, there is no coal whatsoever, no oil or natural gas, and all energy consumed is imported from Israel. The demand for energy has grown continuously in recent years and it is expected to increase sharply (e.g. annual growth rate 12% of electricity, and more than 20% for petroleum). There is lack in electricity supply and > 13% of Palestinians are still not connected to the networks (4.5% without electricity, 8.5 % have partial electricity for 8hrs/day). These people are concentrated in the rural areas [9].

A number of key factors and characteristics shape the Palestinian Territories' energy sector; these are [8]:

- The lack of indigenous energy resources, with the exception of minor certain types of renewable like some wood, straw, olive residue…etc.
- The complete absence of the fossil energy forms, such as gas, coal, oil or nuclear, from the Palestinian Territories' energy balance.

- Complete dependency on imports of electricity and petroleum products from Israel.
- The severe problems and limitations encountered in the energy infrastructure, which are either non-existing (e.g. oil and gas pipelines), or old and highly inefficient (e.g. electricity production, transmission and distribution systems).
- The drastic increases in energy consumption recorded in recent years (see table), which are expected to intensify even more in the future. Annual growth rates of about 12% for electricity and more than 20% for petroleum products are expected in normal circumstances.
- The high-energy prices (see table 2-2), which are a combined result of Israel's monopoly on both electricity and petroleum products import, the very inefficient energy infrastructure systems, the high level of energy losses and the heavy taxation imposed.
- The lack of a coherent and well developed legal and institutional framework in the energy sector.

Table 2.1 Energy Demand and Growth Rate [8].

Fuel type	**1998**	**1999**	**2000**	**2001**	**Annual growth rate%**
Electricity	124.78	139.01	155.80	175.87	10(domestic),35(industry) 4(others)
Gasoline	246.86	283.90	326.48	375.33	15
Kerosene	12.30	12.54	113.79	118.09	2+airport needs
Diesel	275.61	330.66	516.72	600.79	20+ seaport needs
Fuel oil	12.16	14.59	114.87	122.27	20+steel industry
LPG	102.46	122.98	147.57	177.10	20
Solar	37.47	38.78	40.14	41.54	3.5
Biomass	49.16	49.90	50.63	51.41	1.5
Total	860.79	992.36	1466.02	1662.40	

Table (2.2) Electricity Prices in Palestine Compared with Other Neighboring Countries [8]**.**

State	Israel	Jordan	Palestinian territories 1*	Palestinian territories 2**
Price (US cent) per Kw	7.2	7.8	14.0	30.0

* Connected to the electrical network.

**Connected to own diesel generator.

2.5.3 Biogas Technology in Palestine

The biogas energy is considered one of the best alternative energy resources in the occupied Palestinian territories especially in rural areas. The rural areas are considered an excellent environment to construct biogas systems. Hence, previous studies indicated that 60% of Palestinian villagers have their own animals, which their wastes can be used for the generation of the biogas. The spare amount of biogas in occupied Palestinian territories is estimated to be about 33 million cubic meters per annum, which is equivalent to 13.2 million dollars. This amount represents 14% of the sum that spent on petroleum products according to 1987-1990 statics.[10]

i. The feasibility of using biogas in the occupied Palestinian territories

Previous studies indicate that the idea of constructing a biogas unit is acceptable because this technique suits with the conditions prevailing in the occupied Palestinian territories [3].

The situation in Palestine is special; there are no local authorities that could draw economic policy which includes technical plans as biogas technology. The development in Palestine is run mainly by non-governmental organizations (NGOs) who have different strategies and policies.

The construction of a biogas unit depends on many factors such as:

1. Availability of raw materials (bio-waste, animal waste, agriculture residues…etc.).
2. Suitable climate.
3. Availability of constructing materials and labor.
4. Energy needs and high costs.

ii. The importance of biogas technology for the Palestinian society:

When starting any development plan, man should consider many essential factors, such as the people should believe in the development plan and its economical and social benefits for its success. To reach the desired goal, we should use the suitable technology that passes with the prevailing local economic and social conditions.

It is to say that, the transmission of biogas technology to the Palestinian society will lead for deep changes inside this society, and the most important is the fuel development, and refresh the health conditions in the Palestinian cities, towns, villages and camps. This technology will create different job opportunities and save the money which can be used for other developmental purposes.

In order to use this technology in the Palestinian rural areas, we need to find the economic and social benefits for this technology and compare them with its costs (SCBA). This assessment will help in comparing between the biogas technology and other technologies which may give the same benefits.

In comparing between biogas technology and other technologies, the following factors should be considered:

1. Disposal of waste

Here, we should make comparison between the local traditional methods for the disposal of human and animal wastes and the method of using biogas technology, taking into account the following factors:

a. The high cost of transporting the human and animal wastes.
b. The danger on health caused by irrigation of crops with human organic wastes.
c. The environmental pollution that is caused by the removal of waste outside the villages and cities.
d. The bad smells emitted when fertilizing the agricultural lands with animal wastes directly.

2. Environmental Protection

Gathering the animals' wastes needs long time, which causes growth of mosquitoes and insects and spread the diseases. Nevertheless, the biogas technology is considered as a complete integrated system to protect the environment from pollution.

3. Socio-Economic Aspect

The animal waste contains high ratios of organic substances that can be used to produce energy whether by burning it directly as it is followed in many developing countries, or by using indirect methods as anaerobic fermentation to produce methane gas which is used as energy source.

2.5.4 Biogas Experiments in Palestine:

Compared to other countries in the world, the use of biogas technology in Palestine began lately where there are only three projects nowadays using this method:

1. Jericho digester (Pobay garden plant) :

It was constructed in spring 1998 with 5m3 effective volume; it produces about 1 m3 of biogas and 200 liters of natural fertilizer, this plant is used as demonstration model for the garden visitors to give an idea about the biogas production.

2. Agricultural college digester / An Najah University:

It was constructed in 2000, in Al-Khadori College for Agriculture at Tulkarm, to serve the farm that contains 15 cows.
The plant can produce $4m^3$ biogas and about 700 liter of natural fertilizer daily. Its volume is 14 m3 for the digester and 3 m3 for the fixed-dome which can store 60% of the daily production of the biogas.

3. Farajlla Farm In Idna

A biogas plant, following the Indian style was constructed in Farajlla farm in Idna near Hebron as a joint-project with the ministry of agriculture in Palestine.
This plant was constructed in 2002 with effective volume approx. 9 m3. Now this plant is abandoned due to financial difficulties.

2.5.5 Biogas production Sources in Palestine

1. Animal wastes :

Looking after animals and chicken forms a basic support for the rural areas economy. The development in rural areas t go parallel in increasing the rearing of the livestock. As a result, the animal wastes will increase can be treated in a good and suitable way to produce biogas and fertilizer. Table 2.3 shows the number of animals that exist in Palestine prior to the year 1999.

Table 2.3 Animal Number in Palestine Prior to 1999 [12].

Kind	Number
Cows	16000
Sheep	682000
Broiler chicken	29000000
Layer chicken	1900000

2. Agricultural wastes

Palestine is considered an agricultural country that produces various kinds of agricultural residues. These wastes can be used as feedstock to produce biogas. This can create new jobs for many people and saves the farmyard clean.

3. Domestic waste

The human wastes are not used to produce biogas in Palestinian rural areas because wastewater collection systems and treatment plants are not available. The biogas can be produced in some cities when sewerage networks function. Biogas can be extracted from the organic material available in the human wastes.

The human wastes prove to be rich in organic materials that can release good quantities of biogas when treated anareobically.

CHAPTER THREE
PROJECT AREA

3.1 HISTORICAL BRIEF

3.2 AREA AND TOPOGRAPHY

3.3 CLIMATE

3.4 GEOLOGY

3.5 MAIN OBJECTIVES OF THE STATION

3.6 THE FACILITIES AVAILABLE IN THE STATION

3.7 AL-ARROUB AGRICULTURAL SCHOOL

CHAPTER THREE
PROJECT AREA
AL-ARROUB STATION FOR AGRICULTURAL EXPERIMENTS

3.1 HISTORICAL BRIEF

Al- Arroub agricultural station was established in 1935, on a total agricultural land area of 285 dounums of Biet Ummar village just near to Al- Arroub camp, which is 12 km far away from the north of the Hebron city. The region is located 850 m above sea level and has a rainfall average of about 550 mm annually.(see fig. 3.1).
The main purpose of establishing the station at that time was to introduce the farming of fruit trees to the region. So, it was planted with all fruit trees species including different varieties of stone fruits, pome fruits, olive and others. The station considered as a big nursery support of fruit trees for the growers by providing them with seedlings.

In 1963, 120 dounms from its total area was cut to establish the nearest Arroub agricultural school. In 1967, its objectives were expanded to include working on cereals, vegetables and medical herbs. And its activities were expanded to hire 300 dounms in Al- Daheria village for dry land planting.

Recently, and due to the extreme need to develop the agricultural sector which is considered one of the most economic sectors in Palestine and after the arrival of the Palestinian Authority, a decision has been taken by the Ministry of Agriculture to convert Al-Arroub station into horticultural center in order to develop the fruit trees horticulture department in Palestine north districts. So that, they put a developmental plan aims at achieving a number of main and specific objectives.

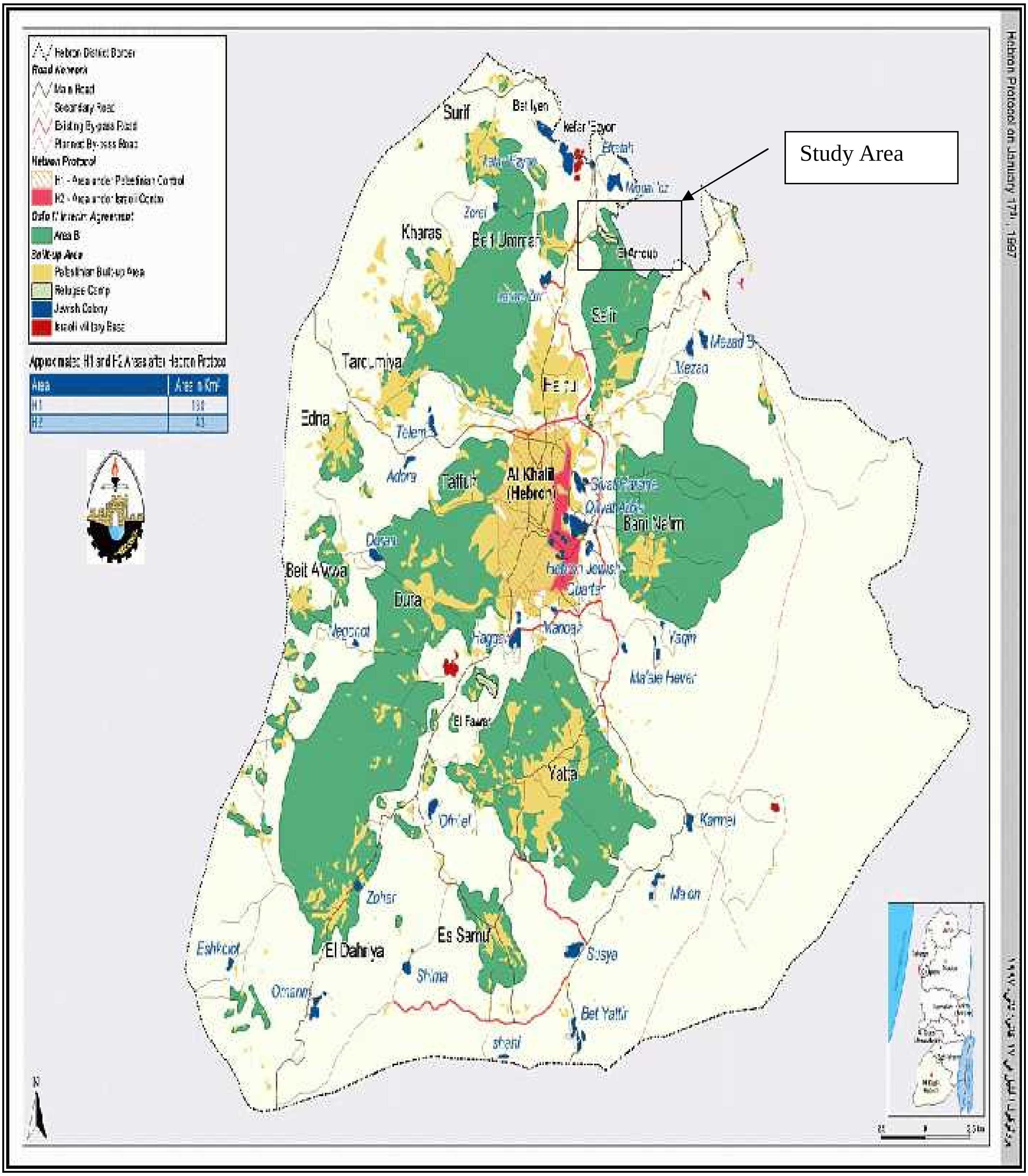


Fig. 3.1 Hebron District and the location of AFC to the north

3.2 AREA AND TOPOGRAPHY:

The area of the farm complex exceeds the 20 hectares (200donums). More than two thirds are rugged land and the rest is semi-plain land. The elevation difference between the lowest and the highest points within the farm vicinity ranges between 40- 55m. The lowest part is located to the east and the highest are those at the two hill tops to the north and south’s where a Wadi runs from west (upstream) to east (down stream) in between them. The W – E topographic slope is gentle and does not exceed the 3^o, while the slopes to the Wadi from the northern and southern hills may reach 10^o to 15^o.

With the farm vicinity, no topographic discrepancies such as saddles or canyons exist.

3.3 CLIMATE:

The average annual rainfall rate with the farmland way reach 550 mls. It usually snows every year there. Winds may exceptionally blow for shorter times in winter.

Minimum temperature is usual in mid winter (January) where they drop below 0 ^oC.

Maximum temperature is reach in mid summer (august) and may rise over 40 ^oC.

3.4 GEOLOGY:

The main outcropping facies within the farm vicinitys are from younger to older:

1. The terra rosa cover that covers most of the plain area (the Wadi). The terra rosa blanket varies in thickness from 2-2.5 m at the central part of the Wadi and wedges out to be very thin sheet directing away from the Wadi center.
2. The bedrock layer, which outcrops everywhere at the rugged land. The rocks are mainly composed of hard white to rose limestone, inter-bedded with

yellowish marlstone and marl pockets. The rock sequence is characterized by being highly fractured and jointed. This means it is a permeable formation and allows any seepage of fluidy waste to percolate to the ground water a aquifers.

The whole rock sequence is of Late Cretaceous time and belongs to the well-known Yatta lithgological formation.

3.5 MAIN OBJECTIVES OF THE STATION

1. To be a modern orchard that serves the scientific agricultural researches and experiments.
2. To be a scientific research center provided with best nursery technology and well equipped laboratories.
3. To be an extension center to provide the farmers with scientific information and to help them to adopt modern scientific agricultural techniques in their farms, and to conduct training courses for agronomists who are recently graduated or have little practical experience.

3.6 THE FACILITIES AVAILABLE IN THE STATION

- **The orcha**rd: New and old orchards, the old one planted with olive, figs, walnut, quince, apricot and pistachio.
- **Forest trees**: serves as wind blocks and fence purpose for some parts of the station.
- **Water resources**: well, natural spring, drip irrigation network and drinking unit source provided by the Palestinian authority.

- **Station staff**: station manager, agricultural engineers, lab. agricultural technical, technical workers, workers chief, tractor driver and 2 guards.
- **Machinery unit (parking):** contain 4 tractors, two of them are from the KR2 project, sprinkling tank, two trailers and different kinds of plowing tools.
- **Laboratory:** simple soil lab.
- **Meteorological substation** established in 1950.
- **Nurseries:** one nursery has been established for the production of forest transplants (seedlings) with a potential production of approximately 250000 seedlings in July/1999.
- **Experience:** continuous work since 1935.
- **Animal Farm:** Cow barn, poultry farm, rabbits, goats\sheep farm, Layers chicken farm.

3.7 AL-ARROUB AGRICULTURAL SCHOOL

It was established in 1964/1965 near Al-Arroub Station for Agricultural. It has about 120 dounum. This land full of trees that give the beautiful sense. The number of student is 200 students. In this school the student studies the agricultural information's and technique and they take essential experience for agricultural skills.

The school is divide into five parts:-

1. Animal production part.
2. Agricultural production part.
3. Bees part
4. Agricultural apparatus part.
5. Foods industrial part.

Table 3.1 shows the animal number in animal production part that wastes can be used to produce biogas and organic fertilizer. The waste of these animals will be used in the present project.

Table 3.1 Animal Number in Animal Production Part at AFC (Personal data collection).

Kind	Number
Cows	55
Sheep	40
Broiler chicken	1000
Layer chicken	1000

CHAPTER FOUR

BIOGAS PLANT

4.1 HOW DOES A BIOGAS PLANT WORK

4.2 AEROBIC AND ANAEROBIC TREATMENT

4.3 THE ANAEROBIC DIGESTION

4.4 LOCATION OF THE BIOGAS PLANT

4.5 PARTS OF BIOGAS PLANT

4.6 TYPES OF BIOGAS PLANTS

4.7 THE ENVIRONMENTAL FACTORS THAT AFFECT AN AEROBIC DIGESTION

4.8 OTHER FACTORS THAT AFFECT ANAEROBIC DIGESTION

CHAPTER FOUR
BIOGAS PLANT

4.1 HOW DOES A BIOGAS PLANT WORK?

Biogas plant assists surrounding farmers in their disposal of animal manure by digesting it in order to create a homogeneous fertilizer.(see Figure 4.1) In addition to the animal manure, the plants also use organic material from slaughterhouse, fishing industry, tanneries, breweries, dairies, oil mills, and the drug industry to produce the fertilizer. The mix is normally approximately 80% animal manure and 20% organic material. The farms that provide the animal manure can use the fertilizer or it can be sold to any farm or industry wishing to replace chemical fertilizer with a cheaper alternative. Biogas plants also gas through an anaerobic digestion process. Heating and power plants can use the gas produced to create energy.

Generally the raw waste material is transported to the biogas plant for disposal. The waste then undergoes anaerobic digestion.

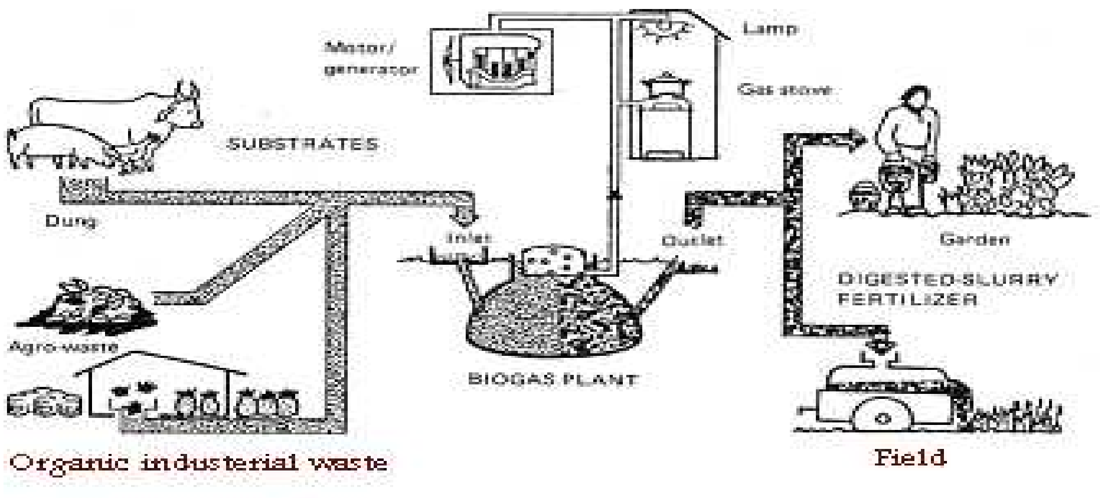


Figure 4.1 Typical Biogas System Configuration

4.2 AEROBIC AND ANAEROBIC TREATMENT

As both a chemical and biological process anaerobic treatment is completely different from aerobic treatment. Aerobic organisms have a ready electron acceptor in the form of oxygen (O_2) while anaerobic digestion is strongly regulated by finding thermodynamically suitable electron acceptors. In many cases, ionic hydrogen (protons) or bicarbonate acts as an electron acceptor to produce hydrogen gas or format as product. Anaerobic treatment has advantages over aerobic treatment in that there are no power requirements for air supply, the methane can be used for energy production and there is a much lower sludge production. Aerobic degradation of organics yields much more energy than anaerobic degradation. Comparisons are deceptive, as the end products, and correspondingly free energy yields are different, but complete aerobic digestion of glucose to carbon-dioxide yields up to 38 mole ATP/mole glucose while anaerobic fermentation to mixed organic acids yields 2-4 mole ATP/mole glucose [1].

