An-Najah National University
Faculty of Graduated Studies

An Educational Biogas Project in Tulkarem

By

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Committee Decision

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This thesis was defended successfully on the 13th of March 2003 and approved by:

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2. Dr. Abdellatife Mohamed – External examiner	
3. Prof. Ghassan Saffarrini – Internal examiner	
4. Dr. Afeef Hasan – Member	

Dedication

To My Parents

My brothers especially Dr. Imad

My Wife

Al-Aqsa martyrs

Acknowledgements

First of all great thanks to God who gave me power to complete this dissertation, I am also too much grateful to my family who gave me assistance throughout the course of this work. My special thanks to my supervisor Dr. Muneer Abdoh who gave full help and advice at any time; also I would like to thank Dr. Abdellatif Mohamed (Director of Irrigation & Environment PARC) for his help. I am grateful to Dr. Jamal Abu Omer for his advice, for Dr. Nidal Zater from chemistry department and Mr. Awad Mufleh Abu Amer for his help. I would like to thank all my instructors in physics department.

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Abstract

The construction and production of biomass digesters has become very important in recent years due to their wide advantages. A systematic study of different properties of the biogas and its amount provides us with a great deal of information about digesters. Thus the appropriate nature and type of digesters are suitable for different areas in Palestine. The experiment described in this work was carried out in Tulkarm city in the northern part of Palestine. The floating drum type of digesters was used in this work.

When the addition rate of slurry added on daily basis was 50 liters/day, the amount of biogas produced is $0.685 m^3$, the average pH is 7.91 and the average ambient air temperature is 34.055°C while for the 100 liters/day rate, the amount of biogas produced was $1.610\ m^3$, the average pH is 7.96, and the average ambient air temperature is 34.29°C. In both cases the slurry temperature was 27°C. Therefore, the possibility of making use of biogas as a source of energy in Palestine is promising and building more biogas digesters in Palestine is recommended.

Chapter One
Introduction

The sun has shunned on the earth for about 5 billion years. The original atmosphere was composed of hydrogen, helium, nitrogen, methane, ammonia, and some carbon dioxide. It should not be surprising that plants have succeeded at using and storing solar energy over the course of three billion years. Humanity has not yet been successful at capturing and storing solar energy for use at later times [1].

Human beings are continuously using biomass as a source of energy such as, wood ‹coal, forage, animal wastes, bagasse (the woody residue of sugar cane), industrial wastes, municipal solid wastes and municipal sewage.

Some countries as, India, China, Brazil, and United States 0f America got to use biomass as a source of energy, since it is considered to be renewable energy and because of the problems which are associated with conventional sources of energy. Sugar cane count for 7% of Hawaii's energy [2], cattle dung is used to supply gas to (20,000) homes in California [1].

Wastes generated in a community can be a valuable energy and material resource; however past and current waste disposal and treatment practices consume energy and have led this resources to become a serious environmental burden. Fortunately, being a resource as well as a burden has generated some extremely creative and economically attractive waste-to-energy systems to utilize wastes while mitigating their environmental impact [2].

It is hoped that this research will promote an appreciation of the environmental problems, energy demand and resources, and will clarify the economics and risks involved are essential to define the vital role of the waste-to-energy systems in the future.

There is a universal concern about four major, ever-increasing environmental problems: urban air pollution, acid rain, the global greenhouse effect and surface and ground water degradation. All have far reaching and profound consequences and can be related directly or indirectly to how we produce and utilize energy and dispose of our wastes [2]. All countries suffer from wastes (waste water, municipal solid wastes, industrial or agricultural wastes), the community must deal with them. Anaerobic digestion is very effective in waste-to-energy systems for many reasons.

The primary reason is that the gas produced will be at least 50% methane, the balance being carbon dioxide. Also, most available wastes have considerable associated water, with moisture levels ranging from 25 to 99% [3]

Anaerobic digestion requires water as a medium and is less affected by variations in moisture level. On the other hand, fermentation of manure to methane and fertilizer by use of an aerobic bacteria could clean up the environment and it supports the agriculture by providing efficient fertilizer to land.

Chapter Two
Digesters and Their Types

2.1 Historical Review

Digesters differ in size depending on whether they serve a family or community. With continuous load digesters organic wastes are introduced regularly to ensure continuous supply of gas [4]. The key to popularize biogas utilization is to obtain cheap and reliable digesters. For this, the Chinese scientists began research on rural digesters as early as some fifty years ago. Among them Luo guo- ruo was the first who had succeeded in obtaining cheap and reliable digesters [5].

Application was considered practical after the operation of several years, and the first batch of biogas digesters was built in Guangdon province in 1929 [5]. Luo`s water pressure digester (fixed dome digester) won the reserved patent approved by the industry and commerce ministry in 1930. In the following year, Luo established in Shanghai China Guo-rui general firm of gas, thus biogas technology was commercialized. The firm had sponsored monthly training courses to train technicians from various places, thus further developed the utilization of biogas. Then in 1936, biogas was adopted to power generation for use of inhabitants at Anhua town of Zhuji country in Zhejiang province [6]. In 1937, two rectangular digesters, 46m^3 each, were built juxtaposedly at Dongyangyuan village of Wu`an country in Hebei province, the digesters are still operational after they have been mended in 1976. Unfortunately, the innovation developed very slowly owing to the lack of attention and support from the government [6].

After the founding of the People's Republic, of China digesters have been successively built in many villages to solve the problem of fuel shortage. A high tide emerged again in Guangiong province in 1958 in the research and development of biogas utilization, and a large number of technicians were trained there for other parts of the country, besides the technicians sent from this province to train technicians there. The first nation wide conference of experience exchange of biogas utilization was convened in Gaohe country of Guanglong by the end of 1953 [7]. Not only water pressure digester was developed then, but also floating cover digester and membrane gas holder digester were put into experiment. By that time, however, problems did exist for all three types of digesters. Anti-leakage was not perfectly achieved for water pressure type. Too high cost was applied to the floating cover, and the membrane was inconvenient owing to low quality. Thus, none of the digesters had been further developed. Water pressure digesters reached a practical stage in 1968 by the improved technology of construction obtained from repeated experiments of some peasants in Zhongjiang country of Sichuan province, and biogas technology was again developed [8]. As a result of attention and promotion from Chinese government, the development was at a peak and some seven million digesters have been built in China [5]. Most of the digesters are of water pressure type, while some floating cover type and membrane gas holder type digesters were also developed [8, 9].

2.2 Biogas plant's components

There are many available simple and developing biogas plants to produce biogas. These plants are developed in European and developing countries. On the other hand, there are completed and heated by solar energy biogas plants [3]. However, a typical biogas plant consists of:

1) A Digester or Fermenter

This 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. Co-fermenters have two or more separated fermenters. The gas can be collected inside the digester, then usually with a flexible cover. The digester can also be filled completely and the gas stored in a separate gas holder.

2) Gas-holder

This is usually made of flexible material. Therefore, it has to be protected against weather. It can be placed either above the substrate, then it acts like a balloon plant, or in a separate gas-bag.

3) Mixing Pit

This varies in size and shape according to the nature of substrate. It is equipped with propellers for mixing and/or chopping the substrate and often with a pump to transport the substrate into the digester. At times, the substrate is also pre-heated in the mixing pit in order to avoid a temperature shock inside the digester.

4) Slurry Store

This is used for storage of slurry during winter. The store can be open (like conventional open liquid manure storage) or closed and connected to gas production. Normally, the store is not heated and only agitated before the slurry is spread on the field.

5) Gas Use Element

In Europe, in 95% of the cases, a thermo-power unit produces electricity for the farm, the grid and heat for the house, greenhouses and other uses. The thermo-power unit has the advantage, that the required energy can be produced in any mixture of gas and fossil energy. It can, therefore, react to periods of low gas production and high energy requirements or vice versa [4].

2.3 Types of Biogas Plants

The most familiar types in developing countries are:

2.3.1 Fixed-dome plants

The costs of a fixed-dome biogas plant are relatively low. It is simple as no moving parts exist. There are also no rusting steel parts and hence a long life of the plant (20 years or more) can be expected. The plant is constructed underground, protected from pHysical damage and saving space. While the underground digester is protected from low temperatures at night and during cold seasons; sunshine and warm seasons take longer time to heat up the digester. No day/night fluctuations of temperature in the digester positively influence the bacteriological processes. The construction of fixed-dome plants is labor-intensive; thus creating local employment. Fixed-dome plants are not easy to build. They should only be built where construction can be supervised by experienced biogas technicians. Otherwise plants may not be gas-tight (porosity and cracks [15] .

The elements of a fixed dome plant (The Nicaro Design) are shown in the fig.1 below:

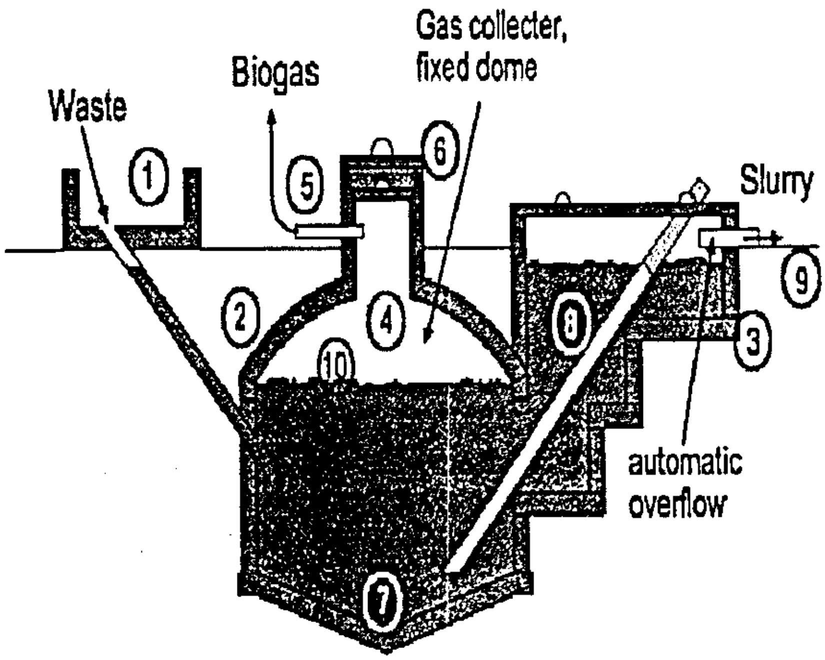


Fig.1 Fixed dome plant Nicaro design : 1. Mixing tank with inlet pipe and sand trap . 2. Digester 3. Compensation and removal tank .4 . Gas holder . 5.Gas pipe . 6. Entry path, with gas tight seal 7. Accumulation of thick sludge. 8. Outlet pipe . 9. Reference level . 10. Supernatant scum broken up by varying level .

