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THE EFFECT OF STRAW AND BLOOD ON BIOGAS PRODUCTION WITH COW MANURE

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BY

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The Effect of Straw and Blood on Biogas Production with Cow Manure

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Supervisor
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ABSTRACT

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One of the most important factors of industrilization and development is energy. Biogas energy has important potential to be used for supporting energy needs of countries. Biogas consists of methane (CH_4) 55-65%, carbon dioxide (CO_2) 35-45%, with the balance being made up of nitrogen (N_2), hydrogen (H_2) and hydrogen sulphide (H_2S).

In this study, description and formation of biogas, which is an alternative energy source, are explained and an experimental batch type biogas system is designed to investigate the biogas production at the different experiments. The system consists of one or more digester tanks, a gas holder, a compressor, a mixer, an arrangement of gas pipes, a burner to burn the collected gas.

The objective of this project is to build a small scale "Batch" anaerobic digester and operate with cow wastes and make some experiments to see the effect of mixing and temperature and the dilution of the manure on biogas production. The experiments were conducted at a controled temperature of 28 ± 2 ^{o}C. Results showed that the mixed digester produced maximum biogas about 3,115 ± 0,034 m^3 from 10 lt fresh-waste and the minumum biogas production was obtained about 2,152 ± 0,049 m^3 when the maximum lag time was 57 days at the minumum temperature 20 ± 2 ^{o}C.

Keywords: Biogas, Anaerobic, Waste, Renewable Energy

ÖZET

İNEK GÜBRESİYLE BİYOGAZ ÜRETİMİNDE SAMAN VE KANIN ETKİSİ

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Sanayileşme ve kalkınmanın temel unsurlarından biri enerjidir. Biogaz enerjisi ülkelerin enerji ihtiyaçlarının desteklenmesinde kulanılmak için önemli potansiyele sahiptir. Biogaz %55-65 (CH_4) Metan, % 35-45 (CO_2) Karbondioksit, dengeleyecek miktarda Nitrojen (N_2), Hidrojen (H_2), ve Hidrojen Sülfat (H_2S) içerir.

Bu çalışmada, alternatif bir enerji kaynağı olan biogazın tanımı ve oluşumu açıklanmıştır ve farklı deneylerdeki biogaz üretimini araştırmak için deneysel kesikli beslemeli bir biogaz sistemi dizayn edilmiştir. Sistem bir veya daha fazla arıtım tankı, bir gaz deposu, bir kompresör, bir karıştırıcı, bir hortum bağlantı düzeneği ve toplanan gazı yakmak için bir yakıcıyı kapsar.

Bu tezin amacı küçük ölçülerde kesikli aneorobik arıtım sistemi yapmak ve inek atığıyla tesisi çalıştırmak ve atığın seyreltilmesinin, sıcaklığın ve karıştırmanın biogaz üretimindeki etkisini görmek için bazı deneyler yapmaktır. Deneyler 28 ± 2 ^{o}C kontrollü sıcaklıkta yürütüldü. Sonuçlar, 10 lt taze atıktan maksimum biogazın karıştırılan arıtım tankında 3,115 ± 0,034 m^3 kadar oluştuğunu ve minimum biogaz üretiminin, gaz üretiminin başladığı günün en düşük sıcaklıkta 20 ± 2 ^{o}C de maksimum 57 gün olduğunda 2,152 ± 0,049 m^3 kadar elde edildiğini göstermiştir.

Anahtar Kelimeler: Biyogaz, Aneorobik, Atık, Yenilenebilir Enerji

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CHAPTER I

INTRODUCTION

There are a variety of gases that are useful as fuel. The three most commonly used world-wide are Liquified Petroleum Gas (LPG, propane, butane), Natural gas and Biogas. A biogas system is a means of digesting animal manure anaerobically to produce methane gas which is burned to provide heat or light. The system consists of one or more digester tanks, a gas holder, an arrangement of gas pipes, and one or more fixtures to burn the gas.

Biogas is produced when bacteria decompose to organic material such as garbage and sewage, especially in the absence of oxygen. Biogas consists of methane (CH_4) 55-65%, carbon dioxide (CO_2) 35-45%, with the balance being made up of nitrogen (N_2), hydrogen (H_2) and hydrogen sulphide (H_2S). **Methane** is the main component of natural gas. It is relatively clean burning, colorless, and odorless. This gas can be captured and burned for cooking and heating. This is already being done on a large scale in some countries of the world. Farms that produce a lot of manure, such as hog and dairy farms, can use biogas generators to produce methane.

For small-scale production of fuel gas, the choice is definitely Biogas because of it's relative ease of production by anaerobic digestion of animal wastes and other organic matter. The active or main flammable component of Biogas is methane which has a little-recognised attribute; although it is in itself a notorious 'Greenhouse' gas, when used as fuel it is the kindest of all because it burns to minimal carbon dioxide and water. True, carbon dioxide is also a greenhouse gas but methane gives off only half as much for a given fuel value than most. Another advantage of methane is that unlike most other fuels, it does not give off poisonous carbon monoxide when burnt, so it is safer to use in the home than other gases for cooking and heating. Biogas can be used as a fuel for gas heating, steam generation or directly as a replacement fuel in internal combustion engines.

Unlike commercially available Natural Gas, Biogas contains a large proportion of carbon dioxide along with water vapour, some ammonia, some hydrogen sulphide and a few traces of other gases which are insignificant for practical purposes. Because of the hydrogen sulphide and the carbon dioxide, biogas needs to be preprocessed in an operation called 'scrubbing'. The main purpose of scrubbing is to remove as much as practicable of the corrosive gases which combine with the water vapour to form acids and hence corrode all metal parts of the gas system, and to get rid of the unburnable carbon dioxide that simply 'takes up space' for no useful return. [1]

During the last few decades, anaerobic digestion of organic matter has been presented as a suitable technology used for treatment of organic wastes and production of energy from combustion of biogas.