4.3 THE ANAEROBIC DIGESTION

The animal manure and organic waste are mixed in a pre-processing tank. The mix is then moved into gas tight digesting tank where the digestion process takes place.
Digestion refers to various reactions and interactions that take place among the methanogenes, non-methanogenes and substrates fed into the digester as inputs. This is a complex physiochemical and biological process involving different factors and stages of change. This process of digestion (methanization) is summarized below in its simple form.

During the digestion process, the mix is heated and bacterial culture, consisting of natural bacteria that adapts to the individual plant over a few weeks or months are added to ensure digestion. The digestion process is completely anaerobic, done without oxygen. bacteria, ferment polysaccharides, lipids and proteins into acetic acid, H_2 and CO_2, one carbon compounds, the hydrogen producing acetogenic bacteria ferment organic acids like butyrate and propionate, ethanol and propanol to hydrogen and acetate, the homo acetogenic bacteria convert carbon compounds to acetic acid and the methanogens, ferment H_2 and CO_2 and acetate into methane. In the absence of dissolved oxygen, aerobic micro-organisms lend to ferment biodegradable matter to carbon dioxide and methane".

After digestion is completed a usable gas (Methane and Carbon dioxide) and a liquid fertilizing agent are produced.

The breaking down of inputs that are complex organic materials is achieved through three stages as described below:

Stage 1: Hydrolysis:

The waste materials of plant and animal origins consist mainly of carbohydrates, lipids, proteins and inorganic materials. Large molecular complex organic substances are solubilized into simpler ones with the help of extracellular enzyme released by the bacteria.

This stage is also known as polymer breakdown stage.

For example, the cellulose consisting of polymerized glucose is broken down to dimeric, and then to monomeric sugar molecules (glucose) by cellulolytic bacteria.

Stage 2: Acidification:

The monomer such as glucose which is produced in stage 1 is fermented under anaerobic condition into various acids with the help of enzymes produced by the acid forming bacteria. At this stage, the acid-forming bacteria break down molecules of six atoms of carbon (glucose) into molecules of less atoms of carbon (acids), which are in a more reduced state than glucose. The principal acids produced in this process are acetic acid, propionic acid, butyric acid and ethanol.

Stage3: Methanization:

The principle acids produced in stage 2 are processed by methanogenic bacteria to produce methane. The reactions that take place in the process of methane production are called Methanization and are expressed by the following equations:

$CH_3COOH \longrightarrow CH_4 + CO_2$

Acetic acid Methane Carbon dioxide

$2CH_3CH_20H + CO_2 \longrightarrow CH_4 + 2CH_3COOH$

Ethanol

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

Hydrogen Water

The above equations show that many products and intermediate products are produced in the process of digestion of inputs in anaerobic condition before the final product (methane) is produced.

The digestion process is continuous in order to ensure a constant supply of bacterial culture and stable gas production. In a given day, the digestion tanks are emptied of gasified material and mixed raw material is pumped in. Raw material takes anywhere from 12 to 25 days to digest completely depending on heat, raw material and bacteria culture. Most plants use thermophilic bacteria operating at 50-53 ºC as opposed to mesophilic bacteria that requires temperature of 30-40 ºC. The use of themophilic bacteria has two advantages: the process takes a shorter time compared to mesophilic digestion and the high temperature ensures a sanitary output.

4.4 LOCATION OF THE BIOGAS PLANT

The location of a biogas unit is a crucial factor to its success as well as to other environmental sanitation requirements. The plant should not be located further than 5 meters from the enclosure. The digester chamber must be in an open area and should not be near any water source or natural water as animal excrement may seep into underground water. The plant should also be situated on a slope and not on the low land to avoid the danger of floods. The excess manure from effluent-receiving chamber should flow into the farmer's field or the storage tank and not into natural water bodies such as rivers or lakes to avoid the risk of pollution.[6]

The following guidelines are helpful for choosing an ideal site for the project:

1. Biogas units must be at a place where water table is low, the maximum that water table may be allowed to rise is 1/2 of the height of the digester. If water table of a tentatively selected site is too high, we should look for another site.
2. It must be located as much as possible downhill or downstream with respect to a well or any water source. Ideally the minimum distance between a biogas unit and a well should be 15-20 meters to avoid water contamination in cases of leaks in the digester.
3. Should be not far from the house or the point of gas utilization to save gas piping cost, but at the same time close as possible to the source of raw materials such as cow barn or biowastes source. This is also to save transport labor and thus guarantee normal gas production.
4. Should be "where there is suitable soil and foundation conditions.(soil not weak)
5. Should "be away from big roots of trees that may damage the structure.
6. Since the biogas unit is completely "underground it could be place either
   a. Near the house, but in an open area which is exposed to sunlight and therefore heat, for greater gas production.

b. Underneath the house/kitchen or under the animal stalls (which arrangement is common in cold places to protect the digester from extremely low temperature).

7. Raw materials (manure, urine, wash water) should be able to "automatically" feed, via sloped canals or troughs, by the force of gravity to the mixing pit/inlet. This is advisable for increased efficiency and to decrease labor cost of hauling and/or lifting the manure.
8. The site should be close to where the effluent is to be used or stored like a vegetable garden or a compost pit.[5]

4.5 PARTS OF BIOGAS PLANT

There are many available simple and developing biogas plants to produce biogas. These plants are developed in European and developing countries.

However, a typical biogas plant consists of:

1. Mixing chamber: where animal excrement is mixed with water before it is poured into digester chamber. It varies in size and shape according to the nature of substrate. It is equipped with propellers for mixing and/or chopping the substrate. At times, the substrate is often pre-heated in the mixing pit in order to avoid a temperature shock inside the digester.

2. Digester or main chamber: where excrement and water are fermented. Methane and other gases will be produced in this chamber and these gases will push manure and slurry at bottom of the floor into mixing chamber. The digester is insulated and made of concrete or steel. To optimize the flow of substrate, large digesters have a longish channel form. Large digesters are almost always agitated by slow rotating paddles or rotors or by injected biogas.
3. Expansion or effluent chamber: receives excess manure and slurry. When gas is being used, manure and slurry will flow back into digester chamber to push gas

up for usage. When the excess manure exceeds the volume of the chamber, the manure will be drained out.

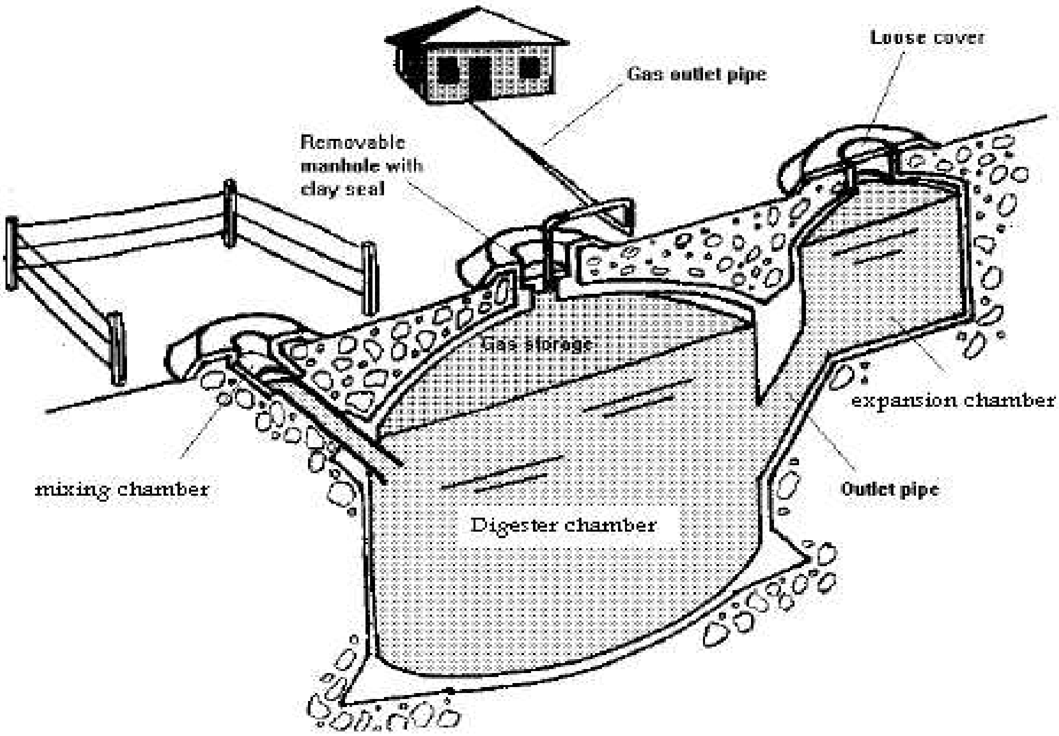


Figure 4.2 Parts of Biogas Plant [22].

This system is called dynamic system, when gas is produced inside the pit, the gas pressure will push manure and slurry at the bottom of the pit to flow up into the expansion chamber. When this gas is used the slurry in the expansion chamber will flow back into the digester chamber to push the gas up for usage. This happens consistently. The plant will be operated efficiently for a long period of time if the gas pit does not cracked and the system runs regularly. In each case the strength of the plant depends on fine construction, specification of materials according to the criteria suggested by the Biogas Program.

4.6 TYPES OF BIOGAS PLANTS

Three main familiar types of simple biogas plants can be distinguished:

4.6.1 Fixed – Dome Plant

A fixed-dome plant (Figure 4.3) consists of an enclosed digester with affixed, non-movable gas space. The gas is stored in the upper parts of the digester. When gas production commences, the slurry is displaced in to the compensating tank. Gas pressure increase with the volume of gas stored, there fore the volume of the digester should not exceed 20 m^3. If there is a little gas in the holder, the gas pressure is low. If the gas is required at constant pressure (e.g. for engines), agas pressure regulator or a floating gasholder is required. Engines required a great deal of gas, and hence large gasholder. The gas pressure then becomes too high if there is no floating gasholder.

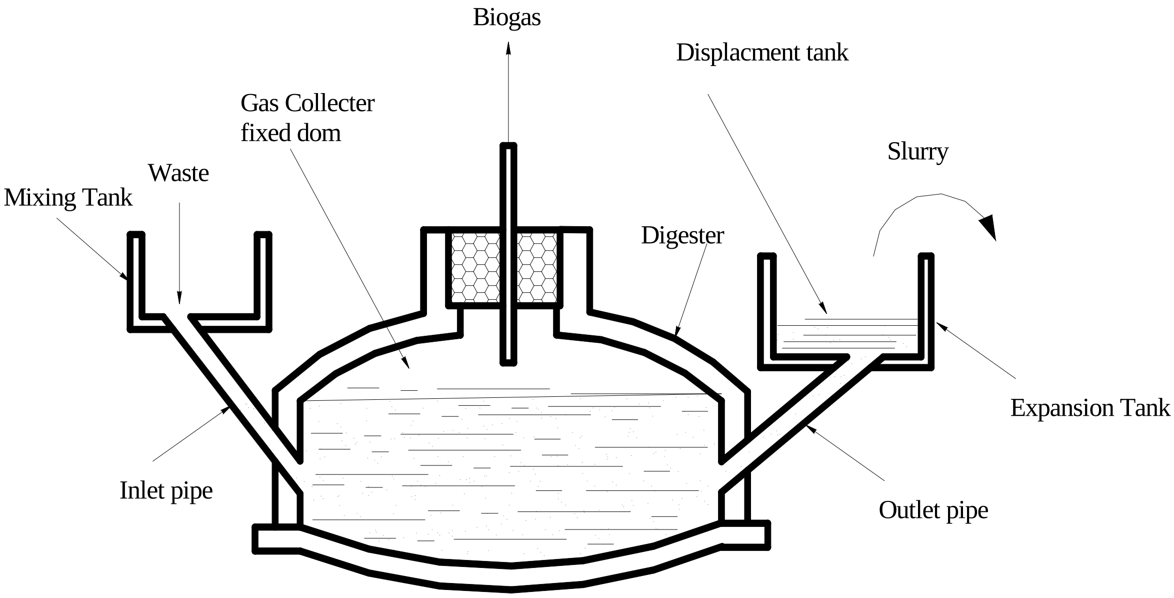


Figure 4.3 Fixed Dome Plant [7].

Advantages:

Low construction cost, no moving part, no rusting steel parts, hence long life (20 years or more), underground construction; protecting from physical damage and saving space. While the underground digester is protected from low temperatures at night and during cold seasons, creates employment locally.

Disadvantages:

Plant often not gas tight (porosity and cracks), gas pressure fluctuates substantially and is often very high, low digester temperature.

Fixed-dome can be recommended only where construction can be supervised by experienced biogas technicians.

4.6.2 Balloon Plant

A balloon plant consists of a plastic or rubber digester bag, (see Figure 4.4) in the upper part of which the gas is stored. The inlet and out let are attached direct to the skin of the balloon. When the gas space is full, the plant works like a fixed –dome plant. i.e. the balloon is not in flated ; its not very elastic. The fermentation slurry is agitated slightly by the movement of the balloon skin. This is favorable to the digestion process. Even difficult feed materials must be UV-resistant. (Upper Violet). Materials which have been used successfully include RMP (red mud plastic), trevira and butyl [7].

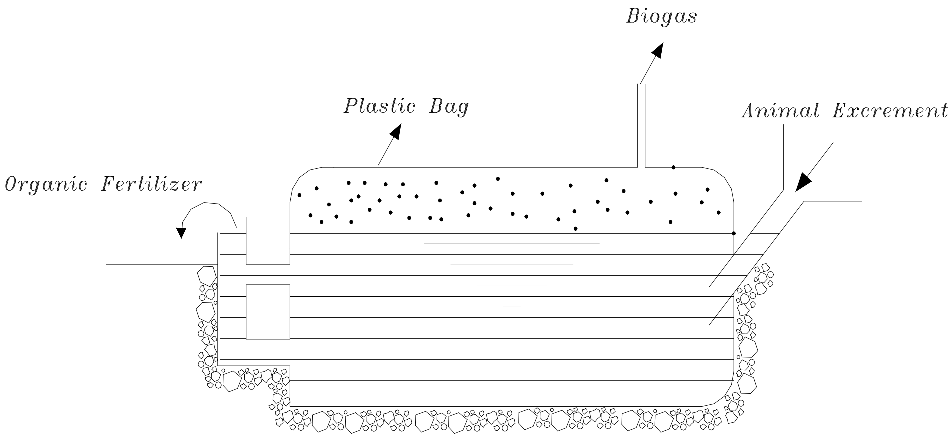


Figure 4.4 Balloon Plant [7].

Advantages:

Low coast, ease to transportation, low construction (important if water table is high), high digester temperature, uncomplicated cleaning, emptying and maintenance.

Disadvantages:

Short life (about five years), easily damage, does not create employment locally, little scope for self-help, hard to repair in emergency cases.

Balloon plant can be recommended wherever the balloon skin is not likely to be damage and where the temperature is even and high. One variant of the balloon plant is the channel-type digester with folia and sunshade. (See the Figure 4.4).

4.6.3 Floating – Drum Plant

Floating-drum plant (Figure 4.5) consists of digester and moving gasholder. The gasholder floats either direct on the fermentation slurry or in the water jacket of its own. The gas collects in the gas drum, which there by rise. If gas is drawn off, it falls again. The gas drum is prevented from tilting by a guide frame.

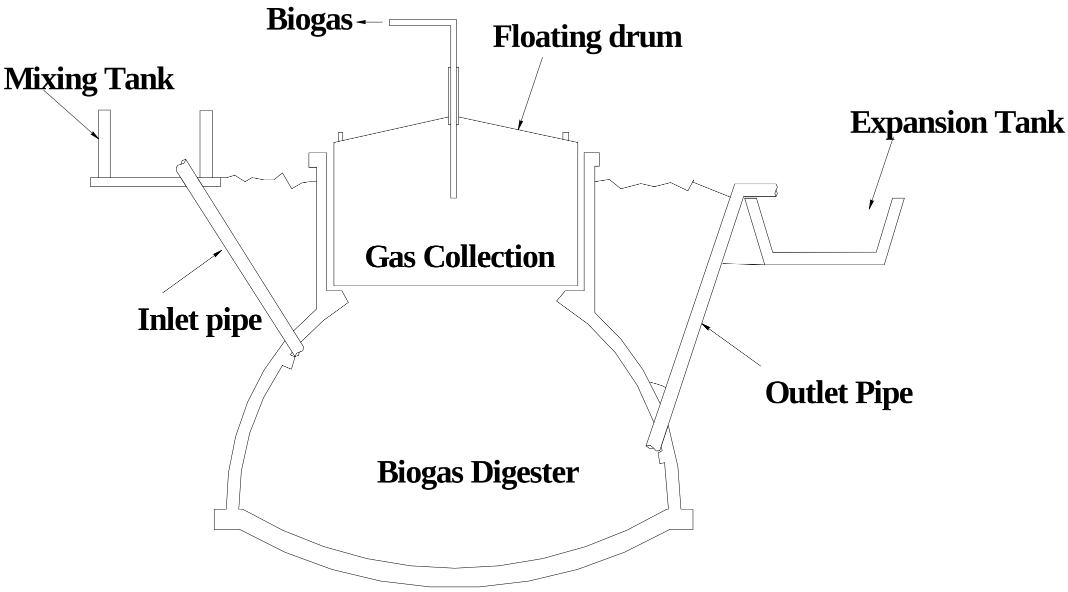


Figure 4.5 Floating Drum Plant [1].

Advantages:

Simple, easily understood operation, constant gas pressure, volume of stored gas visible directly, few mistake in construction.

Disadvantages:

High construction cost of floating-drum, many steel parts liable to corrosion, resulting in short life (up to 15 years; in tropical coastal regions about 5 years for the drum), and regular maintenance costs due to painting.

In spite of these disadvantages, floating-drum plants are always to be recommended in cases of doubt. Water jacket plants are universally applicable and especially easy to maintain. The drum won’t stick, even if the substrate has high solids content [7].

Floating-drum made of glass fiber reinforced plastic and high-density polyethylene has been used successfully, but the construction is higher than with steel. Floating-drums made of wire-mesh-reinforced concrete are liable to hairline cracking and are intrinsically porous. They require a gas tight, elastic internal coating. PVC drums are unsuitable because not resistant to UV.

The floating gas drum can be replaced by balloon above the digester. This reduces struction coats (channel type digester with folia), but in the practice problem always arise with the attachment of the balloon at the edge. Such plants are still being tested under practical conditions.

4.7 THE ENVIRONMENTAL FACTORS THAT AFFECT ANAEROBIC DIGESTION

Environmental factors, which influence biological reactions, such as pH, temperature, nutrients and toxicant concentrations, are amenable to external control in the anaerobic digestion process.

a. pH

Acetate and fatty acids produced during digestion tend to lower the pH of digester liquor. However, the ion bicarbonate equilibrium of the carbon dioxide in the digester exerts substantial resistance to pH change.