A fixed-dome plant comprises a closed dome-shaped digester (fig. 2) with an immovable rigid gas holder and a displacement pit, also named 'compensation tank'. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensation tank. Gas pressure increases with the volume of gas stored, i.e. with the height difference between the two slurry levels. If there is little gas in the gas-holder, the gas pressure is low.

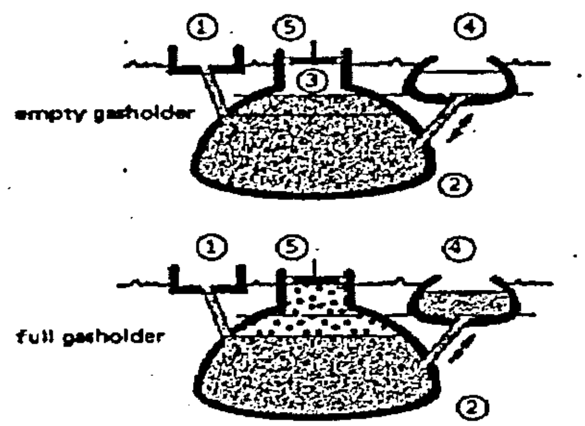


Fig.2 Basic functions of a fixed-dome biogas plant; 1. Mixing pit, 2. Digester 3. Gas holder, 4. Displacement pit, 5. Gas pipe

Digester

The digesters of fixed-dome plants are usually masonry structures, structures of cement and ferro-cement exist. Main parameters for the choice of material are:

- Technical suitability, stability, gas-and liquid tightness
- Cost-effectiveness
- Availability in the region and transport costs
- Availability of local skills for working with the particular building material

Fixed dome plants produce just as much gas as floating-drum plants, if they are gas-tight. However, utilization of the gas is less effective as the gas pressure fluctuates substantially. Burners and other simple appliances cannot be set in an optimal way. If the gas is required at constant pressure (e.g., for engines), a gas pressure regulator or a floating gas-holder is necessary [15].

Gas –Holder

The top part of a fixed-dome plant (the gas space) must be gas-tight. Concrete, masonry and cement rendering (fig.3) are not gas-tight. Gas space must therefore be painted with a gas tight-layer (e.g., Water-proofer, Latex or synthetic paints) a possibility to reduce the risk of cracking of the gas-holder consists in the construction of a weak-ring in the masonry of the digester.

Fig.3: Fixed-dome plant in Tunisia. The final layers of the masonry structure are being fixed

This 'ring' is a flexible joint between the lower water proof and the upper (gas-proof) part of the hemispherical structure. It prevents cracks that develop due to the hydrostatic pressure in the lower parts to move into the upper parts of the gas holder [15].

Types of Fixed Dome Plants

1. Chinese fixed-dome plant (fig.4) is the archetype of all fixed dome plants. Several million have been constructed in China. The digester consists of a cylinder with round bottom and top.

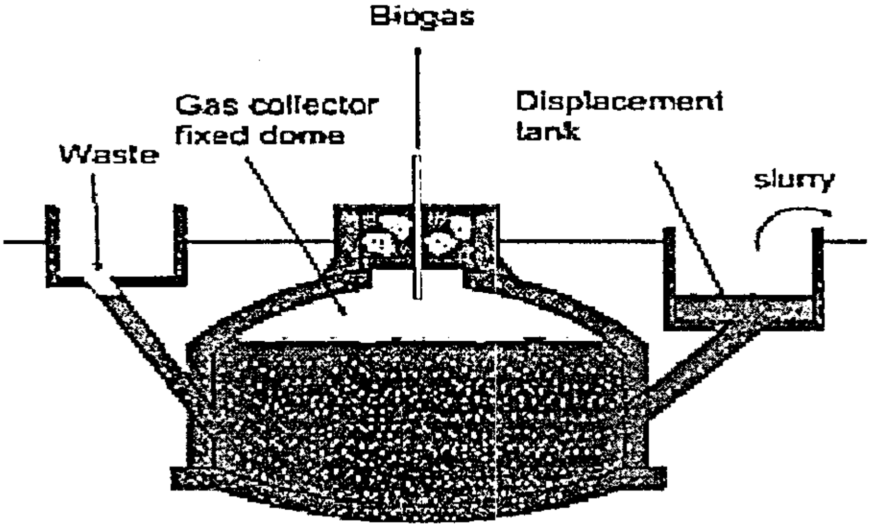


Fig.4 :Chinese fixed dome plant

2. Janata model was the fixed-dome design in India, as a response to the Chinese fixed plant. It is not constructed anymore. The mode of construction lead to cracks in the gas holder – very few of these plant had been gas-tight.

3. Deenbandhu‹ the successor of the janata plant in India, with improved design, was more crack-proof and consumed less building material that the janata plant. with a hemispHere digester.

4. CAMARTEC model (fig.5) has a simplified structure of a hemispherical dome shell based on a rigid foundation ring only and a calculated joint of fraction, the so-called weak/strong ring. It was developed in the late 80s in Tanzania [15].

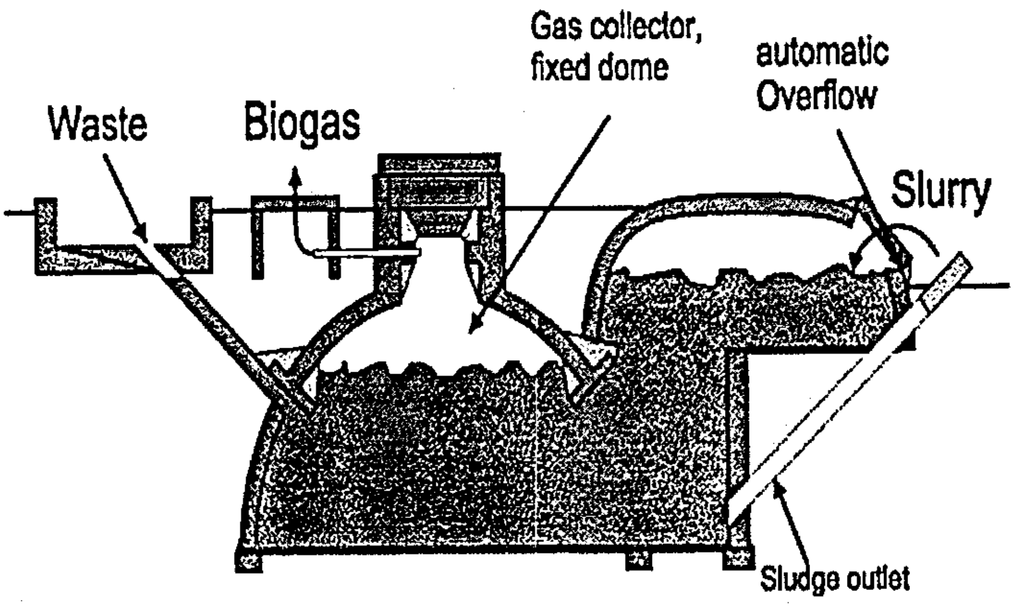


Fig.5 : Fixed dome plant CAMARTEC design

Disadvantages

Masonry gas-holders require special sealing material and high technical skills for gas-tight construction; gas leaks occur quite frequently; fluctuating gas pressure complicates gas utilization; amount of gas produced is not immediately visible, fixed dome plants need exact planning of levels; excavation can be difficult and expensive in bedrock [15].

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

2.3.2 Floating-drum Plants

In the past, floating-drum plants (fig.6) were mainly built in India, a floating-drum plant consist of a cylindrical or dome-shaped digester and a moving, floating gas-holder, or drum. The gas-holder floats either directly in the fermenting slurry or in a separate water jacket. The drum in which the biogas collects has an internal and/or external guide frame that provides stability and keeps the drum upright if biogas is produced, the drum moves up, if gas is consumed, the gas-holder sinks back.