Anaerobic digestion in biogas plants (BGPs) is an alternative way to handle biowaste, which includes animal and human waste. In Europe, increasing numbers of BGPs use food waste and manure as energy sources. In Denmark, there are 19 BGPs, in Germany 11, and in Sweden there are 10 large scale BGPs operating today and additional plants are under construction. Anaerobic digestion produces methane (biogas), reduces odour, and the digested residues may be used as fertiliser in agriculture. [2]

Biogas energy offers many advantages. Biogas-powered electricity plants can be built quickly, simply, and for much less money per kilowatt than coal, oil, or nuclear power plants. Unlike these other current energy sources, Biogas is a **renewable resource**. Methane is also an important greenhouse gas and is a major contributor to the global warming problem. Biogas provides an excellent source of energy that is helpful to the environment. Finally, the residue from the burning of Biogas, called activated sludge, can be dried and used as fertilizer. Biogas, technology is relatively simple and economically attractive. One major source for the raw material for biogas generation is free and abundant manure.

CHAPTER II

LITERATURE SURVEY

2.1. BIOMASS

All organic matters such as wood, plants, residue from agriculture or forestry, and the organic component of municipal and industrial wastes are defined as 'Biomass' and it can be used to provide heat, make fuels, and generate electricity. This is called bioenergy. World-wide, biomass is the fourth most-used fuel after oil, coal and natural gas. Biomass can be converted directly into liquid fuels (biofuels) like ethanol and biodiesel. Even gas can be produced from biomass for generating electricity and this is called as biogas.

Biomass refers to solid carbonaceous material derived from plants and animals. These include the residues of agriculture and forestry, animal wastes and wastes from food processing operations. Biomass energy includes fuelwood, agricultural residues, animal wastes, charcoal and other fuels derived from biological sources. It currently accounts for about 14% of world energy consumption. Biomass is the main source of energy for many developed and developing countries. Biomass can be burnt directly or it can be converted into solid, gaseous and liquid fuels using conversion technologies such as fermentation to produce alcohols, bacterial digestion to produce biogas and gasification to produce a natural gas substitute.

Organic wastes have vital importance for the soil, but fuelwood, animal wastes, agricultural crop residues and logging wastes have been used through direct burning in Turkey for many years. Animal wastes are mixed with straw to increase the calorific value, and are then dried for use. This is the principal fuel of many villages in rural region of Turkey, especially in mountainous regions. Nitrogen is considered particularly important because of its vital role in plant nutrition and growth. When fresh cow dung dries, approximately 30 to 50 percent of the nitrogen escapes within 10 days. While nitrogen escaping from digested slurry within the same period amounts to only 10 to 15 percent. Therefore, the value of slurry as fertilizer, if used directly in the field as it come out of the plant, is higher than when it used after being stored and dried. Biogas manure is ready in shortest possible time. Since animal husbandry and agriculture are highly developed in Turkey, a substantial amount of animal wastes and agricultural crop residues are produced each year. [3]

Furthermore, biomass energy can play an important role in reducing greenhouse gas emissions, since when produced and utilised in a sustainable way, the use of biomass for energy offsets fossil fuel greenhouse gas emissions. Since energy plantations may also create new employment opportunities in rural areas in development countries, it also contributes to the social aspect of sustainability. [4]

All organic matter, or biomass, can in one way or other be used as fuel. It is composed mainly of carbohydrate compounds, the building blocks of which are the elements carbon, hydrogen and oxygen. All ultimately derive from the process of photosynthesis in plants, but may be in many forms, vegetable or animal. Biomass from which energy can be reclaimed can be harvested as specifically grown crops or natural stands, as surpluses or waste from crops grown primarily for food or manufacturing, or as municipal and industrial waste. [5]

2.2. WHAT IS BIOGAS?

Biogas is a medium-Btu methane and carbon dioxide mix produced by bacterial decomposition of organic matter. Its calorific value is between 17 – 25 MJ/m^3. This is the mixture of gas produced by methanogenic bacteria while acting upon biodegrable materials in an anaerobic condition. [6]

Biogas is generated when bacteria degrade biological material in the absence of oxygen, in a process known as anaerobic digestion. Since biogas is a mixture of methane (also known as marsh gas or natural gas) and carbon dioxide it is a renewable fuel produced from waste treatment. For small-scale production of fuel gas, the choice is definitely Biogas because of it's relative ease of production by anaerobic digestion of animal wastes and other organic matter.

Biogas is a low cost form of energy derived from renewable resources: animal dung and human waste. In developing countries such as China, India and Nepal, biogas has been used widely as a source of energy and as liquid fertiliser for soil enhancement, since the 1950's.

Biogas can be utilized as an alternative fuel for natural gas for heating, cogeneration and electricity production. Biogas is a fuel which is produced from the breakdown of organic matter. Biogas consists of methane (CH_4) 55-65%, carbon dioxide (CO_2) 35-45%, with the balance being made up of nitrogen (N_2), hydrogen (H_2) and hydrogen sulphide (H_2S). The relative percentage of these gases in biogas depends on the feed material and management of the process.

Biogas is about 20 percent lighter than air and has an ignition temperature in the range of 650 to 750 ºC. It is an odourless and colourless gas that burns with a blue flame similar to that of Liquefied Petroleum Gas (LPG). Its calorific value is 21 Mega Joules per m^3 and burns with 60 percent efficiency in a conventional biogas stove. [6]

Of the outputs of biogas, the gas is valued for its use as a source of energy and the slurry for its fertilizing properties (soil nutrients). Energy content of biogas can also be transformed into various other forms such as mechanical energy (for running machines) and heat energy (for cooking and lighting) depending on the need and availability of the technology. Some of the common uses of biogas are: cooking, lighting, and running internal combustion engine. [6]

The active or main flammable component of Biogas is methane which has a little-recognised attribute; although it is in itself a notorious 'Greenhouse' gas, when used as fuel it is the kindest of all because it burns to minimal carbon dioxide and water. True, carbon dioxide is also a greenhouse gas but methane gives off only half as much for a given fuel value than most. Another advantage of methane is that unlike most other fuels, it does not give off poisonous carbon monoxide when burnt, so it is safer to use in the home than other gases for cooking and heating. Biogas can be used as a fuel for gas heating, steam generation or directly as a replacement fuel in internal combustion engines. [7]

Factors affecting biogas production and the composition of biogas include the carbon/nitrogen ratio (optimum level is around 25), the pH (6.5 - 7), while the loading rate, temperature and retention time in the digester all also affect gas output. These factors are not mutually exclusive, thus an increase in temperature will allow a shorter retention time or an increased loading rate.