This resistance, known as buffer capacity or buffer intensity, is quantified by the amount of strong acid (or base) added to the solution in order to bring about a change in pH. Thus the presence of bicarbonate helps prevent adverse effects on microorganisms (methanogens), which would result from low pH caused by excessive production of fatty acids during digestion. The higher the concentration of bicarbonate in the solution, the greater the buffering capacity and the resistance to changes in pH.

Most microorganisms grow best under neutral pH conditions, since other pH values may adversely affect metabolism by altering the chemical equilibrium of enzymatic reactions, or by actually destroying the enzymes.

The methanogenic group of organisms is the most pH sensitive. Low pH could cause the chain of biological reactions in digestion to cease.

There are two main operational strategies for correcting an unbalanced, low pH condition in a digester. The first approach is to stop the feed and allow the methanogenic population time to reduce the fatty acid concentration and thus raise the pH to an acceptable level of at least 6,8, Stopping the feed also slows the activity of the fermentative bacteria and thus reduces acid production. Once the pH returns to normal, feeding can be recommenced at reduced levels and then increased gradually so as to avoid further drops in pH.

A second method involves addition of chemicals to raise the pH and provide additional buffer capacity. Reducing the feed rate in conjunction with chemical addition may be necessary in some cases. An advantage of chemical addition is that the pH can be stabilized immediately and the unbalanced populations allowed to correct themselves more quickly.

Calcium hydroxide (lime) is often used Sodium carbonate (soda ash), while more expensive, can prevent calcium carbonate precipitation. Ammonia is also useful, but must be used with care to avoid toxicity.[2]

b. Temperature

The metabolic and growth rates of chemical and biochemical reactions tend to increase with temperature, within the temperature tolerances of the microorganisms. Too high a temperature, however, will cause the metabolic rate to decline due to degradation (denaturing) of enzymes, which are critical to the life of the cell. Microorganisms exhibit optimum growth and metabolic rates within a well defined range of temperatures which is specific to each species, particularly the upper limit which depends on the thermostability of the protein molecules synthesized by each particular type of organism.

Methanogenic bacteria are more sensitive to changes in temperature than other organisms present in digesters. This is due to the faster growth rate of the other groups, such as the fermenters which can achieve substantial catabolism even at low temperatures. All bacterial populations in digesters are fairly resilient to short term temperature upsets up to about two hours, and return rapidly to normal gas production rates when the temperature is restored. However, numerous or prolonged temperature drops can result in unbalanced populations and lead to the low pH problems discussed in the previous section. Temperature variations as small as 2°C can have adverse affects on mesophilic (~35°C) digestion or 0.5°C with thermophilic (~55°C) digestion.

Two distinct temperature regions for digestion of sewage sludge have been noted. Optimum digestion occurs at about 35°C (mesophilic range) and 55°C (thermophilic range), with decreased activity at around 45°C (see Figure 4.6). This response to temperature may be due to effects on methanogenic bacteria, since these appear to exhibit similar optimal.

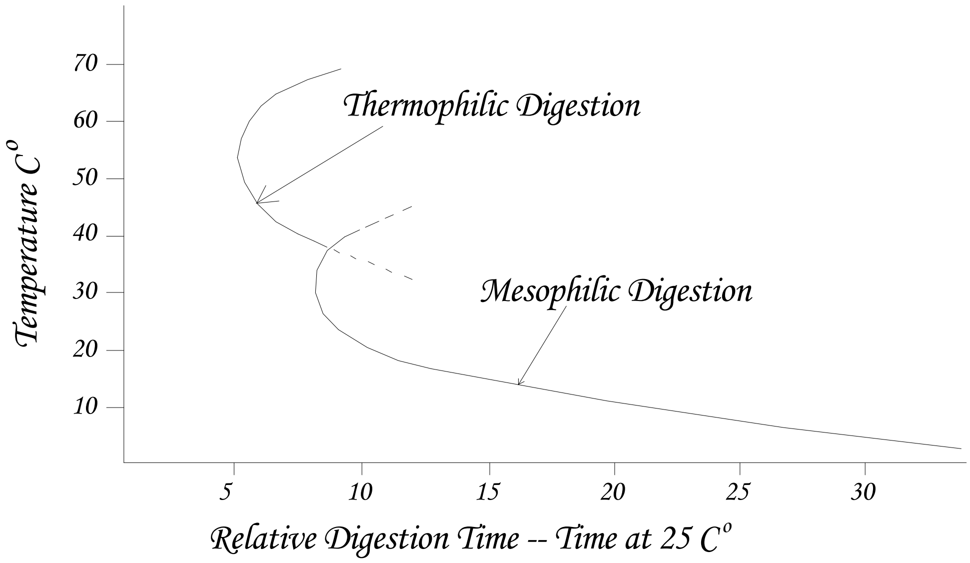


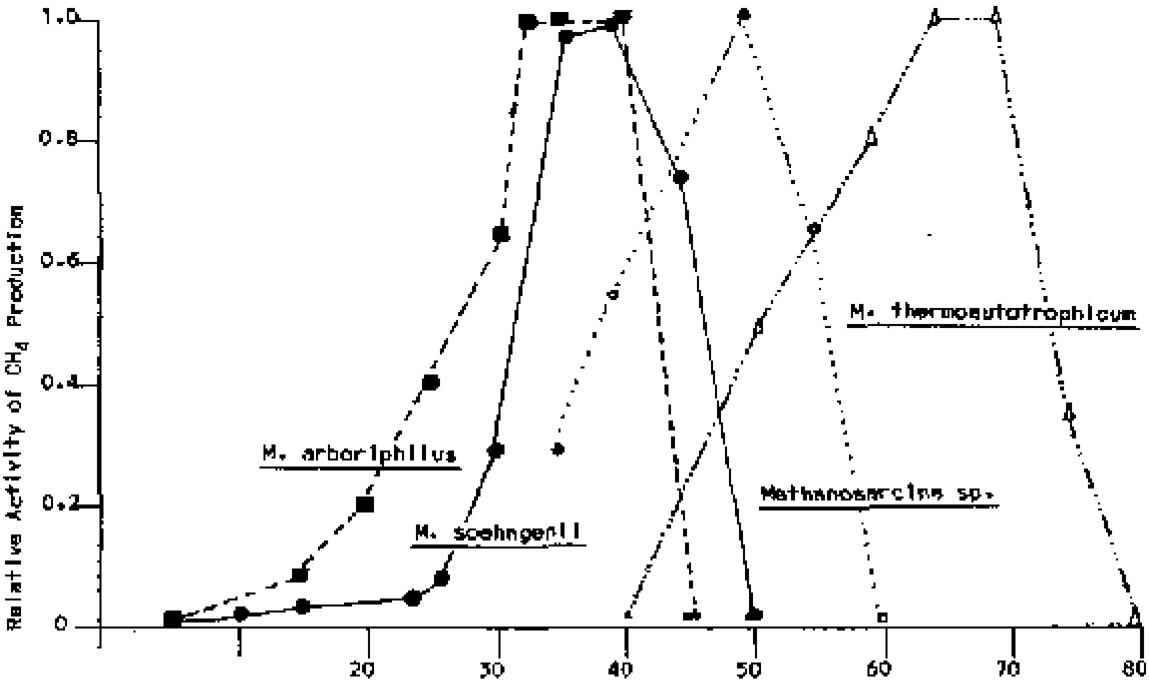
Figure 4.6 Relative Digestion Time of Plain-Sedimentation Sludge digested at Temperatures of 10 °C to 70 °C [2]**.**

Digestion time refers to time required at 25 °C. Regions (see Figure 4.7). Well defined mesophilic and thermophilic regions have been noted for activated sludge and refuse feedstocks.

For beef cattle manure, raw sewage sludge, and some agricultural residues the regions are generally the same, although not so well defined.

An advantage of thermophilic digestion is that the rate of methane production is approximately twice that of mesophilic digestion, so reactors can be half the volume of mesophilic digesters and still maintain the same overall process removal efficiencies. Strong, warm, soluble industrial wastes give high volumetric gas yields of up to eight volumes of gas per volume of digester per day with immobilized cell designs. With warm (~55°C) wastes this has obvious advantages. However, with wastes, which are at ambient temperatures, such as animal manures, considerable energy is needed to raise the temperature of the waste to 55 °C. A number of detailed studies of gas yields and energy consumption have been carried out.

Scientists found that thermophilic digesters could accept higher organic loads than mesophilic systems at the same detention time (O). This advantage became more pronounced as the detention time decreased. With cattle manure at 12% total solids and O = 6 days they obtained volumetric gas yields of 5.5 (versus 3.0 at mesophilie), and found that only 20% of the energy produced was used for heating and mixing.



Temperature co

Figure 4.7 The Effect of Temperature on Methanogens [2].

However, using dairy manure at 15.8% total solids, found that thermophilic operation (O 6.2, T = 60° C) gave lower net energy yields than mesophilic operation (O = 10.4, T =35°C). It was found that mesophilic cultures gave higher methane yield per pound of volatile solids added than thermophilic, and that thermophilic cultures were more unstable and sensitive to mechanical or operational disruptions. This point has been raised by a number of researchers, although there is disagreement as to how unstable thermophilic digestion is. Full scale mechanically stirred thermophilic systems require temperature controls of ±0.5°C while mesophilic systems tolerate variations of ±2 °C.

Thermophilic digestion gave a higher net energy production per unit of capital cost than mesophilic digestion. Excellent results were obtained with an influent concentration of 8 to 10% volatile solids and detention times of four to five days.[2]

c. Nutrient Effects

In addition to an organic carbon energy source, anaerobic bacteria appear to have relatively simple nutrient requirements, which include nitrogen, phosphorus, magnesium, sodium, manganese, calcium, and cobalt

Nutrient levels should be at least in excess of the optimum concentrations needed by the methanogenic bacteria, since these are the most severely inhibited by slight nutrient deficiencies. Nutrient additions are often required in order to permit growth in digestion of simple substrates such as glucose, substrates such as industrial wastes, and crop residues. However, nutrient deficiency should not be a problem with most complex feedstocks, since these substrates usually provide more than sufficient quantities.

An essential nutrient can become toxic to organisms if its concentration in the substrate becomes too great (see section d). In the case of nitrogen, it is particularly important to maintain an optimal level to achieve good digester performance without toxic effects.

d. Toxicity Effects

Toxic compounds (see Table 4.1) affect digestion by slowing down the rate of metabolism at low concentrations or by poisoning or killing the organisms at high concentrations. The methanogenic bacteria are generally the most sensitive, although all groups involved in digestion can be affected. Due to their slow growth, inhibition of the methanogens can lead to process failure in completely mixed systems due to washout of bacterial mass.

In order to control and adjust operation to minimize toxic effects, it is important to identify inhibition in its early stages. The two main inhibition indicators are:

1. Reduction in methane yield over time, indicated by two or more consecutive decreases of more than 10% in daily yield at a constant loading rate.
2. Increase in volatile acids concentration over time, generally occurring when the total volatile acids (expressed as acetic acid) exceed the normal range of about 250 to 500 milligrams per liter.

The major toxicants usually encountered with natural feedstocks are ammonia (NH_3, NH_4), volatile acids, and heavy metals.

Table 4.1: Toxic level of various inhibitors [24]**.**

Inhibitors	**Inhibiting Concentration**
Sulphate (S04--)	5.00 ppm
Sodium Chloride (NaCL)	40.00 ppm
Nitrate (Calculated as N)	0.05 mg/ml
Copper (Cu^{++})	lOOmg/1
Chromium (Cr^{+++})	200 mg/1
Nickel (Ni^{+++})	200-500 mg/1
Sodium (Na^{+})	3.500-5.500 mg/1
Potassium (k^{+})	2.500-4.500 mg/1
Calcium (Ca^{++})	2.500-4.500 mg/1
Magnesium (Mg^{++}	1.00-1.500 mg/1
Manganese (Mn^{++})	Above 1.500 mg/1

e. Ammonia

Ammonia toxicity is often a problem in feedstocks with high protein content. Ammonia (NH_3) is rapidly formed in a digester by deamination of protein constituents. Free ammonia has been found to be much more toxic than ammonium ion (NH_4), and thus ammonia toxicity thresholds are very sensitive to pH below seven. In general, free ammonia levels should be kept below about 80 milligrams per liter to prevent inhibition. A much higher concentration of about 1,500 to 3,000 milligrams per liter of ammonium ion can be tolerated. Concentrations of free ammonia and ammonium ion are related by equilibrium reactions and pH.

f. Volatile Acids

High concentrations of volatile acids such as acetate, propionate or butyrate are associated with toxicity effects. It is not clear whether these acids are themselves toxic, or whether acid buildup (pH <6.8) is merely a manifestation of toxicity. Among these acids, inhibitory effects have been demonstrated only for propionate, and only at relatively high concentrations of greater than 1,000 milligrams per liter.

g. Heavy Metals

Certain heavy metals are toxic to anaerobic organisms, even at low concentrations. Heavy metal ions inhibit metabolism and kill organisms by inactivating the sulfhydryl groups of their enzymes in forming mercaptides. Since these reactions involve metal ions, it is the soluble fraction that is the toxic form and toxic effects are thus affected by the solubilities of heavy metals under various digester conditions. Since many heavy metals form insoluble sulfides or hydroxides under pH conditions in the range of those found in digesters, one, way to avoid heavy metal toxicity is to add chemicals such as sulfates which will form non-toxic complexes or insoluble precipitates. Toxic substances can also be removed from the feedstock or diluted to below the toxic threshold level.

h. Influence of Carbon / Nitrogen (C/N) Ratio on Digestion

Nitrogen presence in the feedstock has two benefits:

1. It provides an essential element for synthesis of amino acids, enzymes and protoplasm.
2. It is converted to ammonia, which, as a strong base, neutralizes the volatile acids produced by fermentative bacteria, and thus helps maintain neutral pH conditions essential for cell growth.

An overabundance of nitrogen in the substrate can lead to excessive ammonia formation, resulting in toxic effects (see above). Thus it is important that the proper amount of nitrogen be in the feedstock to avoid either nutrient limitation (too little nitrogen) or ammonia toxicity (too much nitrogen). The carbon/nitrogen (C/N) ratio of the feedstock has been found to be a useful parameter in evaluating these effects and providing optimal nitrogen levels. A C/N ratio of 30 is often cited as optimum. Since not all of the carbon and nitrogen in the feedstock are available to be used for digestion, the actual available C/N ratio is a function of feedstock characteristics and digestion operational parameters, and overall C/N values can actually vary considerably from less than 10 to over 90 and still result in efficient digestion (see Table 4.2)

Table 4.2 C/N ratios in many selected raw materials [24].

Raw Materials	C/N Ratio
Raw Materials	8
Duck dung	8
Human excreta	10
Chicken dung	12
Goat dung	18
Pig dung	19
Sheep dung	24
Cow dung / Buffalo dung	25
Water hyacinth	43
Elephant dung	60
Straw (maize)	70
Straw (rice)	90
Straw (wheat)	Above 200

4.8 OTHER FACTORS THAT AFFECT ANAEROBIC DIGESTION

a. Dilution and consistency of inputs:

Before feeding the digester, the excreta, especially fresh cattle dung, has to be mixed with water at the ratio of 1:1 on a unit volume basis (i.e. same volume of water for a given volume of dung). However, if the dung is in dry form, the quantity of water has to be increased according 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 from 7 to 10 percent. If the dung is too dilute, the solid particles will settle down into the digester and if it is too thick, the particles impede the flow of gas formed at the lower part of digester. In both cases, gas production will be less than optimum. For thorough mixing of the cow dung and water (slurry), GGC has deviced a slurry Mixture Machine that can be fitted in the inlet of digester. It is also necessary to remove inert materials such as stones from the inlet before feeding the slurry into the digester. Otherwise, the effective volume of the digester will decrease.

b. Loading Rate:

Loading rate is the amount of raw materials fed per unit volume of digester capacity per day.

About 6 kg of dung per m^3 volume of digester is recommended in case of a cow dung plant. If the plant is overfed, acids will accumulate and methane production will be inhibited. Similarly, if the plant is underfed, the gas production will also be low.

c. Retention Time (O):

Retention time (also known as detention time) is the average period that a given quantity of input remains in the digester to be acted upon by the methanogens. In a cow dung plant, the retention time is calculated by dividing the total volume of the digester by the volume of inputs added daily, considering the climate conditions around the digester. A retention time of 40 to 50 days seems desirable. Thus, a digester should have a volume of 40 to 50 times the slurry added daily. But for a night soil biogas digester, a longer retention time (60 to 70 days) is needed so that the pathogenes present in human faeces are destroyed. The retention is also dependent on the temperature and up to 35 degrees C, the higher the temperature, the lower the retention time.

CHAPTER FIVE

DESIGN AND CONSTRUCTION OF PLANT COMPONENTS

5.1 DESIGN AND CONSTRUCTION OF PLANT COMPONENTS

5.2 AL-ARROUB BIOGAS PLANT DESIGN

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Biogas plants of simple design consist of the following main components:

1. Mixing pit.
2. Inlet/outlet (feed/discharge pipes).
3. Digester.
4. Gasholder.
5. Slurry store.

Depending on the available building material and type of plant under construction, different variants of the individual components are possible.

5.1.1 Mixing pit

In the mixing pit, the substrate is diluted with water and agitated to yield a homogeneous slurry.

The fibrous material is raked off the surface, and any stones or sand settling to the bottom are cleaned out after the slurry is admitted to the digester.
The useful volume of the mixing pit should amount to 1.5-2 times the daily input quantity. A rubber or wooden plug can be used to close off the inlet pipe during the mixing process. A sunny location can help warm the contents before they are fed into the digester in order to preclude thermal shock due to the cold mixing water [7].

The optimal mixing ratios of many types of feedstock are shown in table (5-1) below.

Table 5.1: Common substrate mixing ratios [1].

Type of substrate	Substrate : Water
Fresh cattle manure	1 : 0.5 – 1
Semi-dry cattle dung	1 :1 – 2
Pig dung	1 :1 – 2
Cattle and pig dung from a floating removal system	1 : 0
Chicken manure	1 : 4 - 6
Stable manure	1 : 2 - 4

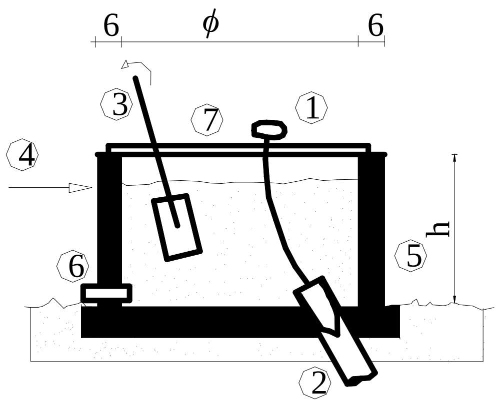

Figure 5.1: Mixing pit: 1. Plug, 2. Fill pipe, 3. Agitator, 4. Fibrous materials, 5. Sand, 6. Drain, 7. Screen cover [7].

In the case of a biogas plant that is directly connected to animal housing, it is advisable to install the mixing pit deep enough to allow installation of a floating gutter leading directly into the pit. Care must also be taken to ensure that the low position of the mixing pit does not result in premature digestion and resultant slurry formation. For reasons of hygiene, toilets should have a direct connection to the inlet pipe.