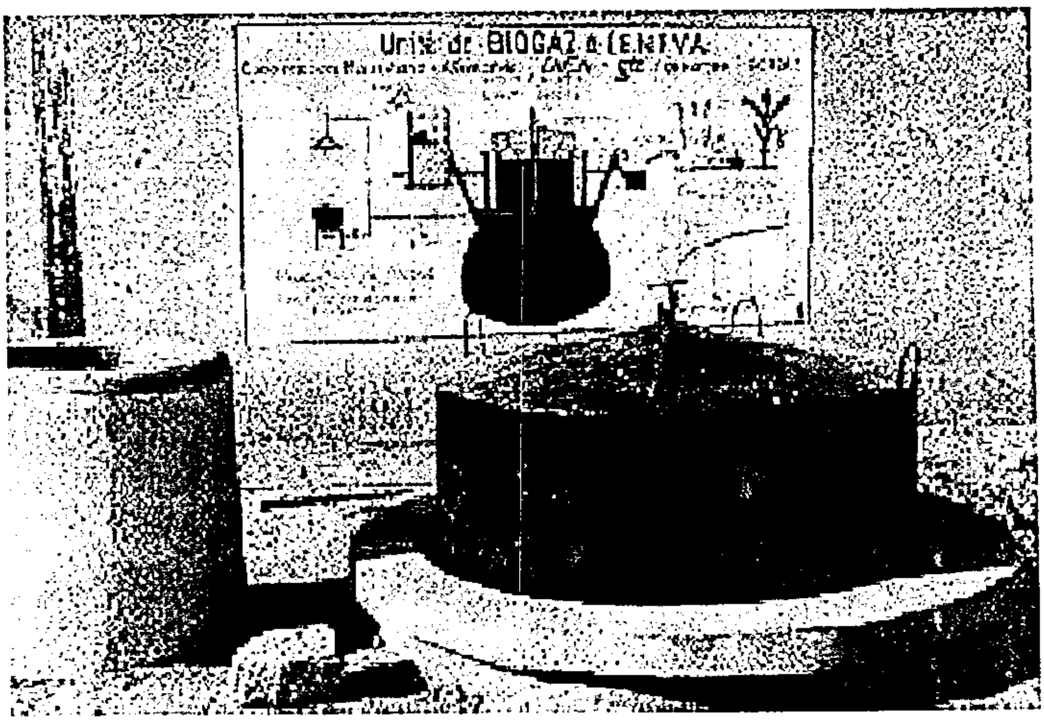


Fig.6: Floating-drum plant in Mauretania

Floating-drum plants are used chiefly for digesting animal and human feces on a continuous-feed mode of operation, i.e. with daily input. They are used most frequently by small-to middle-sized farms (digester size: 5-15 m^3) or in institutions and larger agro-industrial estates (digester size: 20-100 m^3).

Advantages

Floating-drum plants are easy to operate. They provide gas at a constant pressure, and the stored gas-volume is immediately recognizable by the position of the drum. Gas-tightness is no problem, provided the gas holder is de-rusted and painted regularly.

Disadvantages

The steel drum is relatively expensive and maintenance-intensive. Removing rust and painting has to be carried out regularly. The life-time of the drum is short (up to 15 years; in tropical coastal regions about five years). If fibrous substrates are used, the gas-holder shows a tendency to get 'stuck' in the resultant floating scum [16].

It is noteworthy to mention that the constructed digester in Tulkarm is of floating drum type. In addition to mentioned advantages and disadvantages of the floating drum plant above, there are some disadvantages related to this type which are:

1) The smallness of the drum volume.

2) Storage capacity of produced gas biogas in the digester is about 50%.

Water-jacket Floating-drum Plants

Water-jacket plants are universally applicable and easy to maintain. The drum cannot get stuck in a scum layer (fig.7), even if the substrate has a high solids content. Water- jacket plants are characterized by a long useful life and a more aesthetic appearance (no dirty gas-holder). Due to their superior sealing of the substrate, they are recommended for use in the fermentation of night soil. The extra cost of the masonry water jacket is relatively modest [16].

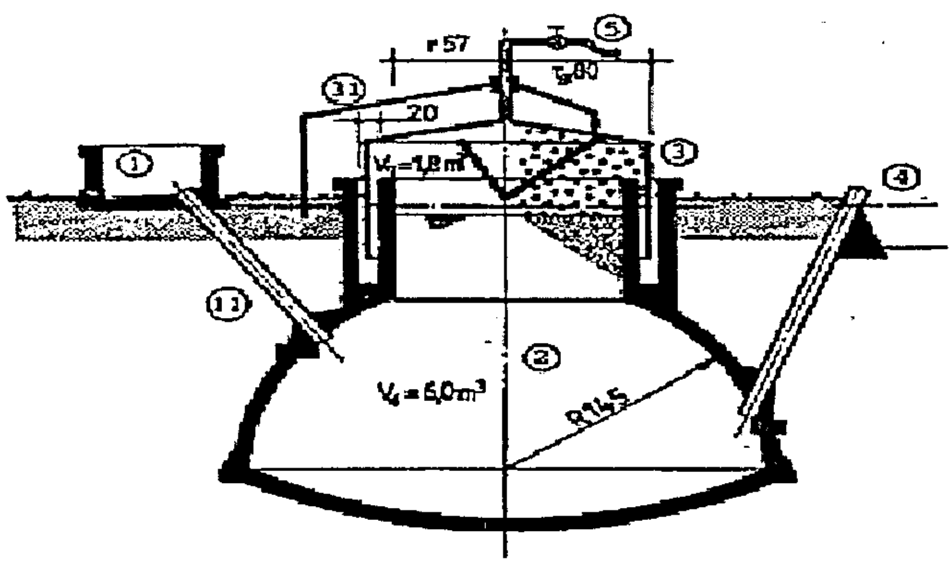


Fig.7 :Water-jacket plant with external guide frame. 1. Mixing pit, 11. Fill pipe, 2. Digester, 3. Gas holder, 31. Guide frame, 4.Slurry store, 5. Gas pipe

Material of Digester and Drum

The digester is usually made of brick, concrete or quarry-stone masonry with plaster. The gas drum normally consists of (2.5) mm steel sheets for the sides and 2mm sheets for the top. It has welded-braces which break up surface scum when the drum rotates. The drum must be protected against corrosion and this can be done through the use of suitable coating products, oil paints, synthetic paints and bitumen paints. Correct priming is important, thus, there must be at least two preliminary coats and one topcoat. Coatings of used oil are cheap and they must be renewed monthly. Plastic sheeting stuck to bitumen sealant has not given good results. In coastal regions, repainting is necessary at least once a year, and in dry uplands at least every other year. Gas production will be higher if the drum is painted black or red rather than blue or white, because the digester temperature is increase by solar radiation. Gas drums made of 2cm wire-mesh-reinforced concrete or fiber-cement must receive a gas-tight internal coating. The gas drum should have a slightly sloping roof, otherwise rainwater will be trapped on it, leading to rust damage. An excessively steep-pitched roof is unnecessarily expensive and the gas in the tip cannot be used because when the drum is resting on the bottom, the gas is no longer under pressure. Floating-drums made of glass-fiber reinforced plastic and high-density polyethylene have been used successfully, but the construction costs are higher compared to using steel. Floating– drums made of wire-mesh-reinforced concrete are liable to hairline cracking and are porous. They require a gas-tight elastic internal coating [16].

Guide Frame

The side wall of the gas drum should be just as high as the wall above the support ledge. The floating-drum must not touch the outer walls. It must not tilt, otherwise the coating will be damaged or it w-ill get stuck. For this reason, a floating-drum always requires a guide. This guide frame must be designed in a way that allows the gas drum to be removed for repair. The drum can only be removed if air can flow into it, either by opening the gas outlet or by emptying the water jacket. The floating gas drum can be replaced by a balloon above the digester. This reduces construction costs but in practice problems always arise with the attachment of the balloon to the digester and with the high susceptibility to physical damage [15].

Types of Floating-drum Plants

There are different types of floating-drum plants which are:

1. KVIC model with a cylindrical digester, the oldest and most widespread floating drum biogas plant in India
2. Pragati model with a hemispHere digester
3. Ganesh model made of angular steel and plastic foil
4. BORDA model: The BORDA-plant combines the static advantages of hemispherical digester with the process-stability of the floating drum and the longer life span of a water jacket plant [15].

To give an overview, we have chosen fictitious designs as they could be found in, for example Europe. The designs are selected in a way that all the typical elements of modern biogas technology appear at least once. All designs are above ground, which is common in Europe.

2.3.3 Balloon Plants

A balloon plant consist of a heat-sealed plastic or rubber bag (balloon), combining digester and gas-holder. The gas is stored in the upper part of the balloon. The inlet and outlet are attached directly to the skin of the balloon. Gas pressure can be increased by placing weights on the balloon. If the gas pressure exceeds a limit that the balloon can withstand, it may damage the skin. Therefore, safety valves are required; if higher gas pressure is needed, a gas pump is required. Since the material has to be weather and UV resistant, specially stabilized, reinforced plastic or synthetic caoutchouc is given preference. The useful life-span does not usually exceed (2-5) years.

Advantages

Standardized prefabrication at low cost; shallow installation suitable for use in areas with a high groundwater table; high digester temperatures in warm climates; uncomplicated cleaning, emptying and maintenance; difficult substrates like water hyacinths can be used.

Disadvantages

Low gas pressure may require gas pumps; scum cannot be removed during operation; the plastic balloon has a relatively short useful life-span and is susceptible to mechanical damage and usually not available locally. In addition, local craftsmen are rarely in a position to repair a damaged balloon [17]. Balloon biogas plants are recommended, if local repair is or can be made possible and the cost advantage is substantial.

2.3.4 Horizontal Plants

Horizontal biogas plants are usually chosen when shallow installation is called for (groundwater, rock). They are made of masonry or concrete.

Advantages

Shallow construction despite large slurry space.

Disadvantages

Problems with gas-space leakage, difficult elimination of scum[17] .

2.3.5 Earth-pit Plants

Masonry digesters are not necessary in stable soil (e.g laterite). It is sufficient to line the pit with a thin layer of cement (wire-mesh fixed to the pit wall and plastered) in order to prevent seepage. The edge of the pit is reinforced with a ring of a masonry that also serves as anchorage for the gas holder. The gas holder can be made of metal or plastic sheeting. If plastic sheeting is used, it must be attached to a quadratic wooden frame that extends down into the slurry and is anchored in place to counter its buoyancy. The requisite gas pressure is achieved by placing weights on the gas holder. An overflow point in the peripHeral wall serves as the slurry outlet.