2.2.1. Comparison of Biogas with Other Fuels

The detailed comparison of effective heat of biogas with the other energy sources is given in Table 2.1.

Table 2.1. Equivalency of Biogas with Other fuels [8]

Type of Fuel	Unit Energy Value	Efficiency	Biogas Equivalency
Biogas	4700 kcal	% 60	1 m^3
Electric	860 kcal	% 70	4,7 kWh
Gasoil	9100 kcal	% 50	0,62 lt
Wood	4700 kcal	% 17	3,47 kg
Dried Dung	2100 kcal	% 11	12,30 kg

2.3. METHANE GAS

Methane is a gas made up of one molecule of carbon and four molecules of hydrogen. It is the major component of the natural gas used in many homes for cooking and heating. It is oderless and colorless.

In 1804 – 1810 Dalton, Henry and Davy established the chemical composition of methane, confirmed that coal gas was very similar to Volya's marsh gas and showed that methane was produced from decomposing cattle manure. [6]

Methane was first recognised as having practical and commercial value in England, where a specially designed septic was used to generate gas for the purpose of lighting in the 1890s. There are also reports of successful methane production units in several parts of the world, and many farmers wonder if such small scale methane production units can be installed at their farms to convert waste into something more valuable. Units to produce methane gas have been successfully applied in meeting energy needs in rural areas, particularly in India and China and are more recently being installed in Vietnam. Small-scale plant can be operated on farms and waste treatment plants in temperate and tropical climates. [5]

Biogas can be used as a fuel for gas heating, steam generation or directly as a replacement fuel in internal combustion engines. Methane has a very slow flame-propagation speed of about 430 mm per second. This means that it burns with a 'whoosh' rather than a 'bang' so it makes a very mild-mannered, tractable fuel for internal combustion engines. [1]

2.4. ADVANTAGES AND DISADVANTAGES OF BIOGAS SYSTEM

Biogas system also provides a residue organic waste, after anaerobic digestion that has superior nutrient qualities over the usual organic fertilizer, cattle dung, as it in the form of ammonia. Anaorobic digesters also function as a waste disposal system, particularly for human waste, and can therefore prevent potential sources of environmental contamination and the spread of pathogens.

Unsafe and improper disposal of decomposable animal waste causes major environmental pollution problems, including surface and groundwater contamination, odors, dust, and ammonia emission. There is also a concern regarding methane emissions, which contribute to the green house. Through anaerobic digestion, these large amounts of waste can be converted to methane, a renewable energy source.

The advantages of a biogas plant for the health of a rural community are four-fold; uncovered faecal waste (human and animal) is removed from open areas near their homes, direct exposure of children to waste is eliminated as they no longer have to play in affected areas, the spread of germs via mosquitoes and flies is reduced; and thus fewer people suffer from diarrhea, worms and their related illnesses. Instead, human and animal wastes are collected directly into latrines or disposed of in sewage pits and stored underground, away from water supplies, (e.g. wells, rivers, houses) people and animals. All wastes decompose into manure, which benefits the soil when used sufficiently on the land, improving its quality. [9]

Everyone's diet is enhanced as they can grow a wider variety of crops and more of them using the organic manure. This manure is very effective at improving soil quality and durability. Communities suffer less from disease too as the quality of drinking water improves due to the risk of sewage contamination being prevented.

Advantages of Biogas Technology:

1. Biogas is an important form of renewable energy, which can be used where organic waste is produced in appropriate quantities.

2. It can make an important contribution to the protection and improvement of natural resources and environment.

3. Slurry, a residue from the process, is a high-grade fertilizer which can replace expensive mineral fertilizers, in particular nitrogen.

4. The technology provides an efficient sanitary system - that enhances effective waste product disposal.

5. The use of biogas enables women, especially in rural areas, to save time for productive agriculture, leisure and family care and welfare.

6. Use of biogas technology improves the standard of living and can directly contribute to economic and social development of a country.

7. Biogas burns excellently in a power plant. Biogas can be easily used on site or piped to a remote user location.

8. Biogas technology is relatively simple and economically attractive.

9. One major source for the raw material for biogas generation is free and abundant manure.

10. Biogas-powered electricity plants can be built quickly, simply, and for much less money per kilowatt than coal, oil, or nuclear power plants.

Disadvantages of Biogas Technology:

1. Initial investment may be costly for a digestion system.

2. The digester requires proper care and feeding, just like an animal. Technical knowledge of the digestion process and good management are required.

3. Labor is required for preventive and unscheduled maintenance. Ideally, one person will be in charge of the digester, and the digester takes precedence over that person's other farm duties.

4. There is no reduction in the amount of manure to be handled. If water is added to the system, the volume is increased.

5. Much of the nitrogen in raw manure is converted from its organic form to ammonium. Ammonium can be transformed to either ammonia or nitrate. Ammonia can be lost from unincorporated, field-applied manure. Nitrate can be leached through the soil and may eventually reach groundwater. [10]

2.4.1. Bioenergy Contributes to Greenhouse Gas Emissions

Burning biomass efficiently results in little or no net emission of carbon dioxide to the atmosphere, since the bioenergy crop plants actually took up an equal amount of carbon dioxide from the air when they grew. However, burning conventional fossil fuels such as gasoline, oil, coal or natural gas results in an increase in carbon dioxide in the atmosphere, the major greenhouse gas which is thought to be responsible for global climate change. Some nitrogen oxides inevitably result from biomass burning (as with all combustion processes) but these are comparable to emissions from natural wildfires, and generally lower than those from burning fossil fuels. The methane has less carbon content, therefore burning biogas results less CO_2.