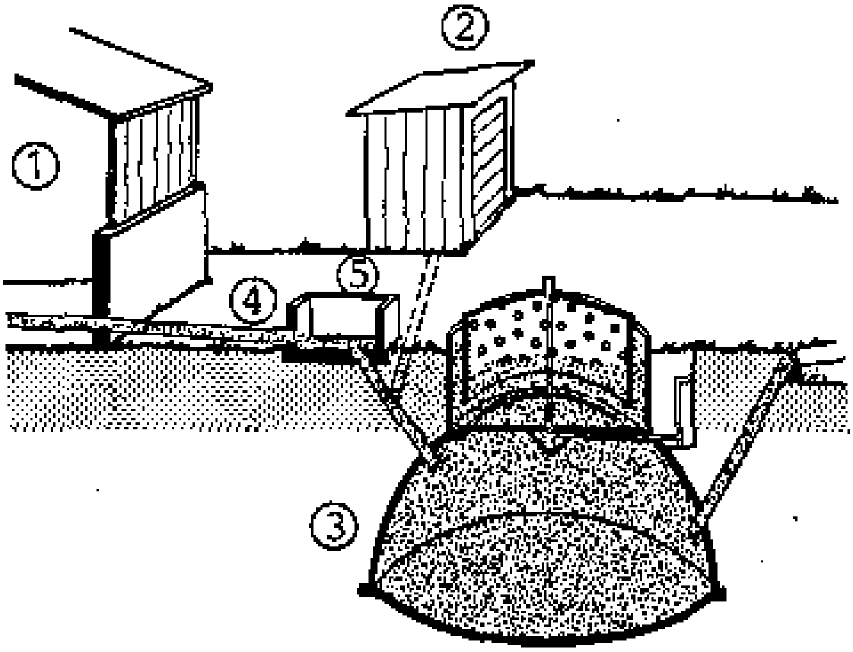

Figure 5.2: Mixing pit, gutter and toilet drainpipe. 1 Barn, 2 Toilet, 3 Biogas plant, 4 Feed gutter (2% gradient). 5 Mixing pit [7].

5.1.2 Inlet and outlet

The inlet (feed) and outlet (discharge) pipes lead straight into the digester at a steep angle. For liquid substrate, the pipe diameter should be 10-15 cm, while fibrous substrate requires a diameter of 20-30 cm. Plastic or concrete pipes are preferred [7].

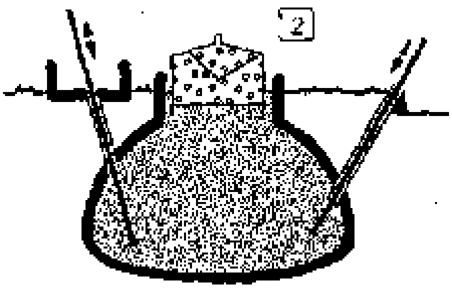

Figure 5.3: Inlet and Outlet for floating drum plant [7].

Note:

- Both the inlet and the outlet pipes must be freely accessible and straight, so that a rod can be pushed through to eliminate obstructions and agitate the digester contents;
- The pipes should penetrate the digester wall at a point below the slurry level. The points of penetration should be sealed off and reinforced with mortar.
- The inlet pipe ends higher than the outlet pipe in the digester in order to promote more uniform flow. In a fixed-dome plant, the inlet pipe defines the bottom limit of the gasholder, thus providing overpressure relief.
- In a floating-drum plant, the end of the outlet pipe determines the digester's slurry level.

5.1.3 Digester

Design

The digester of a biogas plant must accommodate the substrate and bacterial activity, as well as fulfill the following structural functions:

- Accept the given static forces.
- Provide impermeability to gas and liquids.
- Be durable and resistant to corrosion.

As a rule, the digesters of simple biogas plants are made of masonry or concrete.

Such materials are adequately pressure-resistant, but also susceptible to cracking as a result of tensile forces.

The following forces act on the digester:

- External active earth pressures (pE), causing compressive forces within the masonry.

- Internal hydrostatic and gas pressures (pW), causing tensile stress in the masonry.

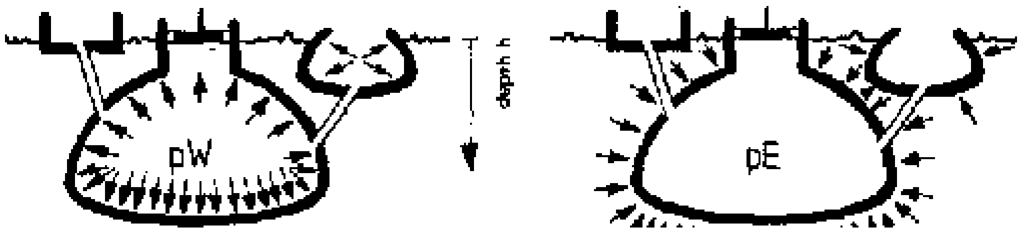

Figure 5.4: Forces acting on spherical dome digester [6].

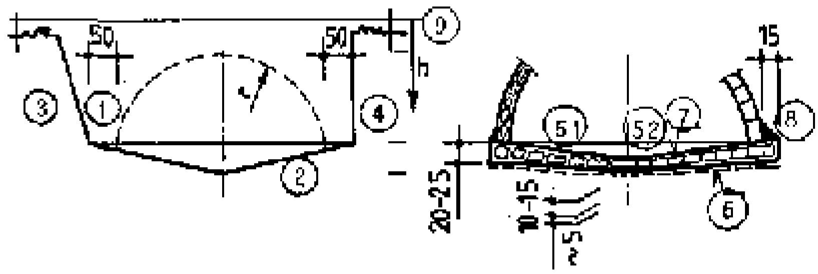

Figure 5.5 : Level line, excavation and foundation. 1 Workspace, 2 Inclination of conical foundation, 3 Sloping excavation, 4 Vertical excavation, 51 Quarrystone foundation, 52 Brick foundation, 6 Packing sand, 7 Mortar screed, 8 Foot reinforcement for fixed-dome plant, 9 Level line [7].

Thus, the external pressure applied by the surrounding earth must be greater at all points than the internal forces (pE > pW).

Round and spherical shapes are able to accept the highest forces and do it uniformly. Edges and corners lead to peak stresses and, possibly, to tensile stresses and cracking. Such basic considerations suggest the use of familiar cylindrical and dome designs allowing:

- Inexpensive, material-sparing construction based on modest material thicknesses
- a good volume/surface ratio and
- Better (read: safe) stability despite simple construction.

The dome foundation has to contend with the highest loads. Cracks occurring around the foundation can spread out over the entire dome, but are only considered dangerous in the case of fixed-dome plants. A rated break ring can be provided to limit cracking.

Groundwork

The first step of building the plant consists of defining the plant level line with a tau string. All important heights and depths are referred to mat line.

Excavation

The pit for the biogas plant is excavated in the shape of a cylindrical shaft. The shaft diameter should be approx. 2 x 50 cm larger than that of the digester. If the soil is adequately compact and adhesive, the shaft wall can be vertical. Otherwise it will have to be inclined. The overburden, if reusable, is stored at the side and used for backfilling and compacting around the finished plant [6].

Foundation

The foundation slab must be installed on well-smoothed ground that is stable enough to minimize settling. Any muddy or loose subsoil (fill) must be removed and replaced by sand or stones. The bottom must have the shape of a shallow inverted dome to make it more stable and rigid than a flat slab. Ouarrystones, bricks and mortar or concrete can be used as construction materials. Steel reinforcing rods are only necessary for large plants, and then only in the form of peripheral ties below the most heavily burdened part, i.e. the dome foundation.

Dome:

The dome of the biogas plant is hemispherical with a constant radius. Consequently, the masonry work is just as simple as for a cylinder and requires no false work- The only accessory tool needed is a trammel. The dome masonry work consists of the following steps;

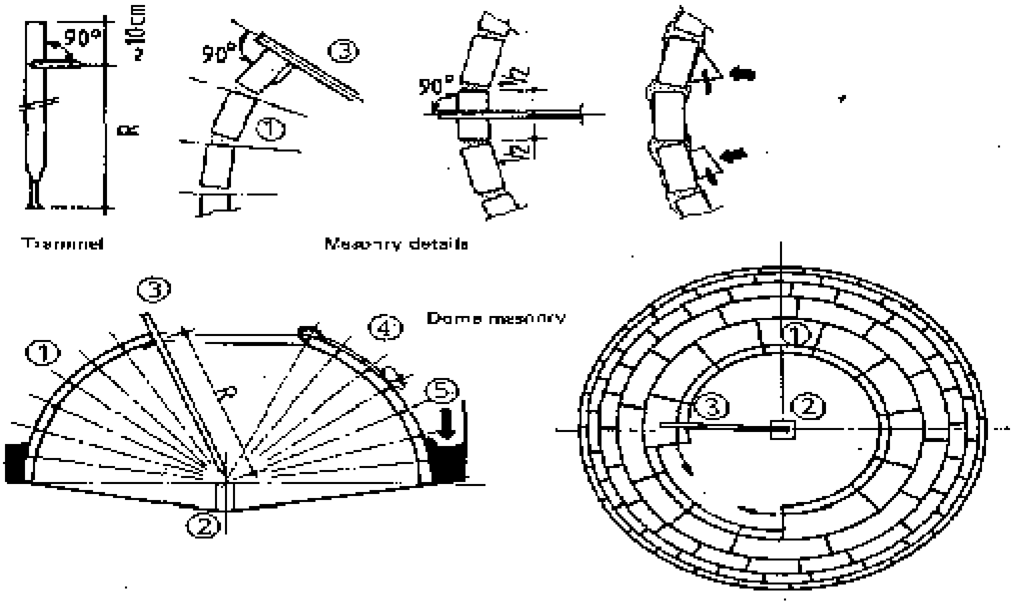

Figure 5.6: Construction of a spherical dome from masonry. 1 Dome/masonry, 2 Establishing the center point, 3 Trammel, 4 Brick clamp with counterweights, 5 Backfill [5]**.**

- Finding and fixing the center point of the dome radius in relation to the level line
- layer-by-layer setting of the dome masonry, with the bricks set in mortar, positioned and aligned with the aid of the trammel and tapped for proper seating

- In the upper part of the dome - when the trammel is standing at a steeper angle than 45°, the bricks must be held in place until each course is complete. Sticks or clamps with counterweights can be used to immobilize them.

Each closed course is inherently stable and therefore need not be held in place any longer. The mortar should be sufficiently adhesive, i.e. it should be made of finely sieved sand mixed with an adequate amount of cement [7].

Rendering

Mortar consisting of a mixture of cement, sand and water is needed for joining the bricks and rendering the finished masonry.

Biogas plants should be built with cement mortar, because lime mortar is not resistant to water.

The sand for the mortar must be finely sieved and free of dust, loam and organic material. That is, it must be washed clean.

Special attention must be given to the mortar composition and proper application for rendering, since the rendering is of decisive importance with regard to the biogas plant's durability and leak tightness. Ensure that:

- Toweling is done vigorously (to ensure compact rendering)
- All edges and comers are rounded off
- Each rendering course measures between 1.0 and 1.5 cm
- The rendering is allowed to set/dry slowly (keep shaded and moist, as necessary)
- The material composition is suitable and mutually compatible
- a rated break ring is provided for a fixed dome plant

Crack-free rendering requires lots of pertinent experience and compliance with the above points. Neither the rendering nor the masonry is gastight and therefore has to be provided with a seal coat around the gas space [7].

Table. 5.2: Suitability lists for rendering/mortar sands [7].

Test	Requirement
1. Visual check for coarse particles	Particle size: <7 mm
2.Determining the fines fraction by immersion in a glass of water: ½ lsand mixed with 11 water and left to stand for 1 h, after which the layer of silty mud at the top is measured.	Silt fraction: <10%
3.Check for organic matter by immersion in an aqueous solution of caustic soda; 1/2 I sand in 11 3 % caustic soda with occasional stirring. Notation of the water's color after 24 h.	*Clear-lo-light-yellow* = low org. content: suitable for use *Reddish brown* = high org, content unsuitable for use

5.1.4 Gasholder

Basically, there are three different design types of construction for gasholders used in simple biogas plants:

- Integrated floating drums
- Fixed domes with displacement system and
- Separate gasholders

Floating-drum gasholders

Most floating-drum gasholders are made of 2 - 4 mm thick sheet steel, with the sides made somewhat thicker than the top in order to counter the higher degree of corrosive attack. Structural stability is provided by L-bar bracing that simultaneously serves to break up surface scum when the drum is rotated.

A guide frame stabilizes the gas drum and keeps it from tilting and rubbing on the masonry. The two equally suitable types used must frequently are:

- An internal rod & pipe guide with a fixed (concrete-embedded) cross pole (an advantageous configuration in connection with an internal gas outlet)
- External guide frame supported on three wooden or steel legs (see Figure 5.7).

For either design, it is necessary to note that substantial force can be necessary to turn the drum, especially if it is stuck in a heavy layer of floating scum. Any gasholder with a volume exceeding 5 or 6 m^3 should be equipped with a double guide (internal and external).

All grades of steel normally used for making gasholders are susceptible to moisture-induced rusting both inside and out. Consequently, a long service life requires proper surface protection consisting of:

- Thorough derusting and desoiling
- Primer coat of minium
- 2 or 3 cover coats of plastic/bituminous paint

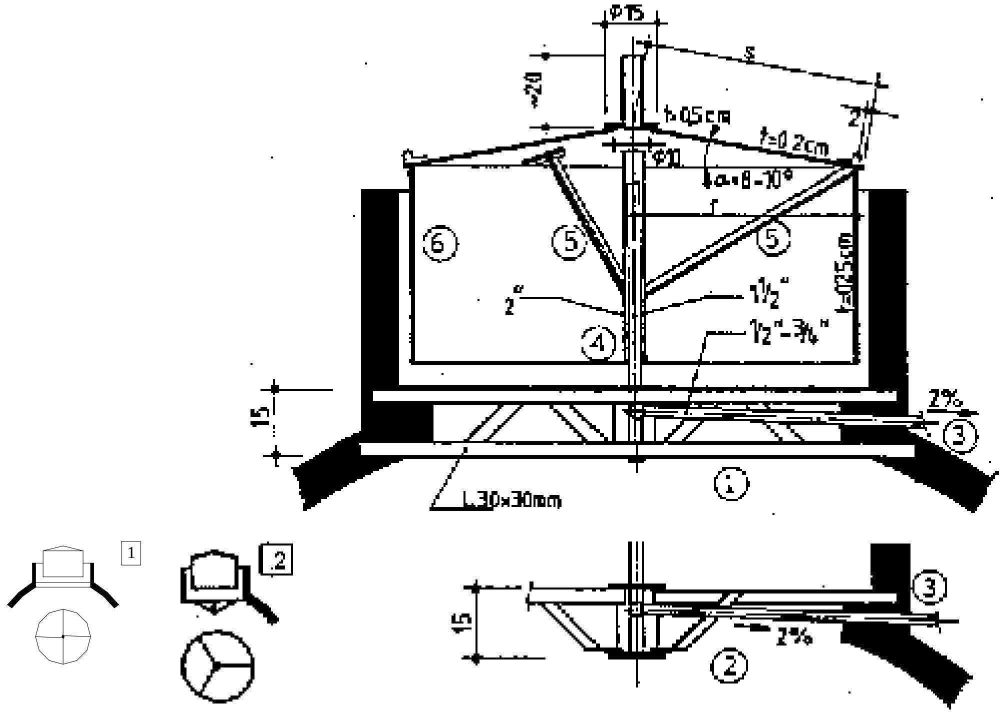

Figure 5.7: Construction of a metal gasholder with internal guide frame- 1 Lattice beam serving as cross pole, 2 Cross pole with bracing, 3 Gas pipe (2% gradient), 4 Guide frame, 5 Braces for shape retention and breaking up the scum layer, 6 Sheet steel (2-4 mm) serving as The drum shell [7].

The cover coats should be reapplied annually. A well-kept metal gasholder can be expected to last between 3 and 5 years in humid, salty air or 8-12 years in a dry climate [1].

Materials regarded as suitable alternatives to standard grades of steel are galvanized sheet metal, plastics (glass-reinforced plastic/GRP, plastic sheeting) and ferrocement with a gaslight lining. The gasholders of water jacket plants have a longer average service life, particularly when a film of used oil is poured on the water seal to provide impregnation.

Fixed domes

In a fixed-dome plant the gas collecting in the upper part of the dome displaces a corresponding volume of digested slurry. The following aspects must be considered with regard to design and operation:

- An overflow must be provided to keep the plant from becoming overfilled.
- The gas outlet must be located about 10 cm higher than the overflow in order to keep the pipe from plugging up.
- A gas pressure of 1 m WG or more can develop in the gas space. Consequently, the plant must be covered with enough earth to provide an adequate counter pressure; special care must be taken to properly secure the entry hatch, which may require weighing it down with 100 kg or more the following structural measures are recommended for avoiding or at least limiting the occurrence of cracks in the dome (see. Figure 5.8):

1. For reasons of static stability, the center point of the dome radius should be lowered by 0.25 R, (corresponding to bottom center of the foundation). This changes the geometry of the digester, turning it into a spherical segment, i.e. flatter and wider, which can be of advantage for the plant as a whole.
2. The foot of the dome should be made more stable and secure by letting the foundation slab project out enough to accept an outer ring of mortar.

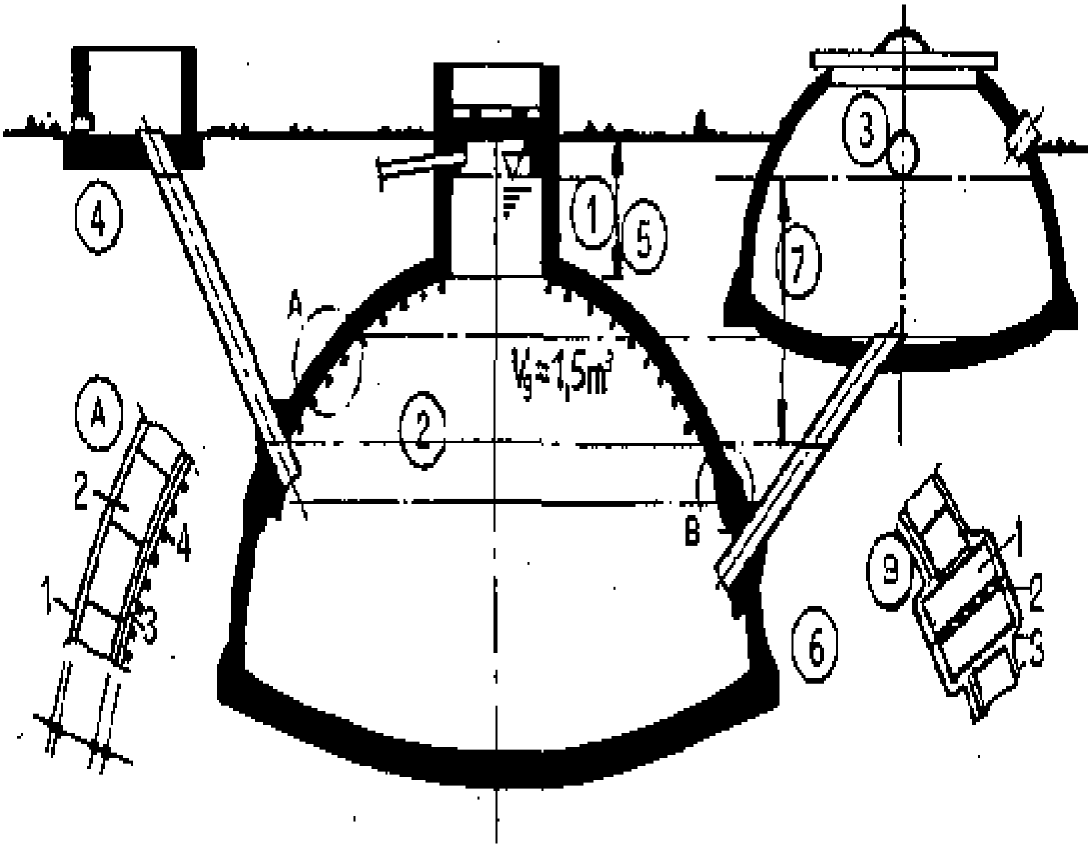

Figure 5.8: Construction of a fixed-dome gasholder. 1 Slurry level for an empty gasholder (zero line), 2 Slurry level for a full gasholder, 3 Overflow, 4 Inlet = overpressure relief, 5 Earth cover (at least 60 cm), 6 Reinforcing ring at foot of dome, 7 Max. gas pressure. A Detail: wall construction: .1 Outer rendering, .2 Masonry, 3 Two layer inner rendering, .4 Seal coat. B Detail: rated break point: 1 Masonry bricks (laid at right angles), .2 Joint reinforced with chicken wire, .3 Seal rendering - inside and out [6].