Advantages

Low cost of installation (as little as 20% of a floating drum plant); high potential for self help approaches.

Disadvantages

Short useful life; serviceable only in suitable, impermeable types of soil[17]. Earth pit plants can only be recommended for installation in impermeable soil located above the groundwater table. Their construction is particularly inexpensive in connection with plastic sheet gas holders .

2.3.6 Ferrocement Plants

The ferro-cement types of construction can be applied either as a self supporting shell or an earth pit lining. The vessel is usually cylindrical. Very small plant (volume under 6 m^3) can be prefabricated. As in the case of a fixed dome plant, the ferrocement gas holder requires special sealing measures (proven reliability with cement on aluminium foil).

Advantages

Low cost of construction, especially in comparison with potentially high cost of masonry for alternative plants; mass production possible; low material input.

Disadvantages

Substantial consumption of essentially good quality cement; workmanship must meet high quality standards; uses substantial amounts of expensive wire mesh; construction technique not yet adequately time tested; special sealing measures for the gas holder are necessary [17].

Ferro-cement biogas plants are only recommended in cases where special ferro-cement know-how is available.

2.4 Merits and Defects

The variance of biogas plants come from the variance of countries state of a fairs, for example there are three different types of digesters adopted in Chinese rural areas – water pressure type, floating cover type and membrane gas holder type [5]. The three digester types are classified according to gas storage manner. The water pressure type stores gas mainly by increasing the volume of gas dome within the digesting chamber by forcing digesting content out of it, and partly by suppressing gas, with the latter equivalent to 15-20% of the former [10]. The biogas produced from this type of digester possesses certain pressure, with the designed maximum pressure taken as

1-1.5m. Water column. Floating cover type stores gas by increasing the volume of the gas dome above liquid surface from raising of the cover. This type of digester possesses not so high a relatively stable pressure of about 2-35 cm. Water column [10, 11].

Membrane gas holder type stores biogas by cover or storage balloon. Pressure of biogas in the gas dome or balloon generally approaches zero while filled full, the pressure maintains a 0.02 - 0.03 m. water column with the control of safety valves [11].

The primary consideration in building a digester is the choice of type. The three common rural types of digesters existing have their respective merits and defects, and the choice of type should be determined according to the demand of the user and the characteristics of the digester. The merits and defects of the three types are listed in the following [5].

2.4.1 Comparison of merits and defects between three types of digesters

2.4.1.1 Water pressure type

Merits

1. No movable parts installed, it may be built with common construction materials.
2. Biogas produced possesses a considerable pressure that could suppress gas to appliances.

Defects

1. High demand for strength of structure and anti-leakage, caused by high pressure.
2. Requires low concentration of digesting content, resulting a low gas production rate.
3. Digested material contacts with air in a large area in high position tank, causing difficulties in heat preservation gas production rate.
4. Only small manhole is set up on the digesting chamber, causing inconvenience in cleaning scum and sludge.
5. Total height of digester is large, in addition to a water pressure tank, which is unsuitable in construction in areas with high water table.
6. Difficulty in management owing to varying liquid level.

2.4.2.2 Floating cover type

Merits

1. Biogas with stable pressure using.
2. Concentration of digesting content may be higher, resulting in a higher gas production rate.
3. Small contact area with air, at inlet and outlet pipes, favors heat conservation, gas production and sanitation management.
4. For the digesters with cover floating directly upon substrate, scum and sludge are easily cleaned when the cover is removed.

5. Stable liquid level favors management.

Defects

1. High cost for the floating cover.
2. Difficulties exist in manufacture, installation and maintenance of medium and large scale digesters.

2.4.2.3 Membrane gas holder type

Merits

1. Low demand for structural strength and anti-leakage, thus suits particularly large scale digester.
2. Concentration of substrate may be higher, resulting in a higher gas production rate.
3. Small contact area with air, at inlet and outlet pipes, favors heat conservation, gas production and sanitation management.
4. For the digesters with cover floating directly upon substrate, scum and sludge are easily cleaned when the cover is removed.

Defects

1. The membrane is vulnerable to breakage.
2. The pressure of gas is too low which often requires additional force to press the gas up to the required flow speed.

From the above comparisons, we consider water pressure type to suit medium and small sizes rather than large scale digesters. Large digesters are vulnerable to breakage owing to the high biogas pressure upon large span.

While a small digester is characterized with prominent merits of low cost and the availability of common construction materials. As the primary factors of consideration for the peasants rest upon the cost and the availability of local materials, the water pressure type digester is most acceptable for the peasants; thus it has the most widespread application. On the other hand, the floating cover type suits small digesters rather than medium and large scale ones, owing to the difficulties in construction, installation and maintenance of the cover . While the storage balloon type suits large digester in particular, and also medium digester assembling with internal combustion engines as the engine sucks in gas. However, this type of digester is inconvenient for domestic cooking and lighting, due to the very low pressure of the produced gas.

2.5 Determining Design Choice

Typical design criteria are:

1. Space: determines mainly the decision if the fermenter is above ground or underground, if it is to be constructed as an upright cylinder or as a horizontal plant.

2. Existing structure: may be used like a liquid manure tank, an empty hall or a steel container. To reduce costs, the planner may need to adjust the design to these existing structure.

3. **Minimizing cost**: can be an important design parameter, especially when the monetary benefits are expected to be low. In this case a flexible cover of the digester is usually the cheapest solution. Minimizing costs is often opposed to maximizing gas yield.

4. **Available substrate**: determines not only the size and shape of mixing pit but also the digester volume (retention time); the heating and agitation devices. Agitation through gas injection is only feasible with homogenous substrate and a dry matter content below 5%. Mechanical agitation becomes problematic above 10% dry matter [17].

2.6 Some Considerations in Design

2.6.1 Selection of Materials

The cost of the digester hinges on the selection of materials. The principles for selection lie on cheap and local availability. As lime could be produced locally in many areas thus it is cheaper than cement; taking full advantages as the substitute for the cement is a major principle in selection materials in these areas.

As structural materials, adobe is the mixture of lime and clay, with occasional adding of sand. The three materials are all cheap and easy to obtain, thus broad uses have been applied. Brick is comparatively expensive, but still broadly accepted considering the convenience in construction [12]. stone and rock are the cheapest for the places producing them, concrete is a cheap material of high quality. In addition, the construction with concrete often needs moulds while wood board is also a kind of short material not to speak of its inconvenience in construction. As for the plastering layer, it is almost completely reliant on cement paste.

2.6.2 Shape of Digester

In determining the shape of digester, there are several points to consider :

1. As reinforcing bars are difficult to obtain in rural areas, it should be avoided if possible; the design of digester should avert tensile stress and bending stress. In view of this, cylindrical and spHerical digesters are preferable than rectangular digesters.
2. Save as much land area as possible; as rural areas in most developing countries has large population but less spare sland.
3. The digester should not be buried too deep in the ground as to avoid inconvenience in cleaning and in construction in areas with high water table.
4. Prevent feedstock flow to the outlet through a short cut in the digester.

Current digesters are generally spherical, cylindrical, rectangular, pear-shaped, conic etc. [5]. Among them, cylindrical is the most commonly adopted shape; as it is better in force bearing and suits various depth in burying. Spherical shape is the best in force bearing, and it is easier in construction in areas with higher water table. However, the digesting content runs a short cut in it. Also the diameter of the digester of this shape should be designed smaller to avoid too deep the pit from too large diameter of the digester. Rectangular digester occupies a small area so that a limited spare area is also available. In addition, the digesting content in it seldom runs a short cut. the initial digesters were mostly rectangular. However, the walls and the top of the rectangular digester must be particularly strong, so as to bear the bending stress generated from external pressure; more materials are thus required and higher cost thus results, and this is why the shape is seldom chosen nowadays.

2.6.3 Position and Location

Almost all digesters are buried underground. The reasons for this are :

1. To maintain a proper temperature for the digesting content.
2. To balance the pressure of inside liquid with the pressure from surrounding soil.

The construction cost is the first consideration of the peasants. To decrease the cost, the peasants prefer not so high a gas production rate under a comparatively lower temperature with a larger digester to satisfy the total fuel requirement than to adopt expensive heating equipments and insulation materials. This does not mean that they neglect heat preservation, as the soil under ground surface is a good natural heater and insulator. Qian ze-shu and wu jin-peng [13] had made year round observations on the relation between the temperature of soil 190cm deep. The result was that both the temperature were almost equal in all the seasons. The temperature of the digesting content, together with that of soil, varies very slowly with the change of seasons, but does not vary with the change of temperature along with the time in one day. For example, when the daily average temperature in winter is 1°C, the temperature of digester content in an underground digester remains around at 14°C. In the populous rural areas in south, central and east China, the underground soil temperature remains at 10–27°C from winter to summer. This means that, in the underground digesters, the digester content may ferment in this range of temperature. For these digesters built on the ground surface, a tensile stress and/or a bending stress may be generated onto the wall by the internal liquid pressure. To deal with this, reinforcing bars or a thick wall is required, and the construction cost increases. On the contrary, underground digester requires no reinforcing bars as the external soil pressure balances the internal liquid pressure. Furthermore, the walls may be built thinner. A domestic digester may have its wall as thin as 3-4cm. Using concrete, and may be 7cm thick when built with bricks, including the plastering layer [5].