The active or main flammable component of Biogas is methane which has a little-recognised attribute; although it is in itself a notorious 'Greenhouse' gas, when used as fuel it is the kindest of all because it burns to minimal carbon dioxide and water. Methane is also an important greenhouse gas and is a major contributor to the global warming problem. Biogas provides an excellent source of energy that is helpful to the environment. Finally, the residue from the burning of Biogas, called activated sludge, can be dried and used as fertilizer. True, carbon dioxide is also a greenhouse gas but methane gives off only half as much for a given fuel value than most. Another advantage of methane is that unlike most other fuels, it does not give off poisonous carbon monoxide when burnt, so it is safer to use in the home than other gases for cooking and heating. [1]

2.4.2. How is Biomass Used to Produce Electric Power?

When biomass is burned, it produces heat (as in any simple fireplace or furnace). In most power plants (*steam-cycle* or *steam-turbine* systems), this heat is captured by boiling water to generate steam, which turns turbines and drives generators that convert the energy into electricity.

New technologies now being evaluated include several types of biomass gasifiers in which biomass are heated to convert it into a gas. This gas is used directly in a gas turbine, which drives a generator (a *simple gas turbine* system). In some cases, the waste heat from the gas turbine may be used to drive a secondary steam turbine, thus converting more of the fuel energy into electricity (a *combined-cycle* system).

2.5. GAS PRODUCTION POTENTIAL OF VARIOUS TYPES OF DUNG

The quantity of manure produced per animal per day depends on factors such as body size, kind of feed, physiological state (lactating, growing, etc.), and level of nutrition. The moisture content of the manure also varies among different types of animals. For example, manures of sheep, horses, and chickens contain about 25%

and of cattle and swine 9-14% dry matter. Gas production of various types of animal dung is showed in Table 2.2.

Table 2.2. Gas Production of Various Types of Dung [6]

Types of dung	**Gas production per kg of Dung (m^3)**
Cattle (cows and buffaloes)	0.023 – 0.040
Pig	0.040 – 0.059
Poultry (chickens)	0.065 – 0.116
Human	0.020 – 0.028

Since different organic materials have different biochemical 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 methanogenes are met. [6]

2.6. BIOENERGY POTENTIAL OF ANIMAL WASTES IN TURKEY

Anaerobic digestion for methane production is a possible solution to recover the wastes as fertilizers and produce energy. For efficient use of bioenergy resources, it is essential to take account of the intrinsic energy potential. Turkey is an energy importing country; it seems necessary to take measures toward the optimum utilization of biomass as an energy source in Turkey. In Turkey, much effort has been put into biogas research and development projects since the 1960s. The biogas potential of animal wastes in Turkey is presented in Table 2.3.

Table 2.3. Biogas Potential of Animal Wastes in Turkey [23]

Kind of Animal	Total number of animals	Total animal waste (Tone / year)	Biogas Potential (m^3 / year)
Cattle	11.054.000	40.347.100	994.860.000
Sheep and goats	38.030.000	26.621.000	1.901.500.000
Poultry	243.510.453	5.357.207	487.020.906
Total	292.594.453	72.325.307	3.383.389.060

The biogas potential of Turkey is 15,9 billion kWh per year. Since animal husbandry and agriculture are highly developed in Turkey, a substantial amount of animal wastes and agricultural crop residues are produced each year. In addition to feasibility studies on biogas utilization, many digesters have been constructed at different places in the country.

2.7. ANAEROBIC DIGESTION

Either biological or thermochemical conversion methods can be used to obtain energy from animal wastes. Anaerobic digestion is a microbial process that occurs in the absence of oxygen. Anaerobic digestion, a biological conversion process, has a number of advantages for waste conversion. [11]

Digestion refers to various reactions and interactions that take place among the methanogens, non-methanogens and substrates fed into the digesters inputs. This is a complex physio-chemical and biological involving different factors and stages of change.

Stage 1 : Hydrolysis
Stage 2 : Acidification

Stage 3 : Methanization

Anaerobic Digestion is biological means of decomposition of manure in an oxygen-free environment, and has the advantage of producing a fuel gas (methane) and odor free residues rich in nutrients, which can be used as fertilizers. [12]

During the last few decades, anaerobic digestion of organic matter has been presented as a suitable technology used for treatment of organic wastes and production of energy from combustion of biogas. Over the past 25 years, anaerobic digestion processes have been applied to a wide array of industrial and agricultural wastes. [13]

Anaerobic digestion is one way of handling biowaste and generating energy in the form of methane (biogas). The digested residue may be used as fertiliser on agricultural land. Anaerobic digestion in biogas plants (BGPs) is an alternative way to handle biowaste, which includes animal and human waste. In Europe, increasing numbers of BGPs use food waste and manure as energy sources. In Denmark there are 19 BGPs, in Germany 11, and in Sweden there are 10 large scale BGPs operating today and additional plants are under construction. Anaerobic digestion produces methane (biogas), reduces odour, and the digested residues may be used as fertiliser in agriculture. [2]

Methanogenesis is a microbial process, involving many complex and differently interacting species, but most notably, the methane-producing bacteria. Methanogenic bacteria develop slowly and are sensetive to a sudden change in physical and chemical conditions. For example a sudden fall in the slurry temperature by even 2 ^{0}C may signifacantly affects their growth and gas production rate.

The anaerobic bacteria responsible for digestion cannot survive with even the slightest trace of oxygen. Thus, because of the oxygen present in the manure mixture fed to the digester, a period of time passes after loading before actual digestion takes place.