A With gas outlet in wedged-in cover

B With lateral gas outlet below weighed-down cover

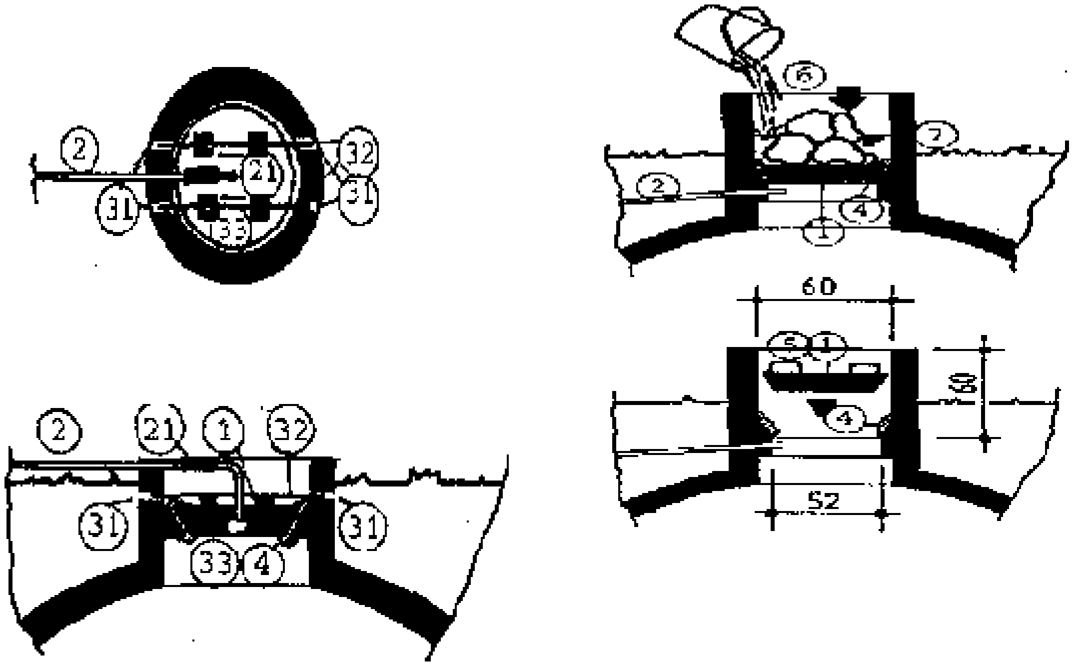

Figure 5.9: Entry hatch of a fixed-dome biogas plant. 1 Concrete cover, 2 Gas pipe, 21 Flexible connection (hose), 3 Cover wedging, 31 Length of pipe anchored in the masonry, 32 Retaining rod, 33 Wooden/metal wedges, 4 Edge seal made of loam/mastic compound, 5 Handles, 6 Weights, 7 Water [6].

A rated break/pivot ring should be provided at a point located between 1/2 and 2/3 of the minimum slurry level. This in order to limit the occurrence or propagation of cracks in the vicinity of the dome foot and to displace forces through its stiffening / articulating effect such that tensile forces are reduced around the gas space.

In principle, however, masonry, mortar and concrete are not gaslight, with or without mortar additives. Gastightness can only be achieved through good, careful workman - ship and special-purpose coatings. The main precondition is that the masonry and rendering be strong and free of cracks. Cracked and sandy rendering must be removed. In most cases, a plant with cracked masonry must be torn down, because not even the best seal coating can render cracks permanently gastight.

Table. 5.3: Quality ratings for various dome-sealing materials [7].

Material	Processing	Seal	Durability	Costs
Cold bitumen	Very good	Satisfactory	Satisfactory	Very good
Bitumen with alu-foil	Good	Very good	Good	Good
Epoxy resin	Very good	Good	Very good	Problematic
Paraffin	Good	Satisfactory	Satisfactory	Very good

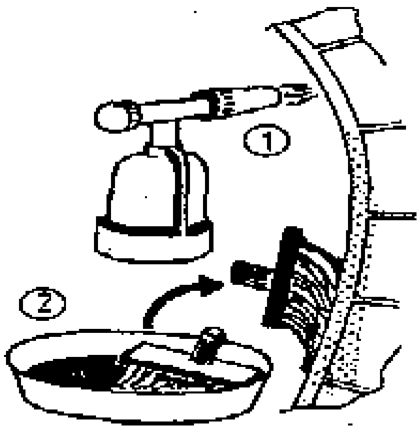

Figure 5.9: Sealing the masonry with paraffin. 1 Heat wall to 60-80 °C with soldering torch. 2 Apply hot (100°C) paraffin

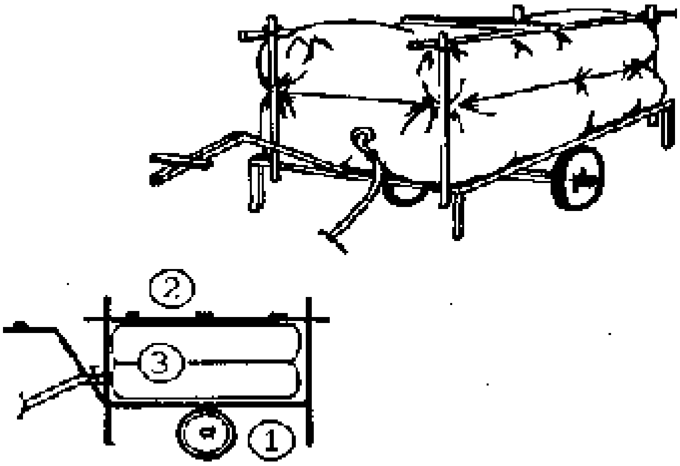

Figure 5.10: Separate, mobile, plastic-sheet gasholder. 1 Cart for gasholder volumes of 1 m^3 and more, 2 Stabilizing weights and frame, 3 Reinforced-plastic gasholder [1] .

Some tried and proven seal coats:

- *Multilayer bitumen,* applied cold (hot application poses the danger of injury by burns and smoke nuisance); solvents cause dangerous/explosive vapors. Two to four thick coats required.
- *Bitumen with aluminum foil:* thin sheets of overlapping aluminum foil applied to the still-sticky bitumen, followed by the next coat of bitumen.
- *Plastics,* as a rule epoxy resin or acrylic paint; very good but expensive.
- *Paraffin,* diluted with 2-5% kerosene, heated to 100 °C and applied to the preheated masonry. The paraffin penetrates deep into the masonry, thus providing an effective (deep) seal. Use kerosene/gas torch to heat masonry.

In any case, a pressure test must be performed before the plant is put in service [7].

Plastic gasholders

Gasholders made of plastic sheeting serve as integrated gasholders as separate balloon/bag-type gasholders and as integrated gas-transport storage elements.

For plastic (sheet) gasholders, the structural details are of less immediate interest than the question of which materials can be used.

Separate gasholders

Differentiation is made between:

a. Low-pressure, wet and dry gasholders (10-50 m bar) Basically, these gasholders are identical to integrated and/or plastic (sheet) gasholders. Separate gasholders cost more and are only worthwhile in case of substantial distances (at least 50-100 m) or to allow repair of a leaky fixed-dome plant [7].

b. Medium- or high-pressure gasholders (8-10 bar / 200 bar) neither system can be considered for use in small-scale biogas plants. Even for large-scale plants, they cannot be recommended under the conditions anticipated in most developing countries. High-pressure gas storage in steel cylinders (as fuel for vehicles) is presently under discussion. While that approach is possible in theory, it would be complicated and, except in a few special cases, prohibitively expensive. It would also require the establishment of stringent safety regulations [6].

5.2 AL-ARROUB BIOGAS PLANT DESIGN

5.2.1 Type of the plant:

AFC plant was chosen to be constructed after the Indian style, because this style is considered one of the most suitable for countries like Palestine. It is considered the simplest and cheapest among other types (e.g. the Chinese dome, the UASB, the inflating bag … etc). It is also considered an explosion-proof kind in a country suffering a sustainable conflict conditions as the movable dome (gasholder) raises automatically and proportionally with the amount of gas generated. Easy to feed and empty. Building AFC plant of cylindrical galvanized iron containers gives it extra advantage that is providing the plant with powerful and reinforced walls which can bear immense stresses without showing any fracture or joint.

Other reasons for choosing the galvanized iron are it is antirust and in case of jointing it is easy to pull the dome out, empty the digester and wild the joints. As well as it fits with the prevailing climatic conditions in Al-Arroub area.

Plant design

The plant was designed to consist of the following components:

- **The main digester chamber**: it is a pit dug in the ground very near to the cow barn. The pit is cylindrical in shape 6m deep × 3m diameter. Instead of building the pit walls out of reinforced concrete, 3" thick galvanized iron cylindrical container with dimensions of 2.7m diameter × 5 m height was selected to be installed in the pit ($V=28.6m^3$) see Figure 5.11. The preference of the iron container was made because galvanized iron is rustproof, very well sealed and does not crack or fail neither partially or completely when subjected to pressure shocks, due to its high ductility.

The ground of the pit was cleaned up and 25cm thick reinforced concrete ground slap was laid down then the container was installed in vertically by using a JCB lift. The spacing left between the pit walls and the iron container were filled with 25 B concrete.

The container upper edges rise about 0.5 m above the ground surface in situ to protect the hole from any fallings or undesired trash.

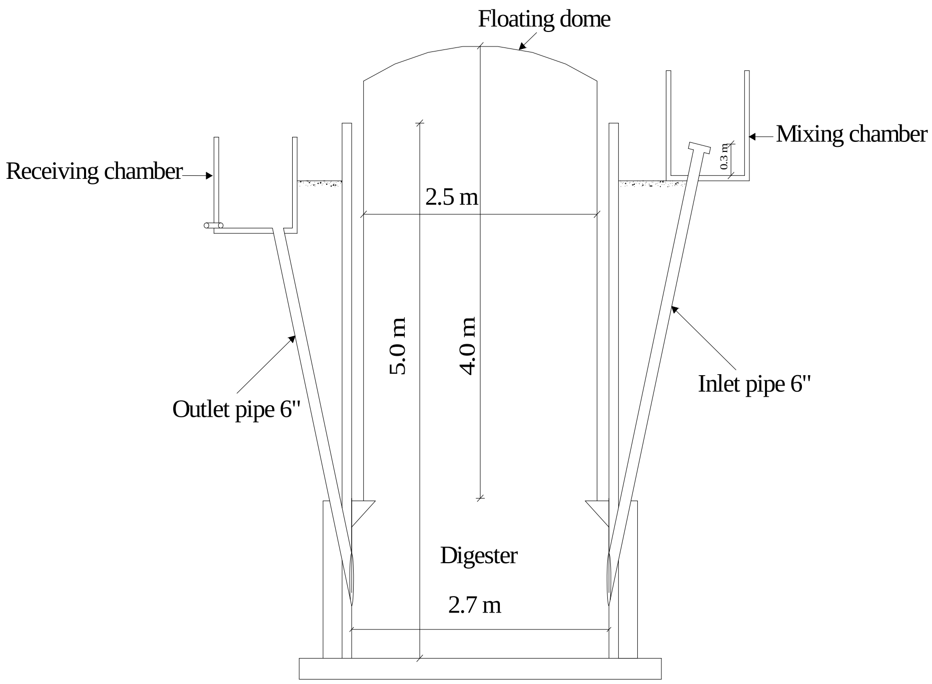

Figure 5.11: AFC plant components

- **The dome or the cover:**

It is made up of the same material as the main container. It is provided with a gas pressure meter and a gas outlet valve on the upper side. Its dimensions are 2.50 m diameter × 4 m height to allow it move freely up and down according to the gas quantity traped in.

- **Mixing chamber:**

  It is approx. 1 m^3 in volume. Made up of reinforcement concrete, cubic sealed and with an inlet pipe of 6″ diameters that 30 cm raised above the ground of the pit. This effected prolongation (the 30 cm) is covered with an orifice of 0.5 cm mish size sieve.

The feedstock should be mixed with water before it is introduced to the main mixing chamber.

- **The effluent receiving chamber:**

  It is similar in size and shape to the mixing chamber but 0.5m lower from it. The out coming digested slurry that rises to this chamber by gravity is directed to the adjacent composting facility nearby.

- **The connections :**

  The mixing chamber pushes its influent to the bottom of the main chamber through a galvanized iron pipe of 4″ diameter via an orifice with 0.7cm mesh cover. This pipe is 25cm above the mixing chamber base to allow segregation of grit and stones and to prevent straw and trimmings from reaching the digester.

  The effluent receiving chamber is connected to the main chamber by galvanized iron pipe of 6″ diameter.

  The moving drum has valve opening of 1/2″ diameter for gas release.

- **The feedstock:**

  In the first phase it is suggested to use only the fresh cow manure mixed with fresh tap water of ratio 1: 9 respectively.

Recommendations were made to screen the slurry mixture prior to introduction in the main chamber in order to free it from grit and straw and to get the highest performance level.

Monitoring the daily temperature and pH of the slurry was proposed to avoid any processing failure and to repair any defect if happened.

- **The cost of the plant:**

The sum lump costs for the whole facilities, works and labor paid to construct the AFC biogas plant exceeded the 7000 US $.

CHAPTER SIX

ECONOMIC ANALYSIS AND SOCIOECONOMIC EVALUATION

6.1 PROCEDURES AND TARGET GROUPS

6.2 WORKING-TIME BALANCE

6.3 MICRO-ECONOMIC ANALYSIS FOR THE USER

6.4 MACRO-ECONOMIC ANALYSIS AND EVALUATION

6.5 ECONOMIC ANALYSES FOR AL-ARROUB BIOGAS PLANT

CHAPTER SIX

ECONOMIC ANALYSIS AND SOCIOECONOMIC EVALUATION

6.1 PROCEDURES AND TARGET GROUPS

Any decision pro or against the installation and operation of a biogas plant depends on various technical criteria as well as on a number of economic and utility factors. The quality and relevance of those factors are perceived differently, depending on the respective individual interest:

- Users want to know what the plant will offer in the way of profits (cost-benefit analysis) and other advantages like reduced workload, more reliable energy supplies improved health and hygiene (socioeconomic place value).
- Banks and credit institutes are primarily interested in the economic analysis as a basis for decisions with regard to plant financing.
- Policy-makers have to consider the entire scope of costs and benefits resulting from introduction and dissemination, since the decisions usually pertain to biogas extension programs instead of to individual plants.

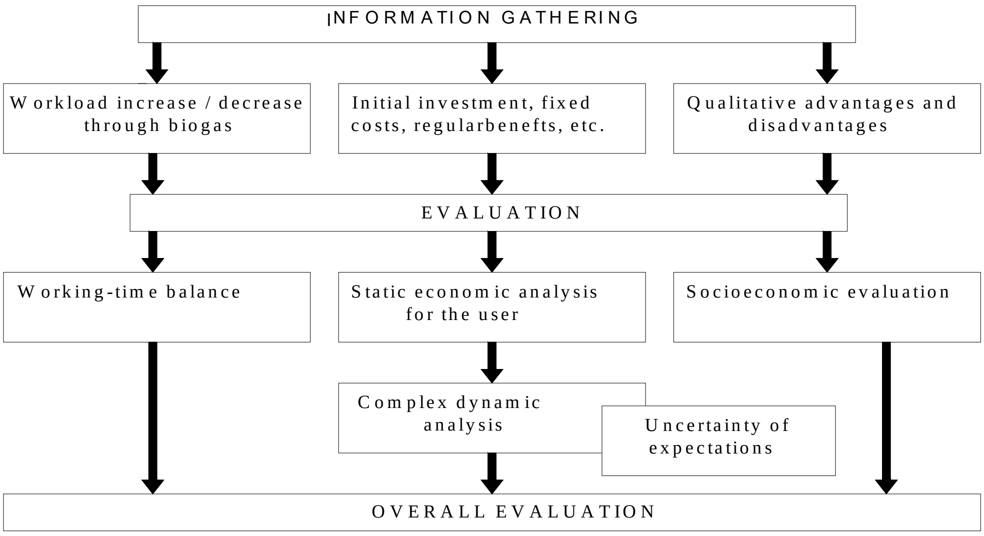

Fig. 6.1: Basic elements of an economic analysis

The evaluation of biogas plants must include consideration not only of the monetary cost/benefit factors, but also of the ascertainable nonpeculiary and unquantifiable factors. Time and again, practical extension work with the owners of small and medium-sized farms shows that a purely monetary approach does not reflect the farmers' real situation. For a farmer who thinks and works in terms of natural economic cycles, knowing how many hours of work he stands to save is often more important than knowing how much money he stands to gain. A similar view is usually taken of the often doubtful monetary evaluation of such a plant's qualitative and socioeconomic impact.

Figure 6.1 surveys the essential parts of an economic analysis. In practice, however, the collecting of information and data can present problems; experience shows, for example, that an exact breakdown of cost and benefits can hardly be arrived at until the plant has been in service long enough for the user to have gained some initial experience with its operation. Economic prognoses therefore should give due regard to such limitations by including calculations for various scenarios based on pessimistic, average-case and optimistic assumptions. Consequently, the data stated in the following calculations and considerations are intended to serve only as reference values.

Any attempt to convert local plant & equipment costs into Euro-values is seriously complicated by the fact that exchange rates are often set more or less arbitrarily and that the figures used may derive from unstable black-market prices.

6.2 WORKING-TIME BALANCE

For the users of family-size plants primarily the operators of small to medium-size farms the following three elements of the biogas plant evaluation have the most relevance:

- Working-time balance
- Micro-economic analysis and
- Socioeconomic and qualitative considerations.

Working-time balancing is most important when the farm is, at most, loosely involved in cash-crop markets, so that the cost/benefit factors are more likely to be reflected in terms of hours worked, as in money.

The best indication of a successful biogas plant is a significant reduction in the average amount of time worked especially by women and children who tend the plant and cook with the gas. If, for example, the family used to cook on wood gathered on the way back from the fields, a practice that involved little extra work, biogas technology can hardly expect to find acceptance under the heading "time saved".

The actual value of time saved depends not only on the quantity saved but also on the quality, i.e. whose workload is reduced at which time of day. Real-time savings let the target group:

- expand their cash-crop and/or subsistence production
- Intensify and improve their animal-husbandry practice
- Expand their leisure time and have more time for their children, education, etc.

It should be noted that all time expenditures and time savings pertaining to anyone participating in the farm/household work and which can be expressed in real monetary terms as cash-flow income or expenses must appear both in the above working-time balance and in the following micro-economic analysis (wage labor during the time saved by the biogas plant).