2.6.4 Shape of Roof

Cut spherical shape is preferable for digester roof. To balance internal biogas pressure and to preserve heat, a thick layer of soil is often spread on the top of the digester. The gravity of the soil and the top itself would apply a high downward pressure upon the roof when the internal biogas pressure is low. Under such a pressure, a flat shape roof would suffer tensile other than pressure stress upon the structure, thus reinforcement concrete has to be adopted. On the contrary, the downward pressure applied upon a cut spHerical roof would generate merely a pressure stress onto the internal structure of the digester roof, adobe, brick or stone might serve as a substitute for reinforcement concrete . For the cut spHerical roof connecting with cylindrical wall, the ratio between the height of cut sphere (h) and the diameter of cylindrical wall (d) should not be too small, h/d is generally taken as (1:4) [18], so to avoid too high the lateral stress upon the upper part of the wall .

Arch roof other than flat roof is adopted for rectangular digesters. The reason in adopting cut spHerical digester roof is the convenience in construction.

2.6.5 Shape of Bottom

For the convenience of construction, flat digester bottom might be taken in place where the water table is low. While for the areas with high water table, an upward cut spHerical bottom is preferable as it suffers from upward pressure from underground water when the digester is empty. Internal structure of the digester bottom would generate a higher tensile stress than to a flat bottom, as what happened to the digester roof. The h/d ratio of the cut spherical bottom is taken according to the height of underground water table and the rigidity of surrounding soil. For areas with low water table and relatively rigid soil, h/d ratio might be taken as small as (1:10), [18]. A manhole should be up on the top of digesters with rigid roofs. The manhole affects in three aspects:

1. To provide natural lighting and ventilation during building and repairing the digesters؛
2. To purge and clean digester
3. To install steel pipe at the plug or cover of the manhole . The pipe is easily repaired or replaced when damaged or corroded by removing the plug or cover from the digester roof [5] . There are two types of manhole – high pressure manhole and low pressure manhole. The former suits water pressure digesters or floating cover digesters with high gas pressure, while the latter suits floating cover digesters with lower gas pressure and membrane gas holder digesters. The diameter of the high pressure manhole should not be too large as to avoid too thick and too heavy the plug, also to avoid too many rocks dumped up to suppress the cover against the internal gas pressure of the digester. While for the low pressure, a larger diameter manhole makes the operation convenient [14].

Chapter Three
Biogas Basics

The biomethanation process was developed as a means to treat wastewater or wastewater sludges. In its application to waste waters and sludges, organisms in the absence of free oxygen break down the organic materials and produce gases and liquids. Gases such as methane, carbon dioxide, hydrogen and hydrogen sulfide are produced in the process which destroys one-half to two-thirds of the solids [19]. The recent interest in both developed and developing countries has been in using the process to produce a fuel gas which can be used for energy purposes. The digester effluent which must be disposed of has been used in algae and fish ponds, for irrigation of orchards and crops and the solids as a soil conditioner. Based on experience, it is doubtful that justification based on a single purpose makes biomethanation economical, but when used to accomplish more than one purpose the process can be economically viable.

The biomethanation process differs from the other biological energy conversion processes in that the feed materials need not be sterilized or pasteurized. The feed stock can be highly heterogenous in nature. It can be used with animal manures, human wastes, urban refuse, agricultural residues, new plant growth both terrestrial and aquatic or mixture of these materials. No special seed culture is required for the process and usually once a conversion unit has been started, all the organisms necessary for the production of methane will flourish. The gases are easy to recover and use. This is not to imply that there are no operational problems with the process.

3.1 Background

Historically, the first water carried waste disposal systems in which biomethanation took place was the cesspools. The cesspool is a tank built underground which has open spaces between the bricks or rock making up the wall and an open floor. The wastewater or sewage enters the tank and the liquids seep into the soil and leave the solids in the tank where digestion takes place. Cesspools often fail i.e. the soil pores adjacent to the tank become plugged and the liquid no longer seeps away. A septic tank with a drain field system was developed to overcome the clogging of the soil pores by solids. In a septic tank the wastewater carrying the solids enters the tank through a baffle system. Baffles are used at the inlet and outlet to attempt to eliminate the short circuiting and to reduce solids in the effluent. Theoretically, the solids settle to the bottom of the tank where biomethanation takes place. The liquids overflow into a tile drain field where they percolate into the soil. There is an evolution of gases, methane and carbon dioxide, from the digestion solids on the bottom of the tank. As these gases rise, they can carry with them small particles to the upper strata of the digester which in turn can be carried into the drain field [5]. The Imhoff tank was the next step in the development of biomethanation systems. The imhoff tank is a two compartments tank where a separate sedimentation and biomethanation compartment are used. The solids settle in the upper compartment and pass through a slot into the bottom compartment where biomethanation takes place. Periodically, the excess solids and digested sludge are removed from the tank.

As wastewater systems grew larger, separate sedimentation and digestion tanks were used. In the sedimentation tank the suspended solids settle to the bottom of the tank and these solids plus the scum are transferred to the digester [20].

A number of different types of tanks and designs are used for biomethanation. In large systems containing more than one digeste, one of the digesters often has a floating drum which acts as a storage system for the gas. These gases are from the system used to produce heat, steam and/or electricity.

3.2 Biogas production

3.2.1 Methanogenic bacteria or methanogens

These are the bacteria that act upon organic materials and produce methane and other gases in the process of completing their life-cycle in anaerobic condition. As living organisms, they tend to prefer certain conditions and are sensitive to micro –climate within the digester. There are many species of methanogens and their characteristics vary. The different methane forming bacteria have many physiological properties in common, but they are heterogeneous in cellular morphology. Some are rods, some cocci, while others occur in clusters of cocci known as sarcine. The family of methanogense (Methanobacteriacea) is divided into following four genera on the basis of cytological differences:

1. Rod-shaped bacteria

a) Non-sporulating, methanobacterium

b) Sporulating,Methanobacillus

2. Spherical

a) Sarcinae, Methanosarcina

b) Not in sarcinal groups, Methanococcus

A considerable level of scientific knowledge and skill is required to isolate methanogenic bacteria in pure culture and maintain them in a laboratory. Methanogenic bacteria develop slowly and are sensitive to a sudden change in physical and chemical conditions. For example, a sudden fall in the slurry temperature by even 20°C may significantly affect their growth and gas production rate [21].

3.2.2 Inputs and their characteristics

Any biodegradable organic material can be used as inputs for processing inside the biodigester. However, for economic and technical reasons, some materials are more preferred as inputs than others. If the inputs are costly or have to be purchased, then the economic benefits of outputs such as gas and slurry will become low. Also, if easily available biodegradable wastes are used as inputs, then the benefits could be of two folds:

A) Economic value of biogas and its slurry

B) Environmental cost avoided in dealing with the biodegradable waste in some other ways such as disposal in landfill. One of the main attractions of biogas technology is its ability to generate biogas out of organic wastes that are abundant and freely available. In addition to the animal and human wastes, plant materials can also be used to produce biogas and bio-manure. For example, one kg of pre-treated crop waste and water hyacinth has the potential of producing 0.037 and 0.045 m^3 of biogas, respectively. Since different organic materials have different bio-chemical characteristics, their potential for gas production also varies. Two or more of such materials can be used together provided that some basic requirements for gas production or for normal growth of methanogens are met.

Some characteristics of these inputs which have significant impact on the level of gas production are described below [21].

A) **C/N Ratio:** The relationship between the amount of carbon and nitrogen present in organic materials is expressed in terms of the Carbon /Nitrogen (C/N) ratio ranging from 20 to 30 is considered optimum for anaerobic digestion. If the C/N ratio is very high, the nitrogen will be consumed rapidly by methanogens for meeting their protein requirements and will no longer react on the left over carbon content of the material. As a result, gas production will be low. On the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of amonia (NH_4), this will increase the pH value of the content in the digester. A pH higher than 8.5 will start showing toxic effect on methanogen population. Animal waste, particularly cattle dung, has an average C/N ratio of about 24. The plant materials such as straw and sawdust contain a higher percentage of carbon. The human excreta have a C/N ratio as low as 8. C/N ratio of some of the commonly used materials are presented in the table 1.

Table 1. C/N Ratio of some organic materials [21]

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

Materials with high C/N ratio could be mixed with those of low C/N ratio to bring the average ratio of the composite input to a desirable level. In China, as a means to balance C/N ratio, it is customary to load rice straw at the bottom of the digester upon which latrine waste is discharged. Similarly, at Machan Wild– life Resort located in Chitawan district of Nepal, feeding the digester with elephant dung in conjunction with human waste enables balancing C/N ratio for smooth production of biogas [21].

B) 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 in order to achieve 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; but 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. Thorough mixing of the cow dung and water (slurry), GGC has devised a slurry mixing 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.

C) Volatile solids: The weight of organic solids burned off when heated to about 538°C is defined as volatile solids. The biogas production potential of different organic materials can be calculated on the basis of their volatile solid content. The higher the volatile solid content in unit volume of fresh dung, the higher the gas production. For example, a kg of volatile solids in cow dung would yield about 0.25 m^3 biogas [21].

3.2.3 Digestion

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

Stage1 Hydrolysis: The waste materials of plant and animal origins consist mainly of carbohydrates, lipids, proteins and inorganic materials. Large molecular complex substances are solubilized into simpler ones with the help of extra cellular 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.

Stage2 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 principal acids produced in stage 2 are processed by methanogenic bacteria to produce methane. The reaction that takes place in the process of methane production is called methanization and is expressed by the following equations [21].

$$\underset{\text{Acetic acid}}{CH_3COOH} \longrightarrow \underset{\text{Methane}}{CH_4} + \underset{\text{Carbon dioxide}}{CO_2}$$

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

Ethanol

$$CO_2 + \underset{\text{Hydrogen}}{4H_2} \longrightarrow CH_4 + \underset{\text{Water}}{2H_2O}$$

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 [21].