During this initial aerobic period, traces of oxygen are used up by oxygen loving bacteria. After oxygen has disappeared, the digestion process can begin. That process involves a series of reactions by several kinds of anaerobic bacteria feeding on the raw organic matter. As these different kinds of bacteria become active, the by products of one type of bacteria provide the food for another bacterial population.

Anaerobic bacteria transform manure and other organic material into biogas and a liquefied effluent during the three stages of biogas production (Figure 2.1). In the liquefaction stage, liquefying bacteria convert insoluble, fibrous materials such as carbohydrates, fats and proteins into soluble substances. However, some fibrous material cannot be liquefied and can accumulate in the digester or can pass through the digester intact. Water and other inorganic material also can accumulate in the digester or pass through the digester unchanged. Undigested materials make up the low-odor, liquefied effluent. Most of the liquified, soluble compounds are converted to biogas by the acid and methane-forming bacteria during steps 2 and 3 of biogas production. [10]

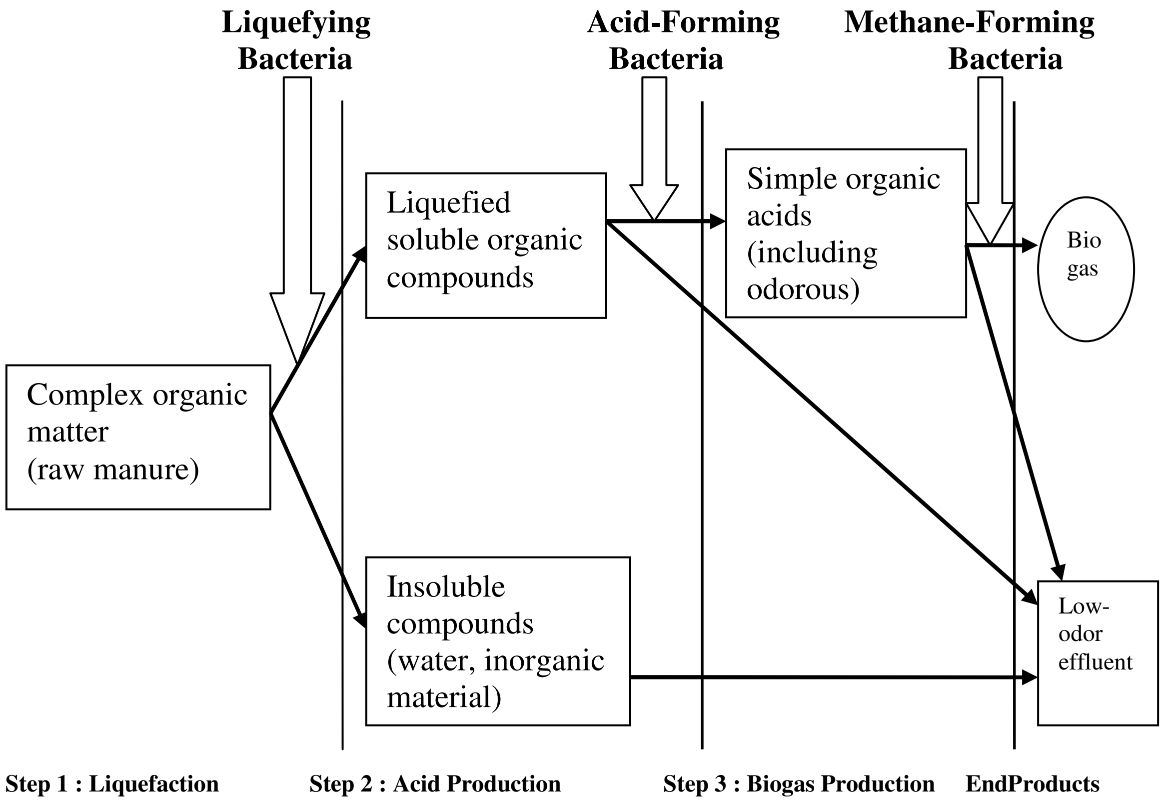


Figure 2.1. The Three Stages of Biogas Production

In the second stage of anaerobic digestion, acid-forming bacteria convert the soluble organic matter into volatile acids, the organic acids that can cause odor production from stored liquid manure. Finally, methaneforming bacteria convert those volatile acids into biogas—a gas composed of about 60 percent methane, 40 percent carbon dioxide, and trace amounts of water vapor, hydrogen sulfide, and ammonia. Not all volatile acids and soluble organic compounds are converted to biogas; some become part of the effluent.

2.8. BIO DIGESTER

The biodigester is a physical structure, commonly known as the biogas plant. As a chamber, it should be air and water tight. In planning a digester there must be clear objectives. This will enable choice of the right type of digester and the criteria on which it must be designed. Commercial digesters are not widely available but producers can make their own quite cheaply, in line with their set objectives.

Biodigesters can play a pivotal role in integrated farming systems by reducing health risks, facilitating control of pollution and at the same time adding value to livestock excreta through production of biogas and improved nutrient status of the effluent as fertilizer for ponds and crop land.

Many developing countries, such as Colombia, Ethiopia, Tanzania, Vietnam, Cambodia, have promoted the low-cost biodigester technology aiming at reducing the production cost by using local materials and simplifying installation and operation.

The polyethylene tubular biodigester technology is a cheap and simple way to produce gas for small-scale farmers. It is appealing to rural people because of the low cost of the installation and therefore of the gas, and the improvement in the environment that the installation allows.

During the last century a number of different types of simple digester have been developed and they can be of the following kinds:

1. Batch- filled in one go and allow to digest, then emptied and refilled.
2. Continuously Expanding- start one third, full filled in stages and then emptied.
3. Plug flow- waste added regularly at one end and over-flow the other.
4. Contact- a support medium is provided for bacteria, continuos flow.
5. Continuous Flow-filled initially and waste added and removed regularly.