6.3 MICRO-ECONOMIC ANALYSIS FOR THE USER

The following observations regarding microeconomic analysis (static and dynamic) extensively follow the methods and calculating procedures described in the pertinent publication by H. Finck and G. Oelert a much-used reference work at Deutsche Gesellschaft fur Technische Zusammenarbeit

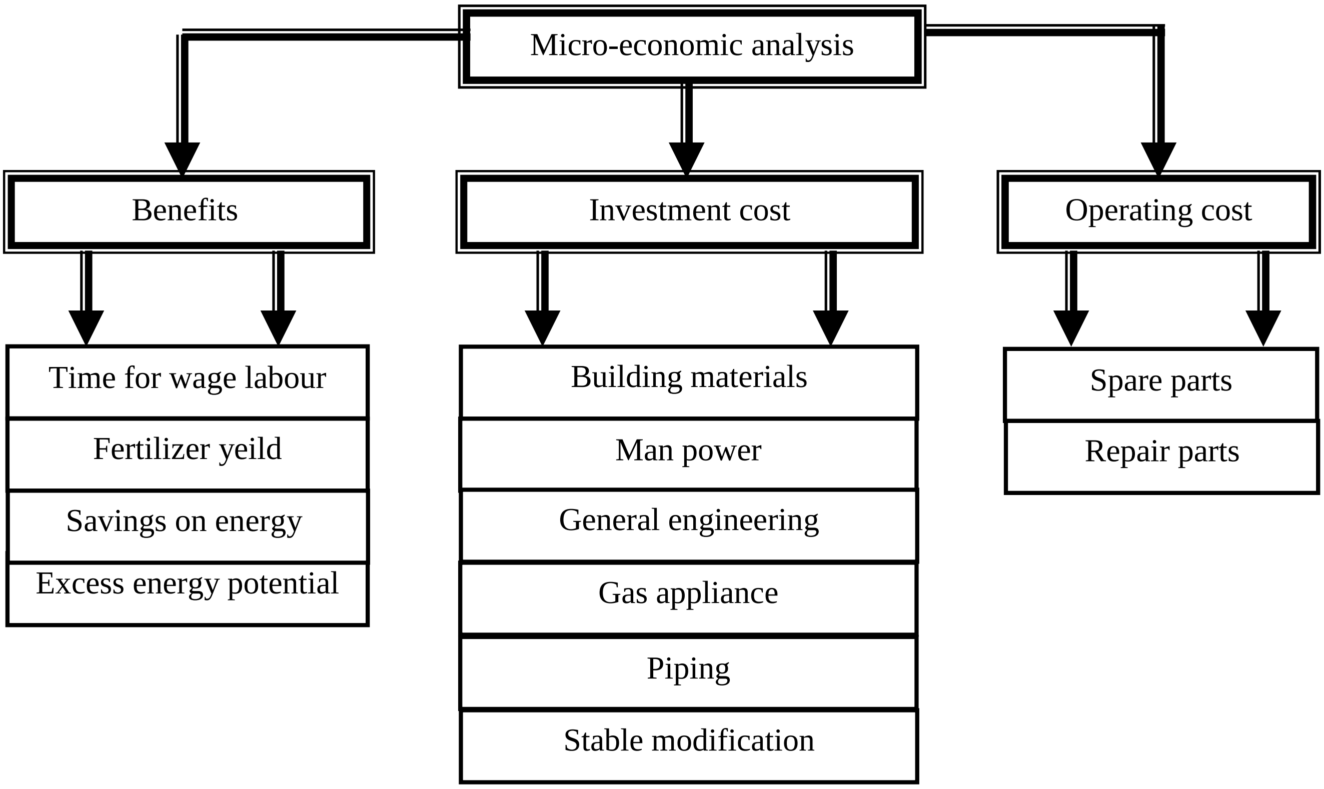

Figure 6.2 shows the micro-economic analysis parts of a biogas plant.

6.4 SURVEY OF THE MONETARY COSTS AND BENEFITS OF A BIOGAS PLANT

Figure 6.2 shows a breakdown of the basic investment-cost factors for a presumedly standardized fixed-dome plant. The cost of material for building the digester, gasholder and displacement pit (cement, bricks, blocks (can, as usual, be expected to constitute the biggest cost item. At the same time, the breakdown shows that the cost of building the plant' alone, i.e. without including the peripherals (animal housing, gas appliances‘ piping) does not give a clear picture.

For a family-size plant, the user can expect to pay between 40 and 200 Euros per m^3 digester volume (see Table 6.1). This table shows the total-cost shares of various plant components for different types of plant.

While the average plant has a service life of 10-15 years, other costs may arise on a re-current basis, e.g. painting the drum of a floating-drum plant and replacing it after 4-5 years. Otherwise, the operating costs consist mainly of maintenance and repair work needed for the gas piping and gas appliances. At least 3% of the initial investment costs should be assumed for maintenance and repair.
The main benefits of a biogas plant are:

- Savings attributable to less (or no) consumption of conventional energy sources for cooking, lighting or cooling
- The excess energy potential, which could be commercially exploited
- Substitution of digested slurry in place of chemical fertilizers and/or financially noticeable increases in crop yields
- Savings on time that can be used for wage work, for example.

Usually, a biogas plant will only be profitable in terms of money if it yields considerable savings on conventional sources of energy like firewood, kerosene or bottled gas (further assuming that they are not subsidized).

Financially effective crop-yield increases thanks to fertilizing with digested slurry are hard to quantify, i.e. their accurate registration requires intensive observation of the plant's operating parameters. Such limitations make it clear that many biogas plants are hardly profitable in monetary terms, because the relatively high cost

Table 6.1 total-cost shares of various plant components for different types of plant [1].

Cost factor	Water jacket plant	Fixed dome plant	Plastic sheet plant
Cost per m^3 digester (Euro)	200-400	150 - 300	80 - 120
Including: Gas holder	23%	Part of digester	8%
Digester/ slurry store	35%	50%	42%
Gas appliances/piping	22%	24%	36%
Stable modification	8%	12%	-
General Engineering	12%	14%	14%

of investment is not offset by adequate financial returns. Nonetheless, if the user considers all of the other (non-monetary) benefits, too, he may well find that operating a biogas plant can be worth his while. The financial evaluation (micro-economic analysis), the essential elements of which are discussed in the following chapter, therefore counts only as one of several decision-making instruments to be presented to the potential user.

The main advisory objective is to assess the user's risk by calculating the payback period (“How long will it take him to get back the money he invested?") and comparing it with the technical service life of the plant. Also، the user must be given some idea of how much interest his capital investment will carry (profitability calculation).

6.5 MACRO-ECONOMIC ANALYSIS AND EVALUATION

The main quantifiable macro-economic benefits are:

1. National energy savings, primarily in the form of wood and charcoal, with the latter being valued at market prices or at the cost of reforestation.
2. Reduced use of chemical fertilizers produced within the country.

Additionally, foreign currency may be saved due to reduced import of energy and chemical fertilizers.

Macro-economic costs incurred in local currency for the construction and operation of biogas plants include expenditures for wages and building materials, subsidy payments to the plant users, the establish of biogas extension services, etc. Currency drain ensues due to importing of gas appliances, fittings, gaskets, paints ... etc.

In addition to such quantifiable aspects, there are also qualitative socioeconomic factors that gain relevance at the macroeconomic level:

- Autonomous decentralized energy supply.
- Additional demand for craftsmen's products (= more jobs)
- Training effects from exposure to biogas technology
- Improved health & hygienic conditions etc.

6.6 ECONOMIC ANALYSES FOR AL-ARROUB BIOGAS PLANT

AFC biogas plant was constructed after the Indian style, e.g. a bio-digester with floating dome. The works and materials involved in building up the plant are as follows: (see Table 6.2)

1. **Digging down the pit:**

A pit of approx. cylindrical shape and with dimensions 6.5 m deep × 3.5 m diameter was dug in a ground 3 m away from the southwestern corner of the cow barn. The lithology of the bedrock, as encountered from the drilling process, is mainly medium hard to occasionally very hard marly limestone and compacted marlstone. The color of the rocks are mainly whitish to reddish yellow. The hardness as well as the rock quality designation (RQD) parameters increase going downwards in the geological section.

Excavation process was carried out by a caterpillar JCP bagger. The cuttings encountered were carried away from the locality.

The drilling process had costed approx. 300 US$.

2. Manufacturing the digester and the dome:

The digester body, as well as the movable dome (cover) are both made up of galvanized iron of 3 mm thick. They were manufactured (“constructed”) in Yata town, as no facilities nearby the locality are able to do the job.

The sum lump paid for the two pieces were approx. 5700 US $.

3. The connections:

The inlet and outlet pipes are also made up of galvanized iron of 3 mm thick. The inlet pipe is 6″ and the outlet pipe is 8″ in diameter.

Money paid for these pipes were 200 US $.

4. Materials and accessories:

To build up the mixing and the effluent receiving chambers ($\cong$ pits) as well as to reinforce and fix the main digester body in the major pit, needed to bay some bricks, cement, iron, aggregates and accessories. The costs paid to accomplish these missions were approx. = 250 US $. This money include also the labour needed to do the work.

5. **Transportation:**

As the manufacturing place Yatta town is approx. 20 km away from the installation locality (Al-Arroub) and because the circumstances within the vicinity of Hebron District are subjected often to Marshal Law by the Israeli occupation forces, transportation process had been subjecting several to unexpected complications and disruptions. It might loading and disloading the freight many times in the way to the installation place.

The transportation cost was $\cong$ 300 US $.

6. **Filling costs:**

To fill the digester with the required manure quantity it was needed to hire a laborer for approx. 30 days, this work had costed 350 US $.

Extra 100 labor days are essential to maintain sustainability of manure filling in the digester for the yearlong. This may add approx. 1100 US $ to the cost.

It is expected (assumed) that the plant service life period will be 15 years.

Other costs like biogas connections from the digester to the consumption place with all its accessories are not the responsibility of EQA.

Table (6.2): Costs in US $ for Al-Arroub biogas utility.

Item	Approx. cost (US $)	Remarks
1. Digging the main pit	300	One time in life
2. Digester + Dome	5700	Every 15 years
3. Connections/ Pipes	200	Every 15 years
4. Materials/ Accessories	250	Every 15 years
5. Transportation	300	One time in life
6. Laborer	1500	Per annum
Total	8250 US $	

It is worth to mention that using galvanized iron in building up this plant is estimated to be approx. 1500 US $ cheaper if Mishtalbout bricks were used. It is also considered cheaper than constructing an airtight chamber of reinforced concrete (the contractor/ personal communication).

6.6.1 Benefits:

AFC biogas plant is considered a pilot project of demonstration purpose, that means it was built up not for developmental objectives in the first line but to show and experiment the possibility of generating biogas from biowaste. The construction of the plant is totally financed by the World Bank through the project called “Regional Initiative for Dryland management (RIDM)” / Waste Valorization sub-project

The main purposes of running such projects are to clean the environment by getting rid of the biowaste pollutants from one side and secondly to benefit from treating these wastes. If man looks to the purpose itself it represents benefits that are immeasurable.

When implementing such projects by the private sector the photo is turned to carry more and more economic aspects, it will be discussed under the" Cost Benefits Analyses "motto".

6.7 Main benefits drawn up from AFC biogas plant are:

Amount and quality of biogas generated in AFC plant depend on the capacity of the effective volume of the digester when all conditions (especially the climate) were optimal.

The benefits are greater the more energy had to be bought in (diesel, benzine, gas, wood ...etc) and the higher the cost of that energy. However, there is always a close relationship between energy costs and those of construction.

For calculating the economic feasibility of AFC biogas plant, it should be taken in consideration that the major two outputs (productions) are the generated biogas and the digested feedstock (slurry).

6.7.1 Biogas:

If we assumed according to our climatic condition, that the average retention time equals to 35 days and the volatile solids percentage (VS %) for our feedstock equals to 9 % , and as the effective volume (V_E) of the AFC biogas plant was

$$Volume = \frac{D^2 ®}{4} \times h = \frac{2.5^2 \times ®}{4} \times 4 = 19.64 \Rightarrow Volume \cong 19.6\, m^3$$

calculated to be then the outputs could be calculated as follows:

Daily feedstock needed = 19.6 m^3 / 35 days

= 0.56 m^3 / day

Feedstock needed / month = 0.56 m^3/day $\times$ 30 day = 16.8 m^3.

Digestable volatile solids / month = 16.8 $m^3 \times 0.09$ = 1.512 m^3 VS.

This equals to approx. 1512 kgs of total VS monthly.

Every 1 kg ("fermented" "decomposed") yields 831 L biogas (literature / modified from many references).

This means:

1512 kg $\times$ 0.831 m^3 $\cong$ 1256 m^3 of biogas / month.

Every 1.83 m^3 biogas used for cooking qualifies 1 L diesel oil (see table 6.3).

1 L diesel $\cong$ 0.52 $ price. (Price in market, 19th May 2004)

Table 6.3 Biogas compared with other fuels [7].

Fuel	Unit u	Calorific value KWh/u	Application	Efficiency ή	Net calorific Value KWh/u	Biogas equiv M^3/u	1m^3 Biogas = u/m^3
Cow dung	Kg	2.5	Cooking	12%	0.30	0.09	11.11
Wood	Kg	5.0	Cooking	12%	0.60	0.18	5.56
Charcoal	Kg	8.0	Cooking	25%	2.00	0.61	1.64
Hard coal	Kg	9.0	Cooking	25%	2.25	0.69	١.٤٥
Butane	Kg	13.6	Cooking	60%	8.16	2.49	0.40
Propane	Kg	١٣.٩	Cooking	60%	8.34	2.54	0.39
Diesel oil	Kg ??	12.0	Cooking Engine	50% 30%	6.0 4.0	1.83 2.80	0.55 ٠.٣٦
Electricity	Kg	1	Cooking Light Motor	67% 9% 80%	0.67 0.09 0.80	0.20 0.50 0.56	5.00 2.00 1.79
Biogas	M^3	5.96	Cooking Light Engine	55% 3% 24%	3.28 0.18 1.43	1 1 1	1 1 1

Then the monthly price equivalent of the generated 1675 m^3 biogas will be calculated as follows:

$$\frac{1256\,m^3 \quad biogas}{1.83\,m^3 \quad biogas \Big/ 1 Liter \quad diesel \quad oil} \cong 686\,liters \quad of \quad diesel \Big/ month$$

686×0.52 \$ $\cong$ 356 \$ / month.

If the plant will work efficiently 7 months long a year, then the total revenue is

7×356 = 2498 \$ / year (7 months meant).

6.7.2 Slurry

The price of 3 m^3 fresh manure (slightly composted "fermented") in the public market is approx. $\cong$ 100 NIS $\cong$ 22.2 \$. We assume that the price of the slurry – which is fully digested "fermented"- is the same as manure.

$$\frac{16.8}{3} \times 22.2 = 124.32\,dollars \quad / month = \text{Re}\,venue \quad from \quad the \quad slurry$$

124.32×7 month / year $\cong$ 870 \$/ year

Gross Income (GI).

The total revenue (GI) = biogas + slurry price

= 2498 + 870 = 3368 US \$/ annum (7 month meant)

Profitability:

The profit expected from the biogas plant is calculated as follows:

- The annual income (revenue) = 3368 \$.

- The laborer wage per year = 1500 $.
- One time in life expenses = 600 $ (see table 6.2).
- Average capital investment consumption per year is:

$$\frac{5700 + 200 + 250\,(table \quad 6.2)}{15\,years} = 410\$/\text{year.}$$

Net profit for the first year is: 3368 – [1500 $ + 600 $ + 410 $] = 858 $.
Net profit for the coming 14 years is: 3368 – [1500+410] = 1458 $ / year.

Payback period:

- from table 6.2, the total costs paid for constructing the AFC plant and making it ready for utilization are:

  300 + 5700 + 200 + 250 + 300 = 6750 $.
- Gross income = 3368 $ / year.
- Laborer wage = 1500 $ / year.
- Net income (profit) = biogas (diesel equivalent) price – labor cost

  = 3368 – 1500 = 1868 $ / year.
- Payback period = total cost / net profit

  = 6750/1868 = 3.61 years.

Profit period = (life – payback period)

= (15 – 3.61) = 11.39 years.

Total Profit for the next 15 years = profit period $\times$ annual net profit

= 11.39 $\times$ 1868 = 21277 $

There is a different in temperature during the four seasons and for that the retention time varying due to that, so there are many scenarios for the retention time. (See Table 6.4)

Table 6.4: Total income due to various retention time (O) with various volatile solid according (VS %) to the equivalent of fuel in 11th June, 04

Case	O	Vs %	Q gas	Diesel equiv. (L)	Income per month ($)	Total income / month ($)	Remarks
1	25	5	277.7	534.0	411.2	585.2	Economically effective
		7	1368.2	747.6	575.7	749.7	Economically effective
		9	1759.0	961.2	740.1	914.1	Economically effective
2	35	5	698.0	381.5	293.8	418.1	Economically effective
		7	977.3	534.0	411.2	535.5	Economically effective
		9	1256.5	686.6	528.7	653	Economically effective
3	45	5	543.0	296.8	228.5	325.2	Economically effective
		7	760.0	415.4	320.0	416.7	Economically effective
		9	977.3	534.0	411.2	507.9	Economically effective
4	60	5	407.0	222.5	171.3	243.8	Not effective
		7	570.0	311.5	240.0	312.5	Not effective
		9	732.9	400.5	308.4	380.9	Economically effective
5	90	5	271.5	148.4	114.3	162.3	Not effective
		7	380.0	207.7	160.0	208	Not effective
		9	488.6	267.0	205.6	253.6	Not effective

CHAPTER SEVEN
FIELD AND LABORATORY EXPERIMENTAL WORK

CHAPTER SEVEN

FIELD AND LABORATORY EXPERIMENTAL WORK

7.1 AIMS OF THIS WORK

This work aims to study and investigate the most appropriate type of feedstock, among many, which is going to be used in the digester. Taking in consideration the climatic conditions prevailing at our country, as well as the socio-economic status and the environmental impacts of implying such projects proofs the process of generating biogas from biowaste to be very promising for the Palestinian society especially in the rural areas.

In these areas, many sorts of feedstock material are available for feeding the digesters like cow, chicken, sheep manure, soft grasses, municipal bio-residues, barn remains and many agricultural (fruits +vegetables) leftover stocks.

In this study we focused the experiments on the cow manure, as it is the most accessible and light to work with feedstock, as well as many cow barns spread allover the country.

7.2 ANALYSES PARAMETERS

The analyses carried out had involved the following parameters:

1. Total solids by percentage in the sample (Ts %).
2. Volatile solids by percentage in the sample (Vs %).
3. Ash percentage in the sample (Ash %).
4. Monitoring the pH of the sample.
5. Monitoring the electric conductivity of the sample in micro siemens per cm (μs/cm).

6. Measuring the total dissolved solvents in the sample in mg/L (TDs).
7. Measuring the moisture content (mc) of the sample.
8. Measuring the temperature of the sample in centigrade degree (^{o}C).
9. Measuring the salinity of the sample (Sal.) in gm/L.
10. Measuring the ambient temp. At the time of sampling, that is the atmospheric temperature in the field and the temperature in the lab. As well as the temperature of the slurry in the digester is recorded at the time of sampling.
11. Measuring the quantity of the biogas produce versus time. (Q in liters and time in hrs).
12. Recording any extra phenomenon (observation) during the experiment. e.g seepage, leakage, lime addition, failure of the system,…, etc.
13. Recording the initial content of the dissolved oxygen in the feedstock.

After recording all these parameters versus time, the relation ship between the different parameters are studied and investigated.

7.3 LABORATORY DIGESTERS

Four small-scale digesters were installed in the laboratory of the Environment Quality Authority EQA in Hebron. The feedstock use in these digesters is the fresh cow manure, brought from the cow barn in Al-Arroub Farm Complex AFC. All four digesters are of batch type.

7.3.1 Digester A:

- Feedstock: Concentrated unscreened cow manure from AFC.
- Date of fed: 14th April / 2004.
- Size: Full plastic bucket of 20 liters capacity.

- Total initial solids (TS) percentage: 14.2 %. Moisture content: 85.8 %.
- Σ Quantity TS: 2840 gms.
- Total initial Volatile solids percentage (VS %): = 9.1 %.
- Initial Total Dissolved Solvents (TDS) = 6.5 gm/l.
- Initial Electric Conductivity (EC) = 11.89 μs/cm.
- Initial pH = 6.80

After the first three days of installation, and the accumulation of approx. 300 mls of gas, seepage was observed. This situation continued until April 17th. As repairing process was in action the reactor exploded vigorously. Fortunately, no harm/damage occurred.

7.3.2 Digester B:

- Feedstock: Diluted Screened Cow Manure from AFC.
- Date of fed: 10th of April 2004.
- Size: 45L as effective size in a 50 L airtight glass bottle.
- Total initial solids (TS) percentage: 1.59 %. Moisture content: 98.41 %.
- Σ Quantity TS: 716 gms.
- Total initial volatile solids percentage (VS %) = 0.52 %.
- Initial Total Dissolved Solvents (TDS) = 2.94 gm/l.
- Initial Electric Conductivity (EC) = 5.32 μs/cm.
- Initial pH = 7.11

No gas release was observed until 10th of May (morning). At this time connections were repaired and the digester was made airtight and some (≈ 10 gms) of CaO (lime) were added (at 12 00) to raise the measured pH, which was found to drop to 6.6 on 10th May 2004 (morning).