3.2.4 Effect of some operating parameters on biogas production rate

1. Temperature: The anaerobic digestion process is carried out by a delicately balanced population of various bacteria. These bacteria can be very sensitive to changes in their environment. Temperature is a prime example. It has been determined that 35°C is an ideal temperature for anaerobic digestion. As the temperature falls, bacteria activity decreases and biogas production decreases. As the temperature increases some bacteria begin to die, once again biogas production decreases. Insulation, heat exchangers, heating elements, water baths, and steam injection are all means which have been used to control digester temperature. Temperature control is an important consideration when designing digesters. The materials list includes two potential heat sources. Anaerobic digestion will occur even at room temperature. However, any method of maintaining digester temperature constant near 35°C will improve digester performance. Any novel means of maintaining temperature are encouraged. After all, practicing engineering design is the primary purpose of this project [22].

2. Alkalinity and pH : Alkalinity is a measure of the amount of carbonate in a solution. Acidity or basicity of a solution is indicated by pH. An acidic solution has more hydrogen or hydronium ions than hydroxide ions. A basic solution has more hydroxide than hydronium ions. At a pH of 7 there are equal amounts of hydroxide and hydronium ions. A pH greater than 7 indicates a basic solution and a pH less than 7 indicates an acidic solution. Alkalinity is important because as acid is added to solution, carbonates will contribute hydroxide ions which tend to neutralize the acid. This is known as the buffering effect of alkalinity.

$$H_2O + H_2O \longrightarrow H_3O^+ + OH^-$$

Water Hydronum ion+ Hydroxide ion

Just as the bacteria population responsible for methane production flourishes in the absence of oxygen and over a relatively narrow temperature range, it also flourishes over the narrow pH range of 6.5 to 8. As the acid-forming bacteria produce acid, the methane-forming bacteria utilize the acid and maintain a neutral pH. Since the reaction rate involving the acid-forming bacteria proceeds much faster than the reaction involving methanogenes, a large population of methanogenes must be nurtured and maintained. Digester start-up is an especially critical time. When the digester is initially fed, acid-forming bacteria quickly produce acid. The methanogen population may not be sufficient to consume the acid produced and maintain a neutral pH. If the pH drops below 6.5, the methanogen population begins to die and the bacteria population becomes further unbalanced. The digester acidifies and produces no gas. In order to allow the methanogen population to grow, digesters are initially fed very small amounts and are often buffered by raising the alkalinity. In addition, raising the pH to approximately 7.5 by adding baking soda also increases the alkalinity or buffering capacity of digester solution [22].

3. Retention Time: Retention time (also known as detention time) is the average period that a given quantity of input remains in the digester to be 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 in Tulkarm. 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°C, the higher the temperature, the lower the retention time [21].

4. Loading Rate : Loading rate is the amount of raw materials fed per unit volume of digester capacity per day. About 6kg 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 [21].

5. Toxicity : Mineral ions, heavy metals and detergents are some of the toxic materials that inhibit the normal growth of pathogens in the digester. Small quantity of mineral ions (e.g sodium, potassium, calcium, magnesium, and sulpHur) also stimulates the growth of bacteria, while very heavy concentration 0f these ions will have toxic effect. For example, presence of NH_4 from 50 to 200 mg/l stimulates the growth of microbes, whereas its concentration above 1.500 mg/l produces toxicity. Similarly, heavy metals such as copper, nickel, chromium, zinc, lead, etc. in small quantities are essential for the growth of bacteria, but their higher concentration has toxic effects. Likewise, detergents including soap, antibiotics, organic solvents, etc. inhibit the activities of methane producing bacteria and addition of these substances in the digester should be avoided. Although there is a long list of the substances that produce toxicity on bacteria growth, the inhibiting levels of some of the major ones are given in the table 2.

Table 2.Toxic level of various inhibitors[21]

Inhibitors	Inhibiting Concentration
Sulphate (SO_4--)	5.00 ppm
Sodium Chloride (NaCl)	40.00 ppm
Nitrate (Calculated as N)	0.05 mg/ml
Copper (Cu^{++})	100 mg/l
Chromium (Cr^{+++})	200 mg/l
Nickel (Ni^{+++})	200-500 mg/l
Sodium (Na^{+})	3.500-5.500 mg/l
Potassium (k^{+})	2.500-4.500 mg/l
Calcium (Ca^{++})	2.500-4.500 mg/l
Magnesium (Mg^{++})	1.00-1.500 mg/l
Manganese (Mn^{++})	Above 1.500 mg/l

3-3 : Utilities of Biogas

Biogas is a lean gas that can ,in principle, be used like other fuel gas for household and industrial purposes, especially for :

1. gas cookers / stoves
2. biogas lamps
3. radiant heaters
4. incubators
5. refrigerators
6. engines

Biogas cookers and stoves must meet various basic requirements:

1. Simple and easy operation
2. Versatility, e.g. for pots of various size, for cooking and boiling
3. Easy to clean
4. Acceptable cost and easy repair
5. Good burning properties, i.e. stable flame, high efficiency
6. Attractive appearance

Two-flame burners:

A cooker is more than just a burner. It must satisfy certain aesthetic and utility requirements, which can vary widely from region to region. There is no such thing as an all-round biogas burner. Most households prefer two-flame burners. The burners should be set initially and then fixed. Efficiency will then remain at a high practical level. Single-flame burners and lightweight cook-stoves tend to be regarded as stop-gap solutions until more suitable alternatives can be afforded.

Gas demand:

The gas demand can be defined on the basis of energy consumed previously. For example, 1 kg firewood then corresponds to (200) l biogas; 1 kg dried cow dung corresponds to 100 l biogas and 1 kg charcoal corresponds to 500 l biogas[23].

Biogas Lamps:

Efficiency of Biogas Lamps:

In villages without electricity, lighting is a basic need as well as a status symbol. However, biogas lamps are not very energy-efficient. This means that they also get very hot. The bright light of biogas lamps is the result of incandescence, i.e. the intense heat-induced luminosity of special metals, so-called (rare earth) like thorium, cerium, lanthanum, etc. At a temperature of 1000-2000°C if they hang directly below the roof, they cause a fire hazard. The mantles do not last long. It is important that the gas and air in a biogas lamp are thoroughly mixed before they reach the gas mantle, and that the air space around the mantle is adequately warm.

Radiant Heaters:

Infrared heaters are used in agriculture for achieving the temperatures required for raising young stock, e.g. chicken in a limited amount of space. The nursery temperature for chicken beings at 30–35°C for the first week and then gradually drops off to an ambient temperature of 18–23°C in the 4th / 5th week. As a rule, temperature control consists of raising or lowering the heater. Good ventilation is important in the stable / nursery in order to avoid excessive concentrations of CO or CO_2. Consequently, the animals must be kept under regular supervision, and the temperature must be checked at regular intervals. Heaters for chicken rearing require some 200–300 l/h as a rule of thumb.

Thermal Radiation of Heaters:

Radiant heaters develop their infrared thermal radiation via a ceramic body that is heated to 600–800°C (red-hot) by the biogas flame. The heating capacity of the radiant heater is defined by multiplying the gas flow by its net calorific value, since 95% of the biogas energy content is converted to heat. Small-heater outputs range from 1.5 to 10 KW thermal power.

Incubators:

Incubators are supposed to imitate and maintain optimal hatching temperature for eggs. They are used to increase brooding efficiency [23].

Refrigerators:

Absorbing–type refrigerating machines operating on ammonia and water and equipped for automatic thermo-siphon circulation can be fuelled with biogas.

Gas Demand:

For 100 liters refrigeration volume, about 2000 l of biogas per day, depending on outside temperatures, must be assumed. A large household refrigerator consumes about 3000 WH per day [23].

Biogas – Fueled Engines:

Gas Demand:

If the output of a biogas is to be used for fueling engines, the plant must produce at least 10 m^3 biogas per day. For example, to generate 1KWH electricity with a generator, about 1m^3 biogas is required. Small-scale systems are therefore unsuitable as energy suppliers for engines [23].

Types of Engines:

The following types of engines are, in principle, well-suited for operating on a biogas [23]:

1. Four stroke diesel engines
2. Four stroke spark-ignition engines
3. Converting diesel engines
4. Converting spark-ignition engines

Chapter Four
Experimental Work

4.1 Introduction

In developing countries more than 80% of the population lives in the rural areas and about 90% of the energy consumed in rural areas comes from non-commercial sources mainly cellulosic in nature (e.g wood and dung). These sources are used for domestic purposes primarily for cooking and heating. The balance of about 10% of the energy consumed is in the form of kerosene for lighting, cooking, and fuels for transport, small scale industries, promotion of agricultural production, social communal activities.

The world available resources today for fossil fuels cannot sustain the present level of technology for long. It is therefore imperative that new and renewable sources of energy such as biogas have to be developed and utilized to supplement the available commercial energy sources in both rural and urban areas.

Biogas is a mixture of colorless flammable gases obtained by anaerobic digestion of plant based organic waste materials. The composition of biogas is: methane 50-70%, carbon dioxide 30-40% and the rest is made up of traces elements of hydrogen, nitrogen and hydrogen sulfide. It is obtained by fermentation of organic waste materials such as animal, human, agricultural and industrial wastes after mixing with water. The technology of biogas has been developed to convert biomass into useful energy without destroying the fertilizer properties of organic waste materials. Biogas when generated can be used to supply energy for domestic cooking, lighting, water heating, fuel for automobiles, refrigeration, electricity, water pumping etc [23].

4.2 Objectives

The main objective of this research is to get the optimum volume of dung for the available digester. Also from another view point, in particular, economic explanation of the need of increasing the number of digesters in order to get more amounts of the produced biogas. Thus, wide use of this type of the digester throughout the West Bank will reduce the need of importing low pressure gas for the houses utility; such as cooking, heating, lighting and others.