A Batch Digester operates on a single charge until it is exhausted, producing gas via a scrubber to a storage device. At the end of the digestion cycle, the Batch Digester is emptied, cleaned, recharged and restarted for a new cycle then left until done. This cycle time may be as long as six weeks. Operating the batch digestion system requires that you have two or more digesters to be able to have a more or less continuous gas supply. Three is more practical. Batch digesters have the quality of predicability because once started they are not disturbed or interrupted.

On the other hand, Continuous-Feed Digesters have increments of charge added and subtracted on a daily basis to provide an ongoing replenishment of charge materials and water. It is obvious that the amounts withdrawn and replaced should be exactly the same or the digester may become either overloaded or underloaded. Knowledge of your feedstock that with water makes up your digester charge is vital. One daily increment that contains a bacteriacide will kill off the bacteria, necessitating a time and energy consuming cleanout of the entire digester system and a restart from 'scratch'. In the intervening two to three weeks there will be no gas production. Continuous-feed digester systems are less expensive to set up due to lower capital costs (you only need one digester, not several) but they do require close monitoring of feedstock solids. On the other hand, they are easier to automate due to their incremental nature. [14]

There are many designs of biogas plants ranging from large commercial units to small plants. The most common are the floating canopy Indian type and fixed dome Chinese models, which are of self-mixing, continuous flow design.

2.8.1. Balloon Plants

The balloon plant consists of a digester bag (e.g. PVC) in the upper part of which the gas is stored. The inlet and outlet are attached directly to the plastic skin of the balloon. The gas pressure is achieved through the elasticity of the balloon and by added weights placed on the balloon.

Advantages are low cost, ease of transportation, low construction sophistication, high digester temperatures, uncomplicated cleaning, emptying and maintenance. [15]

Disadvantages can be the relatively short life span, high susceptibility to damage, little creation of local employment and, therefore, limited self-help potential. [15]

A variation of the balloon plant is the **channel-type digester**, which is usually covered with plastic sheeting and a sunshade. Balloon plants can be recommended wherever the balloon skin is not likely to be damaged and where the temperature is even and high.

2.8.2. Fixed Dome Digester

The fixed-dome plant consists of a digester with a fixed, non-movable gas holder, which sits on top of the digester. When gas production starts, the slurry is displaced into the compensation tank. Gas pressure increases with the volume of gas stored and the height difference between the slurry level in the digester and the slurry level in the compensation tank.

Advantages are the relatively low construction costs, the absence of moving parts and rusting steel parts. If well constructed, fixed dome plants have a long life span. The underground construction saves space and protects the digester from temperature changes. The construction provides opportunities for skilled local employment. [15]

Disadvantages are mainly the frequent problems with the gas-tightness of the brickwork gas holder (a small crack in the upper brickwork can cause heavy losses of biogas). Fixed-dome plants are, therefore, recommended only where construction can be supervised by experienced biogas technicians. The gas pressure fluctuates substantially depending on the volume of the stored gas. Even though the underground construction buffers temperature extremes, digester temperatures are generally low. [15]

Fixed dome Chinese model biogas plant (also called drumless digester) was built in China as early as 1936 (Figure 2.2). It consists of an underground brick masonry compartment (fermentation chamber) with a dome on the top for gas storage. In the design, the fermentation chamber and gas holder are combined as one unit. This design eliminates the use of costlier mild steel gas holder which is susceptible to corrosion. [6]

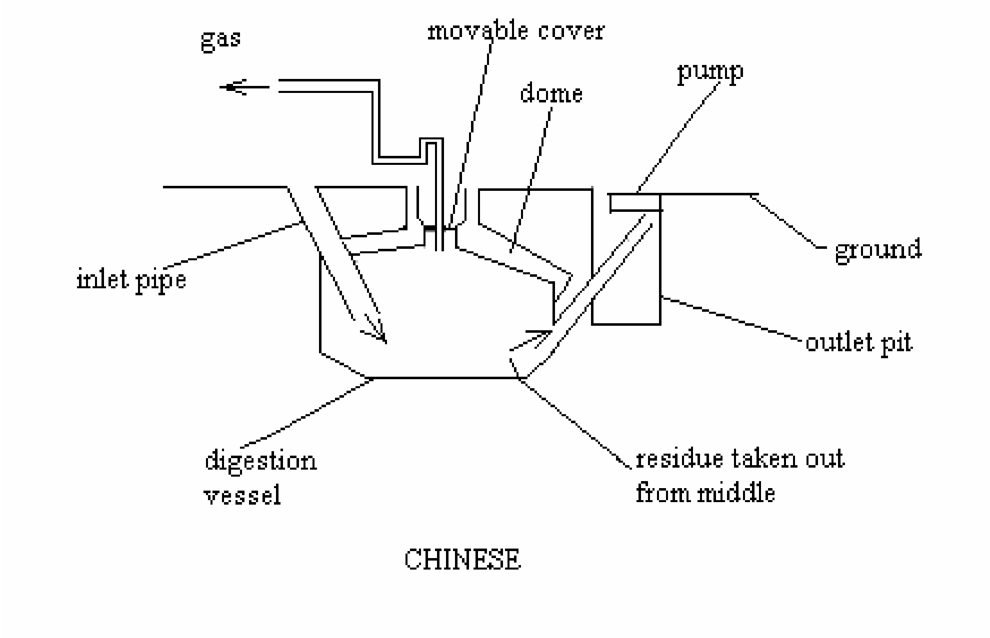
2.8.3. Floating Drum Digester

Floating-drum plants consist of an underground digester and a moving gas-holder. The gasholder floats either directly on the fermentation slurry or in a water jacket of its own. The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored. The gas drum is prevented from tilting by a guiding frame. If the drum floats in a water jacket, it cannot get stuck, even in substrate with high solid content.