After all these maintenance steps were carried out, the reactor started yielding gas with time as shown in Table 7.1 and Figure 7.1.

Table 7.1 Gas Yielding with Time in Digester B.

Date	hrs passed	Cumulative yielded gas quantity(l)	Remarks
10th, May, 04 12:30	0	0	Lime added Connections air tight
16th, May, 04 12:30	144:30	1000.0	
17th, May, 04 12:30	168:30	1400.0	
19th, May, 04 12:30	216:30	1650.0	
20th, May, 04 12:30	240:30	2000.0	
22th, May, 04 12:30	288:30	2800.0	
23th, May, 04 12:55	312:55	3350.0	
24th, May, 04 12:30	336:30	3955.0	
27th, May, 04 12:30	408:30	6955.0	
29th, May, 04 12:30	456:30	9605.0	
31th, May, 04 12:30	504:30	13605	
2nd , June, 04 12:30	552:30	15605	

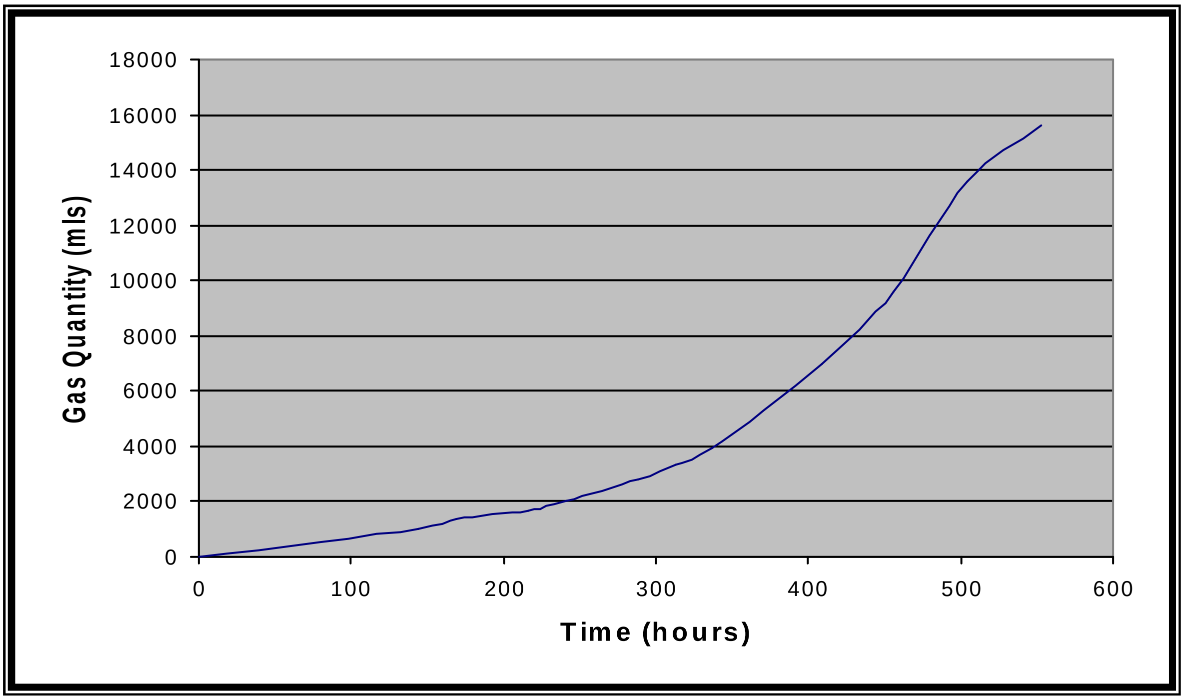

Figure 7.1 Cumulative Yielded Gas Quantity Versus Time in Bio-digester B.

From the gained results, it is observed that gas yield started increasing up highly after 300 hours of making the reactor totally gastight; this means that the methanogization process became more and more effective.

7.3.2 Digester C:

- Feedstock: Concentrated Unscreened Cow Manure from AFC.
- Date of fed: 10^{th} of April 2004.
- Size: 16 liters of feedstock in a plastic bucket of 20 liters capacity
- Initial total solids (Ts) percentage: 14.5 %. Moisture content: 85.5 %.
- Initial total Volatile solids percentage: 9.2 %.

- Initial Total Dissolved Solvents = 2.94 gm/l.
- Initial Electric Conductivity = 12.61 μs/cm.
- Initial pH = 6.72

The digester was made airtight and in the next day gas was yielded and followed the following scheme (see Table 7.2 and Figure 7.2):

Table 7.2 Gas Yielding with Time in Reactor C.

Date	hrs passed	Cumulative yielded gas quantity(l)	Remarks
10^{th}, May, 04 12:00	0	0	
11^{th}, May, 04 13:15	25:15	1200.0	
12^{th}, May, 04 10:45	46:45	2000.0	
13^{th}, May, 04 12:30	72:30	3200.0	
16^{th}, May, 04 12:30	144:30	5800.0	
17^{th}, May, 04 12:30	168:30	6200.0	
18^{th}, May, 04 12:30	192:30	6650.0	
19^{th}, May, 04 12:30	216:30	7200.0	
20^{th}, May, 04 12:30	240:30	7700.0	
22^{th}, May, 04 12:30	288:30	8500.0	
23^{th}, May, 04 12:55	312:55	8900.0	
24^{th}, May, 04 12:30	236:30	No record	Gas leakage and reactor stopped

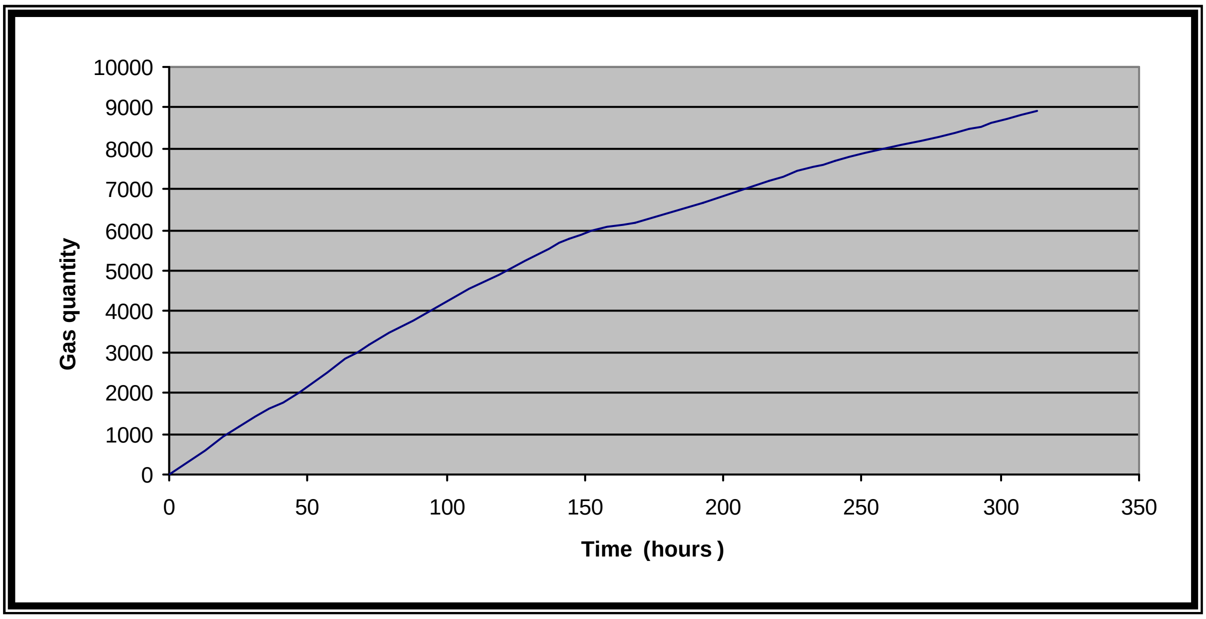

Figure 7.2 Cumulative Yielded Gas Quantity Versus Time in Bio-digester C.

Notice: the feedstock use in this reactor was the same feed stock used in the defaulted digester A (which means we started with already seeded feedstock) plus approx. 7 liters of original fresh manure which was kept in the refrigerator as stock.

7.3.3 Digester D:

- Feedstock: Concentrated Screened Cow Manure from AFC.
- Date of fed: 4^{th} of May 2004.
- Shape: two cylindrical plastic buckets, one as feedstock container and the other as dome and gas.
- Dimensions: container diameter ≈ 8.8 cm and height =17 cm, while the dome diameter ≈ 8.5 cm, and height = 16cm
- Total initial solids (Ts) percentage: 7.2 %. Moisture content: 92.8 %.

- Total initial Volatile solids percentage: 2.0 %.
- Initial pH = 7.08

The digester was made and in the next day gas was yielded and followed the following scheme

Table 7.3 Gas Yielding with Time in Reactor D.

Date	hrs passed	Cumulative yielded gas quantity(mls)	Remarks
4th, May, 04	0	0	Starting day
9th, May, 04	120	125	Friction between dome and container estimated
12th, May, 04	192	216	Friction between dome and container estimated
16th, May, 04	288	318	Friction between dome and container estimated
27th, May, 04	552	415	Stop

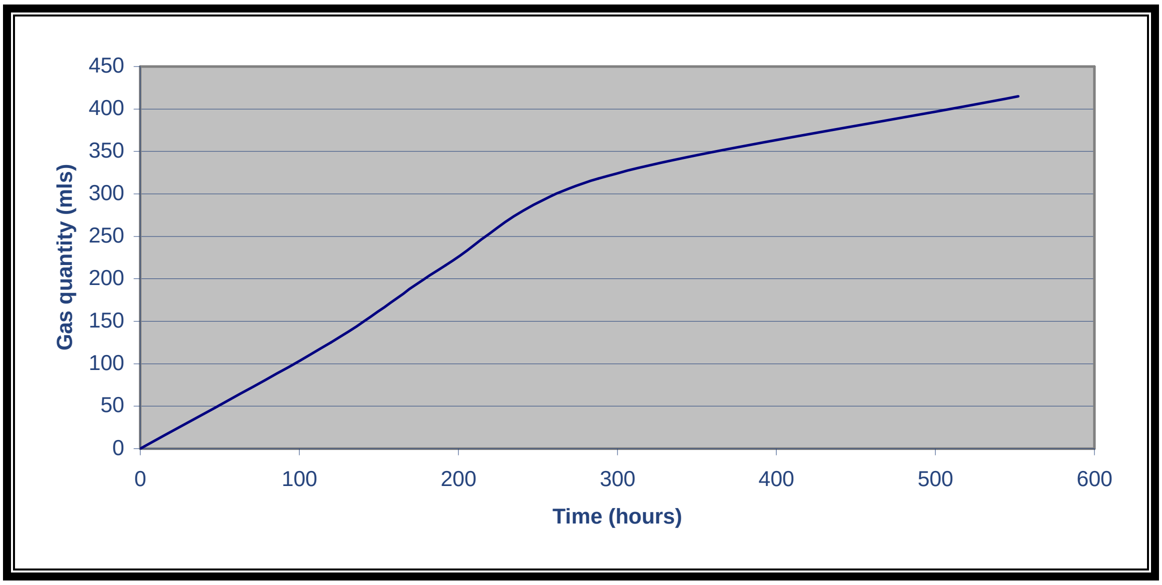

Figure 7.3 Cumulative yielded gas quantity versus time in bio-digester D.

7.4 AFC BIOGAS PLANT

- Type: Indian type.
- Date of construction: March 2004
- Date of fed: 10^{th} –17^{th} of May 2004.
- Digester effective volume (V_D)= 19500 L.
- Feedstock: Concentrated Screened Cow Manure from AFC.
- Total initial solids (Ts) percentage: 1.4 %.
- Total solid Quantity of feedstock (Q_{total}) = 275 kg.
- Total initial Volatile solids (Vs) percentage: 0.4 %.
- Total Quantity of Vs = 78 kg
- Initial Total Dissolved Solvents = 4350 gm/l.
- Initial Electric Conductivity = 4900 µs/cm.
- Initial pH = 7.2
- Initial dissolved oxygen = 1.02 g\L.

- Retention time proposed = 35 days : 1 cycle.
- Quantity of slurry required per cycle = 19500L.
- Daily supply = 19500/35 = 557 L/day.

Table 7.4 Gas Yielding with Time in AFC plant.

Date	**Hrs Passed**	**Average reading (cm)**	**Quantity of gas generated (L)**	**pH**	**Temperature (bar)**	**Remarks**
May 10th 04 12:00	00.00	00.00	0	7.11	20	Installation of the bioreactor
May 11th 04 12:00	24	52.50	2120	7.2	21	Feeding goes on
May 12th 04 12:08	48:08	52.50	2120	7.12	28	Feeding goes on
May 13th 04 12:30	73:38	69.00	2813	7.12	25	Gas pressure meter is defect
May 14th 04 --:--	No measurement record					Feeding goes on
May 15th 04 10:50	120:00	78.75	3210	7.2	21	Feeding goes on
May 17th 04 08:00	164:00	89.50	3649	7.13	20	Feeding goes on
May 18th 04 09:00	189:00	108.75	4433	7.18	20	Feeding goes on
May 19th 04 09:00	212:00	199.25	8123	7.27	22	Feeding goes on
May 20th 04 09:00	237:30	267.00	10885	7.85	15	Feeding goes on
After that the gas outlet was opened until the gas dome lowered to 0.0 cm (on 20th May 2004 17:30, the major constitute of the yielding biogas was found to be CO_2						
May 21th 04 --:--	No measurement record					
May 22th 04 10:00	277:00	37.00	13800	7.8	23	No more feeding
May 23th 04 10:00	302:45	74.10	14700	7.3	24	No more feeding
May 24th 04 10:00	328:00	100.75	15800	7.45	28	No more feeding
May 25th 04 10:00	350:00	127.75	16500	7.43	25	No more feeding
May 26th 04 09:00	373:00	149.00	17500	7.12	24	No more feeding
May 27th 04 12:00	401:00	186.25	18800	7.3	28	No more feeding
May 29th 04 12:00	449:00	235.25	20800	7.43	28	No more feeding
May 30th 04 09:00	470:00	263.00	21607	7.13	28	No more feeding
After that the gas outlet was opened until the gas dome lowered to 0.0 cm (on 30th May 2004 09:30, the major constitute of the yielding biogas was found to be CO_2						
June 1st 04 08:00	517:00	49.20	23613	7.11	20	No more feeding
June 2nd 04 09:00	542:00	99.00	25643	7.15	20	No more feeding
June 3rd 04 10:00	567:00	146.60	27584	7.16	25	No more feeding
June 4th 04 12:00	593:00	196.30	29610	7.13	25	No more feeding

June 5th 04 12:00	617:00	241.30	31445	7.2	26	No more feeding
June 6th 04 12:00	641:00	291.00	33471	7.15	27	No more feeding
After that the gas outlet was opened until the gas dome lowered to 0.0 cm (on 6th June 2004 09:00, the major constitute of the yielding biogas was found to be CO_2						
June 7th 04 12:00	663:00	56.00	35754	7.11	28	No more feeding
June 8th 04 08:00	683:00	92.00	37322	7.23	27	No more feeding
June 9th 04 09:00	708:00	147.50	39484	7.23	21	No more feeding
June 10th 04 08:00	731:00	162.50	40112	7.15	20	No more feeding
June 12th 04 10:00	781:00	201.00	41662	7.2	28	No more feeding
June 14th 04 10:00	821:00	217.00	42322	7.11	26	Gas grow slowly
June 16th 04 10:00	861:00	240.00	43282	7.05	25	Gas grow slowly
June 17th 04 10:00	911:00	249.50	43642	7.2	27	Gas grow slowly

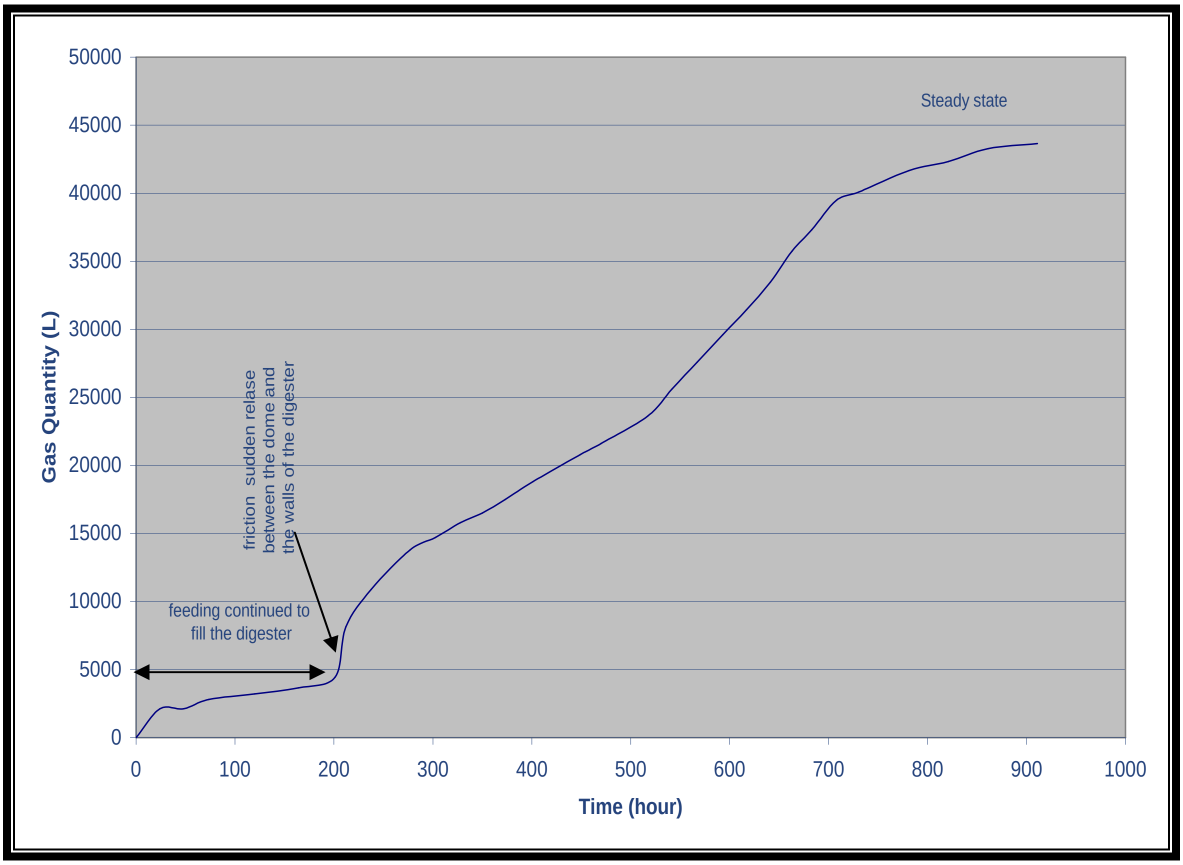

Figure 7.4 Cumulative Yielded Gas Quantity Versus Time in AFC Plant.

- **Comment:**

In the first stage of operating the biogas- meant after putting down the gas holder (Dome) - feeding continued to fill the digester up to the desired size (19.6 m^3) for some few days (approx. 10days).

Most biogas released was found to be rich in CO_2, H_2O and < H_2S (and others???)., trying to burn the biogas released failed which means that the methane percentage in the released biogas was still below at least the 60 % of the total volume of the biogas. This percentage (60% methane) is considered the minimum percentage needed for the biogas to be burnable. (Many references in the literature).

In the 12^{th} of June the trying to burn the biogas was successfully, the characteristics of the flame were odorless and colorless.

CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

8.2 RECOMMENDATIONS

CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS

This study presents the conclusions only related to the AFC biogas plant. These conclusions could be -but with reservation- applied to other areas in Palestine taking in the account their special environmental, social and economical conditions.