4.3 Materials and Methods

The fresh cow dung used in this investigation was obtained from the cows farm of the Faculty of Agriculture at An-Najah University including eleven cows, set up for scientific researches and purposes. Instruments that were used to record data are digital pH meter to measure PH degree by inserting plastic tube in the digester, where the main process (digestion) takes place. Thermometer is of mercury type, to measure the ambient temperature directly. Slurry temperature is recorded by inserting thermometer to digester where digestion process takes place; and gas flow meter is to measure the amount of biogas produced, it is located at the end of the (0.5) inch pipe that releases gas.

The digester used was fabricated locally by Palestinian Agricultural Relief Committees (PARC) which is located adjacent to the cows farm which belongs to the agricultural college of An-Najah National University including 11 cows at the time of experiment. The biogas plant used was of floating drum type.

Description of Biogas Plant

The biogas plant consists of four major parts as shown in fig.8, the first part is the mixing chamber made of concrete, the substrate is mixed with water 1:1 by electrical mixing machine, then directed to 6 inches PVC pipe leading to the chamber where biological process takes place .

In the opposite side, there is the digested slurry outlet storage made of concrete or bricks (outlet PVC pipe 6 inches diameter), which is prepared for getting rid of the digested amount of slurry.

The main part of biogas plant is consisted of two major parts, the floating drum and the digester. Metallic dome for gas holding and storage of about 60% of daily gas production made of steel of 3mm thickness, the dome has to be painted 3 times before installation, the floating drum is of the cylindrical shape whit 1.94m diameter with a maximum stroke of 1.10m, also prepared to leak biogas produced through 0.5 inch steel pipe in axial direction of the drum, it floats up or down according to the amount of gas produced.

The digester is the main body made of thermal bricks and reinforced concrete of $6m^3$ volume, hemispherical shape of 1.7m in radial direction, with a concave bottom to counteract the effect of soil pressure. The retention time for cows manure reaches 40 days in winter and 25 days in summer for complete mineralization, because the ambient basically affects the retention time, besides other factors like pH degree and others.

It is important to state that the main part is built underground to protect the digester from high pressure resulting from slurry. Gas meter used to measure amount of gas is of flowmeter type holded on the outlet of gas leakage (0.5) inch steel pipe.

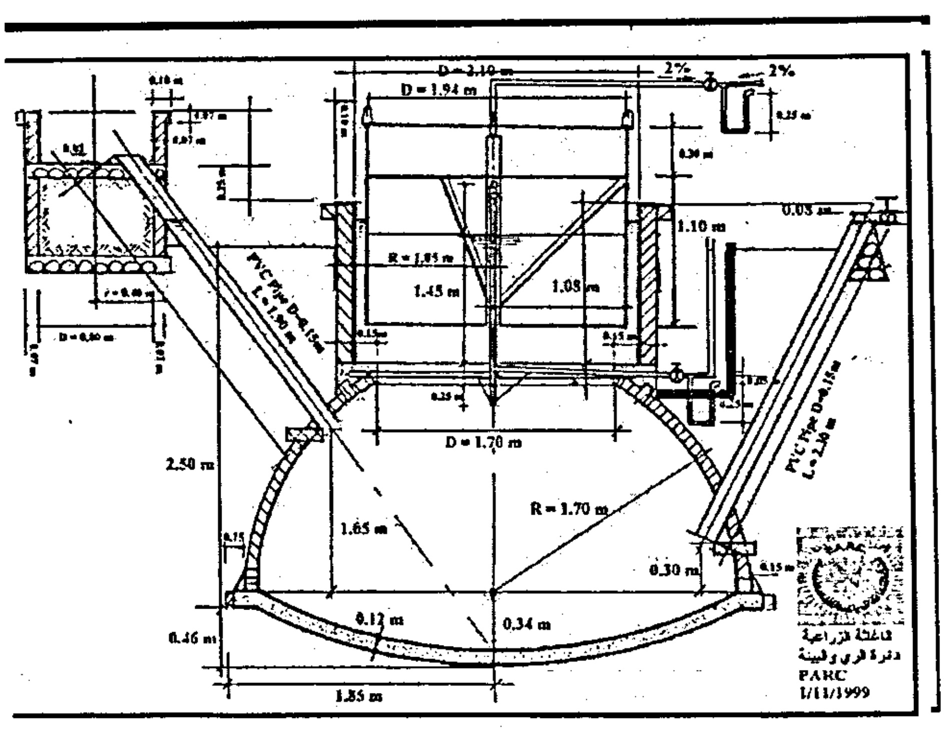


Fig.8 Main parts of biogas plant in Tulkarm

Methods

a) Daily rate production of biogas for 50 liter slurry

The amount of 50 liter slurry in the ratio 1:1 (25 liter cow dung with 25 liter water) is mixed by using electric mixing machine, for 10 minutes to be certain that mixture is homogenous. After that mixture is added to the digester through inlet. Then the amount of gas produced is with- drawn, measured by gas flow meter. Also pH degree is measured by taking a sample from digester using a plastic pipe inserted into the digester, hence digital pH meter is used to measure pH degree.

Air temperature is recorded by using a mercury thermometer measuring the ambient temperature under the shadow of a tree adjacent to the plant. Thermometer is tied to a steel bar, and then inserted to the body of digester, withdrawing it fast after 5 minutes to record the slurry temperature accurately as could as possible, the data were collected for 31 days. Also dry matter measurements is taken randomly, by taking a sample and put it in oven until the weight of sample becomes constant. The average dry matter measurements were then calculated. The data collected is in the time interval between 11.00 AM and 13.00 PM daily. Interruption of the experiment happened after 31 days experiment, 19 days after the stabilization of gas production.

b) Daily rate production of biogas for 100 liter slurry

This experiment started after 11 months of interruption of the first xperiment. The reactor was daily charged with cow dung and water in the ratio 1:1 (50 liter cow dung and 50 litter water). The procedures for mixing, measuring air temperature and PH are similar to those mentioned previously for 28 days.

4.4 Results and Discussion

The results of measurements are given in tables (3 and 4), recorded after adding the homogenous slurry to the digester.

Table 3. Daily rate production of biogas for 50 liter slurry

Day	Gas flow meter number (m3)	Amount of biogas (m3)	pH value	Ambient temperature / °C
0	4.04	0.00	7.60	33.2
1	4.15	0.11	7.65	32.8
2	4.26	0.11	7.85	33.4
3	4.43	0.17	7.70	32.8
4	4.58	0.15	7.50	32.6
5	4.84	0.26	7.45	33.0
6	5.10	0.26	7.48	33.0
7	5.44	0.34	7.80	33.0
8	5.77	0.33	7.75	33.0
9	6.11	0.34	7.70	33.0
10	6.52	0.41	7.68	33.2
11	6.89	0.37	7.63	33.0
12	7.39	0.50	7.82	33.3
13	7.93	0.54	7.90	32.8
14	8.44	0.51	7.40	32.6
15	9.04	0.60	7.55	33.0
16	9.59	0.55	7.25	33.2
17	10.21	0.62	7.70	33.1
18	10.95	0.74	7.75	33.2
19	11.69	0.74	7.78	33.0
20	12.49	0.80	7.65	33.0
21	13.51	1.02	7.68	32.9
22	14.69	1.18	7.67	32.8
23	15.85	1.16	7.80	32.8
24	17.01	1.16	7.48	32.7
25	18.18	1.17	7.80	32.8
26	19.33	1.15	7.68	32.8
27	20.53	1.20	7.82	33.0
28	21.73	1.20	7.82	33.0
29	22.88	1.15	7.73	33.0
30	24.06	1.18	7.74	33.2
31	25.26	1.20	7.50	33.5

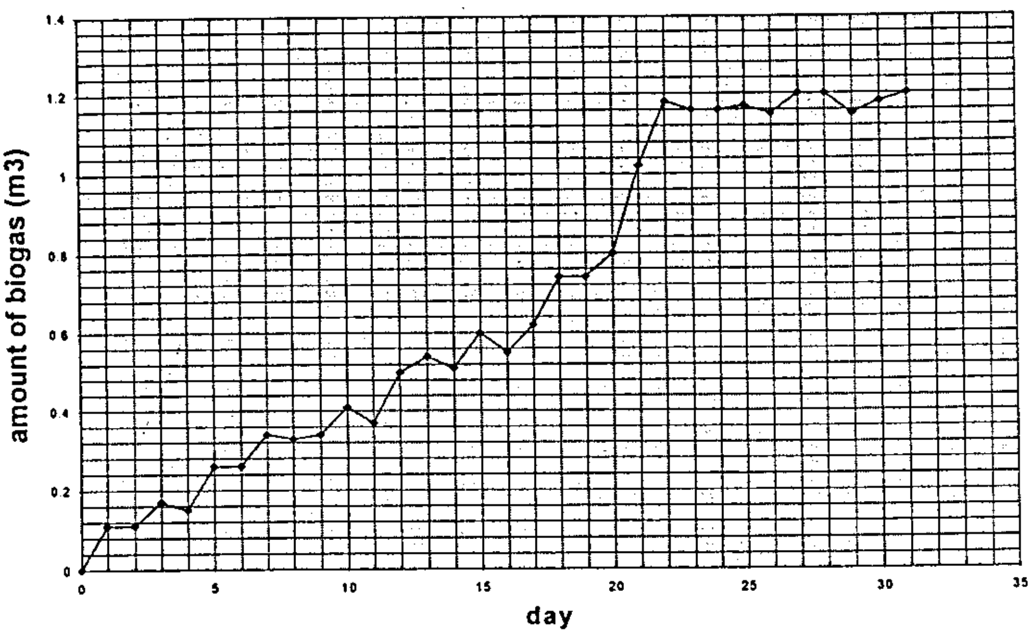
Average PH for 50 liter was 7.91, average air temperature was 34.055 °C, slurry temperature 27°C, and dry matter was 22%.