Advantages are the simple, easily understood operation - the volume of stored gas is directly visible. The gas pressure is constant, determined by the weight of the gas holder. The construction is relatively easy, construction mistakes do not lead to major problems in operation and gas yield. [15]

Disadvantages are high material costs of the steel drum, the susceptibility of steel parts to corrosion. Because of this, floating drum plants have a shorter life span than fixed-dome plants and regular maintenance costs for the painting of the drum. [15]

In 1962, Patel's design was approved by the Khadi and Village Industries Commission (KVIC) of India and this design soon became popular in India and the world. In this design, the digester chamber is made of brick masonary in cement mortar. A mild steel drum is placed on top of the digester to collect the biogas produced from digester. Thus, there are two separate structures for gas production and collection (Figure 2.2). [6]



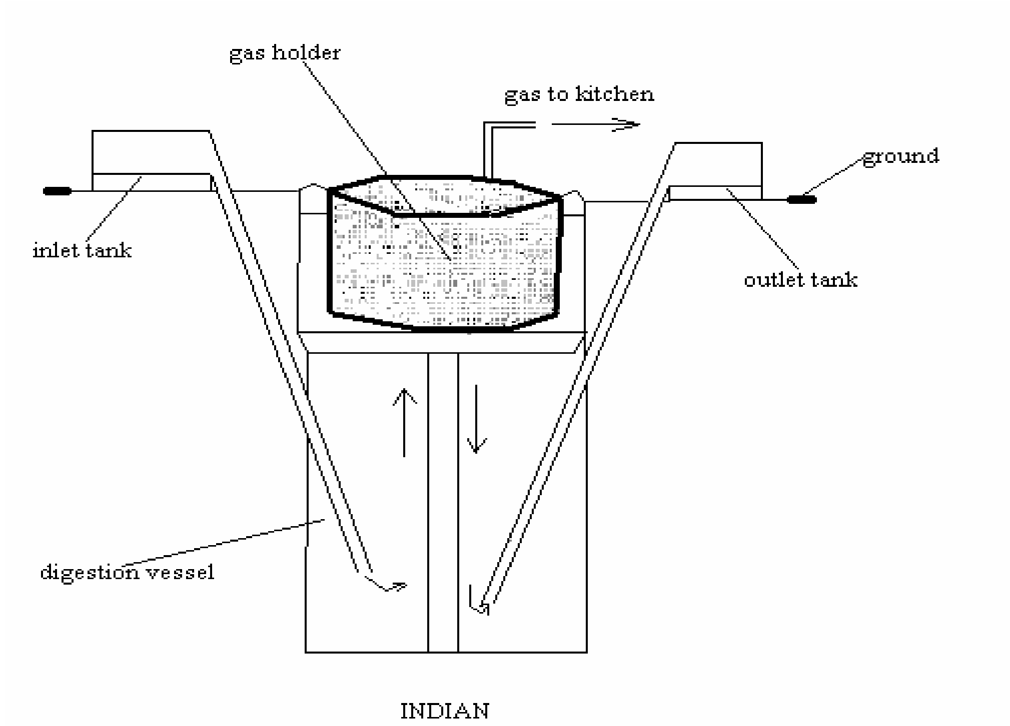


Figure 2.2. Digester Types

2.8.4. Plug Flow Digester

A plug flow digester vessel is a long narrow (typically a 5:1 ratio; 5 times as long as the width) insulated and heated tank made of reinforced concrete, steel or fiberglass with a gas tight cover to capture the biogas. These digesters can operate at a mesophilic or thermophilic temperature. In theory, manure in a plug flow digester does not mix longitudinally on its trip through the digester but can be imagined to flow as a plug, advancing towards the outlet whenever new manure is added. When the manure reaches the outlet it discharges over an outlet weir arranged to maintain a gas tight atmosphere but still allow the effluent to flow out. In actuality the manure does not remain as a plug and portions of the manure flow through the digester faster than others and some settles or floats and remains in the digester.

Advantages are good track record with dairy manure. It works well with scrape systems. There are many successful examples at present. [16]

Disadvantages are required high solids manure (11-14 %). It is not compatible with sand bedding. [16]

The first documented using of this type of design was in South Africa in 1957. This type of appropriate technology for low-income small farmers can be easily constructed and makes better use of livestock waste, reducing the pressure on natural resources due to pollution and fuel collection. [5]

2.9. ANAEROBIC WASTE TREATMENTS AND BIOGAS PRODUCTION

Methane is insoluble, already separated from the fermentation system and is easily collected in a gas container. Methane gas is readily combustible and is a valuable energy source.

The gas is also explosive and high-care safety standards must be maintained at all times during the operation period. The pressure in the cylinder must be above 34,450 kPa for liquefaction of methane, so gas is best used on site as it is generated, rather than being stored in bottles for mobile use.

The amount of gas produced increases with digester temperature, with retention time and with the percentage of total solid in the slurry. Typically for 25 ^{o}C to 44 ^{o}C, 0.25 to 0.40 m^3 of methane gas is produced for each kilogram of volatile solids destroyed. [5]

2.9.1. Temperature

Anaerobic digestion can take place at any temperature between 4 ^{o}C and 60 ^{o}C. There appear to be two main temperature ranges within this wider range corresponding to two different sets of bacteria, usually called the mesophiles, those which operate best at 20-40 ^{o}C, and the thermophiles, which prefer to live at temperatures between 40 - 60 ^{o}C.

Digestion can also occur in the psychrophilic range, 4-20 ^{o}C, but is much slower. The rate of gas production increases with increased temperature but there is a distinct break in the rise around 40 ^{o}C, as this favours neither the mesophiles nor thermophiles. [9]

A small capacity digester can be used if supplementary heat is supplied to maintain a constant temperature of 35 ^{o}C, if it is to be loaded with one type of material (for example pig manure) and if it has some form of agitation to keep slurry gently stirred. Methane bacteria can tolerate a minimum temperature of about 4 ^{o}C but function best in higher temperature ranges up to 60 ^{o}C. [5]

Temperature is perhaps the most consideration. Gasification is found to be maximised at about 35 ^{o}C and below this temperature, the digestion process is slowed, until little gas is produced at 15 ^{o}C and under. Therefore in areas of temperature changes, such as mountains region, or winter conditions that may be more accentuated inland, mitigating factors need to be taken into occunt, such as increased insulation. [6]

The methanogens are inactive in extreme high and low temperatures. When ambient temperature goes down to 10 ^{o}C, gas production virtually stops.