8.1 CONCLUSIONS

From the literature review laboratory and field investigations and experiments run, the following conclusions could be drawn:

1- To use biogas technology in Palestine began lately compared with other regions in the world or even in the Middle East countries.

2- In addition to AFC plant, there are three other plants in work now; the first is the Jericho Pobay Garden Plant established in 1998 with $5m^3$, effective volume, the second is Al Najah University Plant constructed in the year 2000, with effective volume of 15 m^3, and the third is Farajalla Farm biogas plant in Edna- Hebron, which was built in 2002 with effective volume approximately $9m^3$(now abandoned due to financial difficulties).

3- Bio-waste decomposition via anaerobic fermentation in Palestine follows the same trends as in many other countries with the same geographic, environmental and climatic conditions.

4- The amount of biogas that can be generated in the Palestinians territories could be huge enough to cover considerable demands especially in the rural fertile areas. This fact can be enhanced through disseminating the culture of biogas generation processes among various sectors in the Palestinian society.

5- Using the Indian biogas model in AFC is considered a good real start to generate methane from cow manure. Anyhow, some modifications to AFC design should be added if new plants are going to be constructed.

6- AFC biogas plant is considered a major part in the AFC integrated system to manage and valorize the wastes (especially the bio-wastes) in the farm. It turns the cow manure into beneficial biogas and soil fertilizer (effluented slurry) (see Figure 8.1).

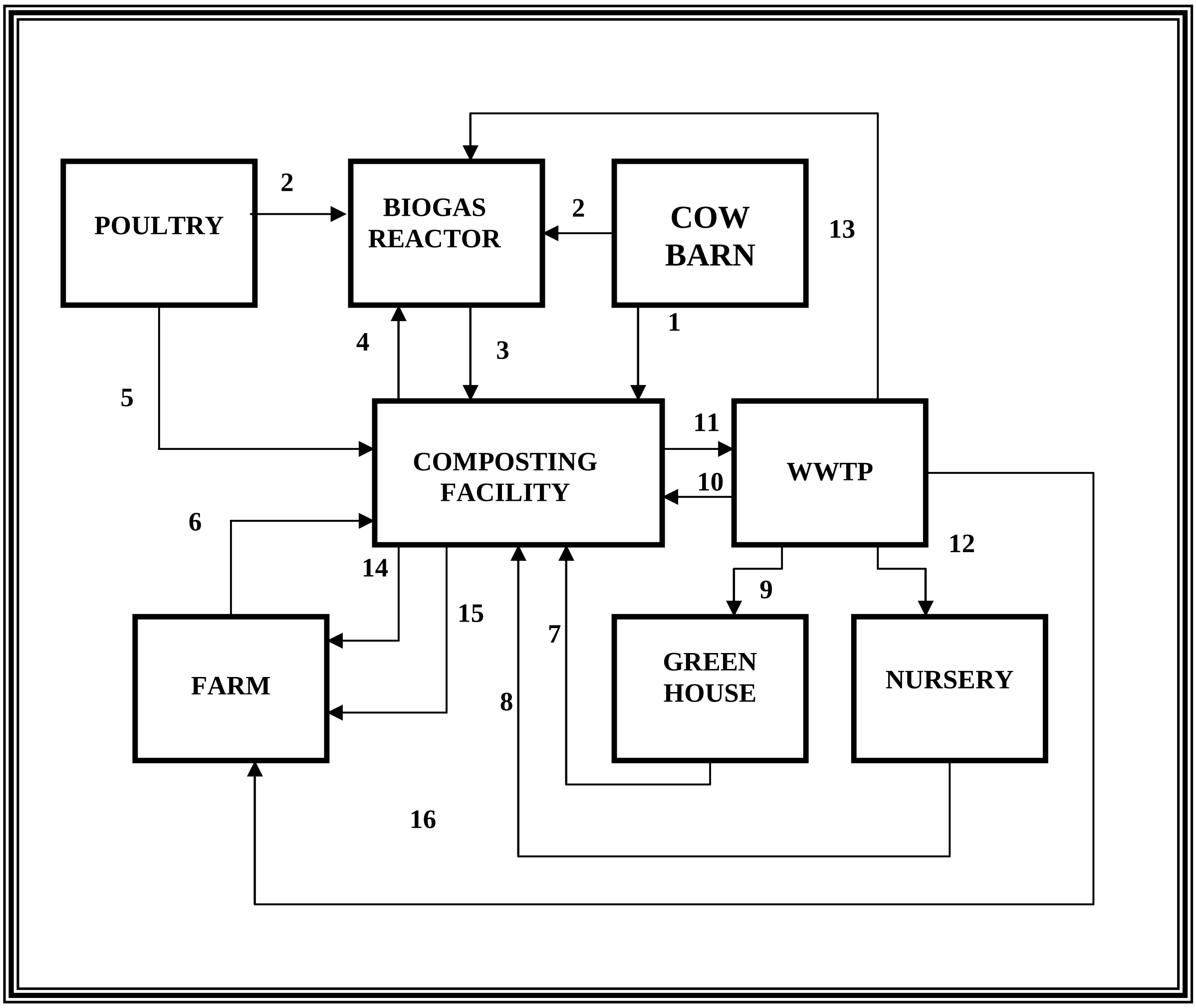

Fig 8-1: Symbiotical wastes reclamation - system in Al-Arroub Farm Complex: (1.2.5 Manure 3: bio digester effluent; 4, 11, 14: Compost tea 6.7.8 Farm residues, straw, trees trimmings 9, 12, 16 reclaimed water. 10, 13: sludge. 15: Compost).

7- It is found that generation of biogas in AFC is economically feasible and environmentally beneficial and it helps improving the cleaning level in the farm.

8- AFC presents an excellent example as demonstration site to extend and disseminate the biogas generation methodology from bio-waste in the southern regions of West Bank of Palestine.

9- A water-jacketed biogas plant would for sure increase the efficiency of yielding methane at winter time. The hot water can be obtained from a hot water solar cell.

10- Produced biogas did not burn during the first approx. 2 weeks of dome installation, because the percentage of CH_4 (methane) was still under 60% which is the lowest percentage in the whole gas produced needed for biogas to burn. This was detected by smelling the biogas. It was observed that the percentage of bad odours (mainly due to the higher content of H_2S in the biogas) decreases as the percentage of methane increases. This increase in methane percentage is axiomatically on the cost of CO_2 gas.

    On Thursday 10th of June 2004 and during the daily examination to try to burn the biogas produced, it was observed that the biogas started to burn which means that the percentage of the methane (CH_4) in the generated biogas should have crossed the 60% of the total.

    To detect qualitatively and quantitatively the types of gas produced, it is recommended to buy a gas chromatographer.

8.2 RECOMMENDATIONS

For sure, many recommendations could be drawn from this study, among them are:

1- It would have been better if some modifications were introduced in the AFC plant design. Such modification are:

a- to build up a pipe of galvanized iron in the middle of the digester body that erects perpendicularly upwards where a pillar in the dome can enter easily to avoid any distortion or tilting of the dome (gas holder), in going upwards when full or downwards when empted (see Figure 8.2). This modification can save building up many other accessories like iron arms, wheels and rails and other fixing devices.

b- Its worth to mention that both the pipe and the pillar should be originally centralized to get the desired smooth and light tracking of the dome in and out of the digester.

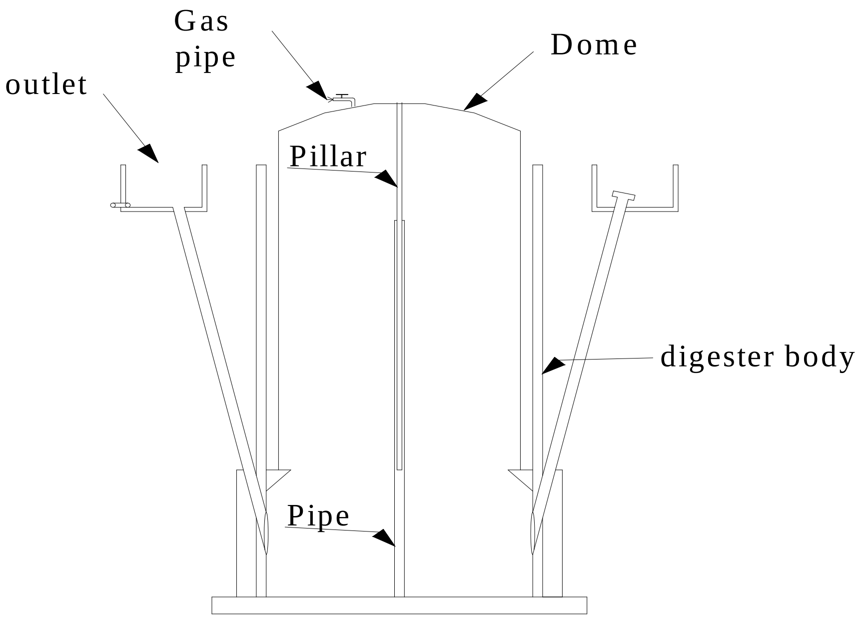

Figure 8.2: Simplified pipe and pillar building up in a movable dome reactor.

2- It is recommended to disseminate the technology of generating biogas from bio-waste to many sectors in the Palestinian society.

3- A complete and efficient design for a biogas plant in a cow barn is proposed in the figure below (Figure 8.3)

This design may save costs, spare time and efforts and yields more biogas. To implement such a design in the ground it is recommended to evaluate its performance in advance.

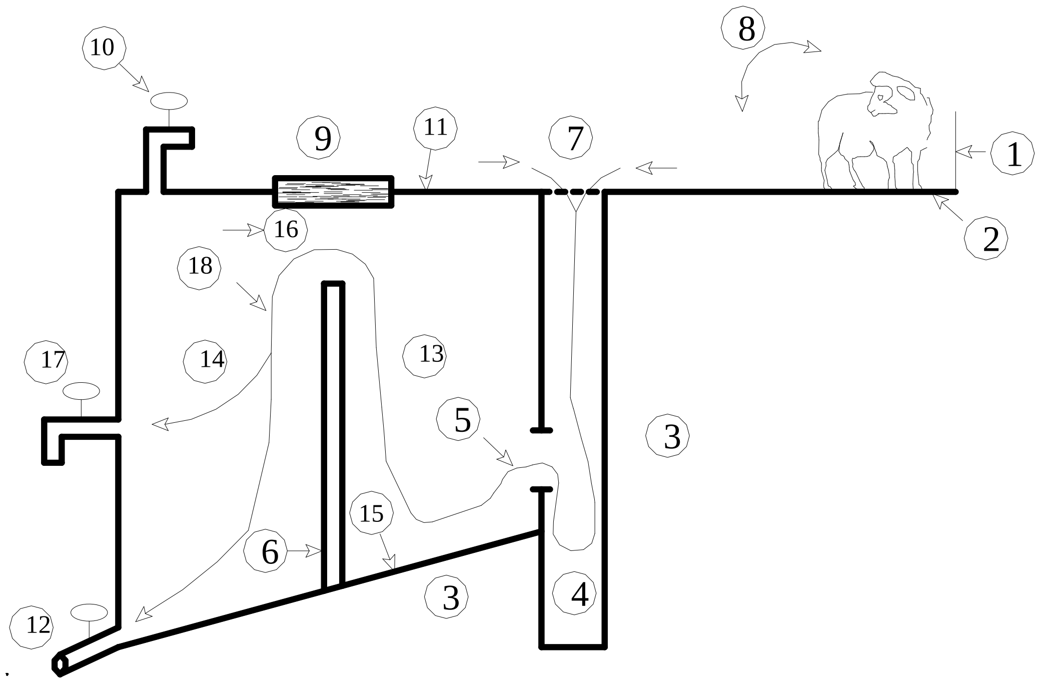

Fig 8.3: Proposed new biogas generation plant for cow barn

1. Fence of barn for a cow barn.
2. Ground of the barn with a slope of $1^0 – 2^0$ towards the mixing pit.
3. The bedrock.
4. Sedimentation (pit) tank to collect grit and stones. it is also the mixing pit.
5. Opening to the main chamber.
6. Crossing wall.

7. Galvanized iron sieve (heavy duty type) with openings of 1/2 to screen Straw and trimmings and large blocks from entering the mixing pit.
8. The cow barn and cows.
9. Manhole cover: gastight 100%.
10. Gas outlet valve.
11. Digester ceiling: slope 1 - 20 towards the mixing pit.
12. Outlet valve to empty the tank.
13. Digester first chamber.
14. Digester second~ chamber.
15. Digester ground: slope 4 - 50.
16. Opening between the two chambers.
17. Slurry outlet valve.
18. Slurry track.

4- To utilize the excess quantities of bio-wastes like tree trimmings, grass, straw and many other barn and agricultural residues specially in winter times, it is recommended to build up a closed chamber of suitable size capacity and dump all the above mentioned biosolids in. By closing the chamber firmly, the fermentation process will start acting releasing considerable quantities of biogas and leaving high quality compost in the chamber.

بسم الله الرحمن الرحيم

نموذج رصد محطة بيوغاز

اسم المحطة: محطة مزرعة العروب النموذجية.
نوع الهاضم: قبة متحركة
التاريخ: / /٢٠٠٤ الساعة: ....

الرقم	الظاهرة	نعم	لا	ملاحظات
١	هل توجد روائح؟ نوعيتها ومن اين تخرج؟			
٢	هل هناك تنفيس في القبة المتحركة؟ اين وما حجمه؟.			
٣	هل هناك تسريب في الهاضم؟ من اين وما حجمه؟			
٤	حموضة الحمأة في الهاضم .			
٥	حشرات. حدد نوعها.			
٦	طيور او حيوانات.حدد نوعها.			
٧	هل تم وضع خامة هذا اليوم؟ الكمية والتركيز.			
٨	هل هناك مواد طافية في الهاضم؟ما هي؟			
٩	هل القبة عمودية؟ في اي اتجاه ميلها وما قيمته؟			
١٠	هل هناك اية نباتات أو طحالب في الهاضم؟			
١١	هل هناك أية كائنات دقيقة مرئية في حمأة الهاضم؟ ما هي؟			
١٢	هل دخل الهاضم اية مواد غريبة؟ ما هي ؟			
١٣	شمس..			ساطعة ،مع قليل من الغيوم، غيوم كثيفة
١٤	مطر..			رذاذ،مطر عادي،أمطار غزيرة
١٥	رياح.			نسيم، رياح عاديه،رياح عاتية،خماسين.
١٦	هل لاحظت اي خلل فني في الهاضم؟ حدد نوع الخلل وموقعه.			
١٧	هل مؤشر الغاز يعمل؟ ما هي القراءة؟			
١٨	وضع حجرة التزويدInfluent؟			
١٩	وضع حجرة السيبEffluent؟			
٢٠	أية امور اخرى؟			

درجة حرارو الجو عند أخذ العينات : .... درجة حرارة الخامة في الهاضم: ....

اسم وتوقيع معبئ البيانات..

فريق البحث:
عبد الرزاق ابو رحمة.
رامي دراغمة.

Figure A-1: The AFC cow barn

Figure A-2: The pit dug for the AFC plant, rain water was emptied afterwards.

Figure A-3: The location of the pit near thr cow barn.

Figure A-4: Composting facility (chamber receiving the biogas slurry)

Figure A-5: Digester + connection pipe to the outlet chamber.

Figure A-6: Inlet opening to the digester horizontal with cantilever beam

Figure A-7: Digester during installation in the pit.

Figure A-8: Floating Drum ceiling from inside

Figure A-9: Outlet pipe and 8" (with the floor level of the effluent receiving chamber)

Figure A-10: Inlet pipe 6" in the mixing chamber with screened mesh (notice that the pipe is 30cm higher than the ground.

Figure A-11: Digester prior to floating dome installation

Figure A-12: Convex ceiling

Figure A-13: Dome (inside view)

Figure A-14: Digester + the mixing chamber + outlet receiving chamber + barn flushing chamber (middle) does not connect to the digester.

Figure A-15: Digester during installation

Figure A-16: 2 days installation of the plant

Figure A-17: AFC biogas plant (gas trapped in)

Figure A-18: General view of AFC plant

Figure A-19: Gas holder full of biogas

Figure A-20: General view of cow barn

Figure A-21: Ignitions of biogas from laboratory biogas reactor.

Figure A-22: Gas meter device

Figure A-23: pH meter

Figure A-24: Dissolved total oxygen apparatus.

Figure A-25: Laboratory balance

Figure A-26: Batch bio-digester

Figure A-27: Students in lab work.

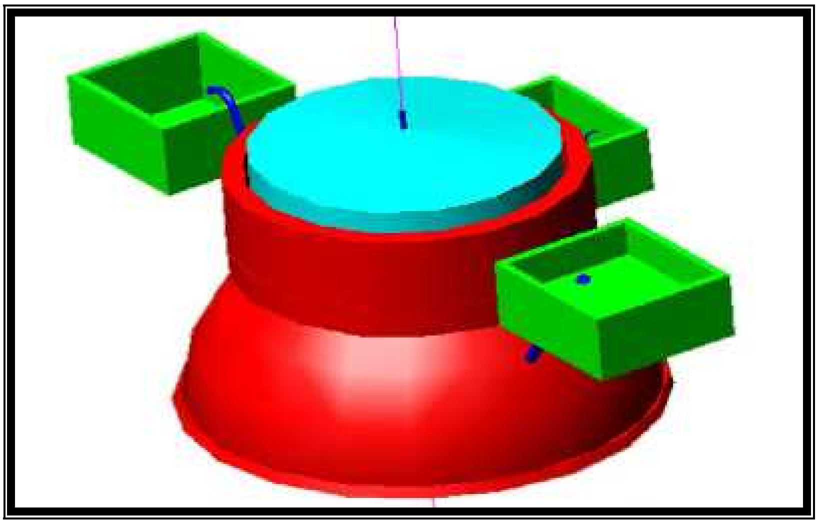

Figure A-28: AutoCAD image of Edna biogas plant

APPENDIX "A"

APPENDIX "B"

APPENDIX "C"

Total Volatile Solids Calculation

Date: 2-5 May 04.

Procedure of measuring the total volatile ("degradable") solids of the manure (bio-waste) sample:

1. Stir and mix the feedstock (biowaste / manure ….etc) to make it completely homogeneous.
2. Take at least 3 batches from the will mixed feed stock, each batch at least 150 grams.
3. Put every 150 grams in an aluminum tray of defined weight (wt. of container). And then put them in the oven at 105 C^o for 24 hrs. Weigh the tray with the wet matter (wt. of container + wet matter) before inserting it in the oven.
4. Take the tray out of the oven and quickly weigh it (wt. of container + dry matter) with its contained dry feedstock.
5. Put the tray with its dry contents in the oven at approx. 600 Co for 1 hrs; then take it out carefully and weigh it again (wt. of container + ash).
6. to calculate the following parameters:

   Total solids (TS %), the total volatile solids (VS %) and the moisture content (MC %), we follow the Table below.

Reactor	Sample	Container wt. (gm)	Cont. + wet feedstock wt (gm)	Wt. of con. + dry FS after 24 hrs at 105 C^o	Wt. of con. + dry FS after 1 hr at 600 C^o	Ash wt.	MC	VS%	TS%
A	1	68.1	273.1	97.21	78.56	10.46	85.8	9.1	14.2
	2	69.2	307.9	102.52	80.86	11.66	86.0	9.1	14.0
	3	69.1	289.9	100.67	80.58	11.47	85.7	9.1	14.3
B	1	70	311.2	73.83	72.58	2.58	98.41	0.52	1.59
	2	68.1	401.7	73.37	71.60	5.27	98.42	0.53	1.58
	3	68.8	420.0	74.35	72.56	5.55	98.42	0.51	1.58
C	1	69.6	291.3	101.35	81.35	11.75	85.5	9.2	14.5
	2	68.7	327.7	106.26	82.95	14.25	85.5	9.0	14.5
	3	69.4	298.2	103.1	81.7	12.3	85.4	9.2	14.6

APPENDIXES

LIST OF FIGURE

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