Table 4. Daily rate production of biogas for 100 liter slurry

Day	Gas flow meter number (m3)	Amount of biogas (m3)	pH Value	Ambient temperature / °C
0	29.10	0.00	7.67	33.0
1	30.06	0.96	7.66	33.2
2	31.00	0.94	7.63	33.2
3	32.20	1.20	7.80	33.2
4	33.62	1.42	7.95	33.2
5	35.10	1.48	7.35	33.0
6	36.62	1.52	8.00	32.8
7	38.30	1.68	7.20	32.7
8	39.73	1.43	7.78	32.8
9	41.11	1.38	7.75	33.2
10	42.81	1.70	7.68	33.1
11	44.63	1.82	7.66	33.4
12	46.32	1.69	7.68	33.5
13	48.10	1.78	7.68	33.2
14	49.91	1.81	7.69	33.4
15	51.68	1.77	8.20	33.4
16	53.46	1.78	8.10	33.2
17	55.06	1.60	7.90	32.9
18	57.12	2.06	7.38	32.8
19	58.61	1.49	7.45	33
20	60.40	1.79	7.67	33.4
21	61.82	1.42	7.69	33.2
22	63.50	1.68	7.66	33
23	65.25	1.75	7.65	33
24	67.02	1.77	7.67	33
25	68.80	1.78	7.68	33.3
26	70.56	1.76	7.30	33.4
27	72.31	1.75	7.68	32.8
28	74.09	1.78	7.68	32.7

Average pH for 100 liter was 7.96, average air temperature was 34.29 °C, slurry temperature 27 °C, and dry matter was 22%.

The results of this investigation are presented in figures 9 and 10. Anaerobic digestion may be described as a three stage process. The first stage consists of facultative microorganisms attacking the organic matter i.e, complex organic compounds such as glucose and fructose. Polymers are fig.9 : Biogas production rate for 50 liter slurry



transformed into soluble monomers through enzymatic hydrolysis. These monomers become the substrate for the microorganisms in the second stage where soluble organic are converted into organic acids by a group of bacteria collectively called acid formers. Soluble organic acids consisting primarily of acetic acid form the substrate for the third stage. In this last step, methanogenic bacteria, which are strictly anaerobic in nature, can generate methane by two different routes: one is by fermenting acetic acid to generate methane (CH_4) and CO_2 to CH_4 via hydrogen gas or by other bacterial species.

From the result of the daily rate production of biogas for 50 liter slurry, presented in (fig. 9), it can be concluded that biogas production continue to increase from the 1st to the 22th day and approximately remains steady from 22th to 31st day.

fig.10 : Biogas production rate for 100 liter slurry

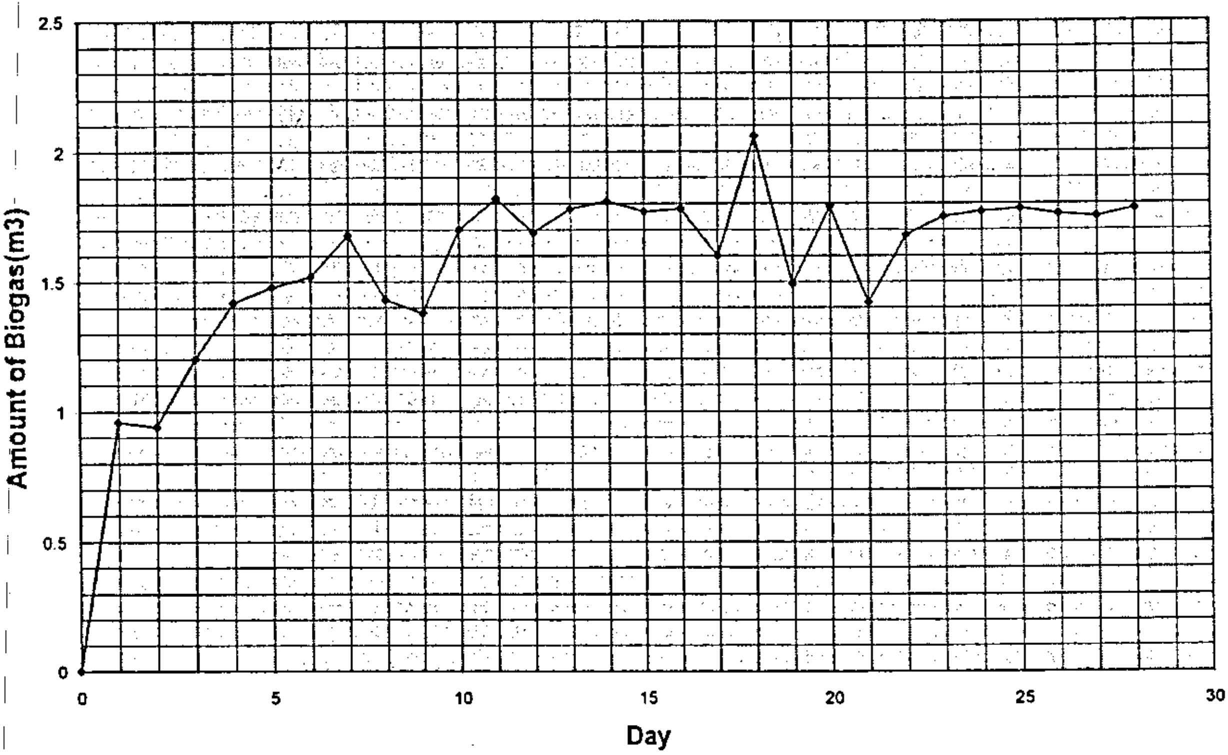


Fig. 10 presents the result of the daily rate production of biogas for 100 liter slurry. Results show that gas production, in the first day is almost $1m^3$, because the number of methane forming bacteria increasing rabidly and continue to increase from 1^{st} to the 7^{th} day, it decreases from 7^{th} to the 9^{th} day and increases to the 11^{th} day, after which the rate appears approximately steady from 11^{th} to 28^{th}.

The behavior of the two curves can be divided into two stages:

The first stage showed an increasing biogas production, because in this interval the methane forming bacteria is growing up, where the amount of biogas was increased.

The second stage was a steady state, because the number of methane forming bacteria reached the maximum. So during this interval the amount of biogas remained almost constant.

In general, the whole process is depending on the number of methane forming bacteria existing in the slurry.

4.5 Conclusions

As the amount of slurry added to the digester is increased, the curve is reaches its steady state, biogas amount is proportionally equal to the amount of slurry, also the time interval of steady state gets longer, in addition to that the growing interval in less amount of slurry is longer. During the experiment, it is found that bacteria is sensitive to the external conditions especially the dynamic conditions. The general shape of the biogas production average takes the same curve regardless of the slurry amount added. It is clearly concluded that the daily average of produced biogas for 100 liters was not equal as double as to that for 50 liters, for example, at steady state for 100 liters the amount of produced biogas was $1.610m^3$, while it was $0.685m^3$ for 50 liters. The change in the temperature of ambient doesn't lead to change the slurry temperature during the time of the experiment. To prevent leakage of biogas from the digester, which is built in Tulkarm, when the amount of slurry is increased more than 100 liters, the digester should be discharged twice or more to collect the amount of biogas exactly.

4.6 Recommendations

The findings of this research seems to indicate that the methane yield was satisfactory and courageous, therefore, it is recommended that digester can be used to supply methane to homes, after using pressure regulator to meet house utilities such as cooking, lighting, heating and others.

Appropriate authorities should courage and aid to spread this type (floating drum) in villages and towns famous of breading cows and sheep.

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جامعة النجاح الوطنية
كلية الدراسات العليا

الغاز الحيوي: مشروع تعليمي في منطقة طولكرم

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قدمت هذه الاطروحة استكمالا لمتطلبات درجة الماجستير في الصحة العامة بكلية الدرسات العليا في جامعة النجاح الوطنية في نابلس ، فلسطين 2003

ملخص الدراسة

تركيب وإنتاج هواضم المادة الحية أصبح مهماً جداً في الوقت الحاضر تبعاً لأهميتها الواسعة. الدراسة المنهجية لمختلف خصائص الغاز الحيوي وكمياته تزوّدنا بقدر كبير من المعلومات حول الهواضم؛ لذا فإنّ الطبيعة الملائمة ونوعية الهواضم تتلائم مع مختلف المناطق الفلسطينية. التجربة الموصوفة في هذا البحث أُجريت في مدينة طولكرم التي تقع في شمال فلسطين، حيث استخدم هاضم من نوع (القبة العائمة).

لقد كان معدل الغاز الحيوي الناتج عند إضافة خمسين لتراً من مخلّفات الأبقار الممزوجة بالماء بنسبة واحد / واحد يومياً 0.685 متر مكعب ، ونسبة الحموضة 7.91، ومعدل درجة الحرارة المحيطة بالهاضم 34.055 درجة مئوية. بينما كانت كمية الغاز 1.610 متر مكعب ، ونسبة الحموضة 7.96 ومعدل درجة الحرارة المحيطة بالهاضم 34.29 عند إضافة 100 لتر يومياً. وفي كلتا الحالتين كانت درجة حرارة المخلّفات الممزوجة بالماء 27 درجة مئوية. لهذا فإنّ إمكانية الاستفادة من الغاز الحيوي كمصدر للطاقة في فلسطين تعتبر مشجعة، وبناء المزيد من الهواضم أمر ينصح به.