2.9.2. Retention Time

Retention time is the average period that a given quantity of input remains in the digester to be acted upon by the methanogens. The retention time is also dependent on the temperature, the higher temperature provides the lower retention time. Because, the methanogens are inactive in extreme low temperatures.

The length of time that volatile solids remain in an anaerobic digester is an important factor in the digestion process. The solids retention time (SRT) represents the average time microorganisms spend in the system.

Minimum solids retention times for anaerobic digestion systems are in the range of 2-6 days, depending on the temperature. In completely mixed anaerobic digesters where no recycling occurs, the SRT is equal to the hydraulic retention time (HRT).

Hydraulic retention times usually vary from 15 to 60 days depending on the temperature. Typical hydraulic retention times of anaerobic digester at various temperatures are presented in Table 2.4. If solid retention time is too short the microbes are "washed out" of the digester and digestion process fails, while a long retention time requires a large digester.

Table 2.4. Typical Hydraulic Retention Times of Anaerobic Digester at Various Temperatures [5]

Digester Temp (^{o}C)	Retention Time (days)
15	56
26	30
37	24
49	16

2.9.3. pH Value

The optimum biogas production is achieved when the pH value of input mixture in the digester is between 6 and 7. The pH in biogas digester is also function of the retention time.

In the initial period of fermentation, as large amounts of organic acids are produced by acid forming bacteria, the pH inside the digester can decrease to below 5. This inhibits or even stops the digestion or fermentation process. Methanogenic bacteria are very sensitive to pH and do not thrive below a value of 6,5. Later, as the digestion process continues, concentration of NH_4 increases due to digestion of nitrogen which can increase the pH value to above 8. When the methane production level is stabilized, the pH range remains buffered between 7,2 to 8,2. [6]

2.9.4. C/N Ratio

The relationship between the amount of carbon and nitrogen present in organic materials is expressed in terms of the C/N ratio. A C/N ratio ranging from 20 to 30 is considered optimum for anaerobic digestion. C/N ratio of various types of dung is given in Table 2.5.

Table 2.5. C/N Ratio of Various Types of Dung [6]

Types of dung	C/N Ratio
Duck	8
Human	8
Chicken	10
Goat	12
Pig	18
Sheep	19
Cattle (cows and buffaloes)	24

If the C/N ratio is very high, the nitrogen will be consumed rapidly by methanoges for meeting their protein requirements. And there 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 ammonia (NH_4).

NH_4 will increase the pH value of the content in the digester. When the pH is higher than 8.5 it 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 has a C/N ratio as low as 8. [6]

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 Wildlife Resort located in Chitawan district of Nepal, feeding the digester with elephant dung in conjunction with human waste enabled to balance C/N ratio for smooth production of biogas. [6]

2.9.5. Dilution and Consistency of Inputs

Before feeding the digester, especially fresh cattle dung, has to be mixed with water at the ratio of 1:1 on a unit volume basis. However, if the dung is in dry form, the quantity of water has to be increased accordingly to arrive at the desired consistency of the inputs. The dilution should be made to maintain the total solids from 7 to 10 percent. If the dung is too diluted, 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. Rate of dilution of various types of dung is given in Table 2.6.

Table 2.6. Rate of Dilution of Various Types of Dung [25]

Types of Dung	Amount of Moisture (%)	Rate of Dilution (dung/water)
Cattle	80-85	1/1
Pig	75-80	1/2
Poultry (chickens)	70-80	1/3
Goat	75-80	2/3
Human	75-80	3/7

2.9.6. Volatile Solids

Volatile solids are the portion of the total solid that are organic in composition. The biological organisms utilise a portion of this material as a substrate and make volatile solids an important parameter in estimating potential gas production. Around 20 per cent of the volatile solids in pig manure are bio-degradable. [5]

The weight of organic solids burned off when heated to about 538 ^oC is defined as volatile solids. The higher volatile solid content in a unit volume of fresh dung provide the higher gas production. For example, a kg of volatile solids in cow dung would yield about 0,25 m^3 biogas. [6]

2.10. STORING METHANE GAS

There are three methods available for storing gas:

1. The water sealed gasometer made from galvanised steel sheet or fiberglass, preferably corrugated.

2. Reinforced butyl rubber or heavy plastic bags made for the purpose.

3. High-pressure steel or aluminium alloy cylinders, filled by a three-stage compressor. Methane, known as a permanent gas, does not liquefy at low pressure as LPG does. Heavy steel cylinders or special aluminium alloy cylinders are necessary so the gas can be compressed to a high pressure of 28 to 35 MPa. This is the only way sufficient gas can be carried to give reasonably long operating periods for mobile use, so use in stationary application is simpler. For liquid storage of methane, refrigerate it to -178°C. For anything other than the high-tech. approach, liquid methane storage is impractical. It is the most compact form of storage, though. [5]

To store the gas you will need a 'gasometer' or a compressor and some gas bottles. The compressed form of the gas is not as compact as would be the liquid, but is marginally useable for local vehicular travel. The liquified form would be ideal for vehicles, but to liquefy methane requires a considerable energy expenditure of about 20% to 33% of production, depending on operational scale, and needs expensive cryogenic equipment. The cost of the gas-filling and compressing equipment for compressed gas handling is not cheap, either, and requires a licence to operate in most Shires in Australia. The gasometer route is the one to take for most home use scenarios. It won't allow you to use it in your car, but it can be used for small stationary engines for various purposes such as pumping water, driving fixed machinery or generating electricity.

What is a gasometer? A gasometer is simply a variable-volume storage tank for gas, normally at a fairly low pressure suitable for the appliances that use it. A fixed dimension container for gas suffers from a problem when delivering it's gas to the user site in that the pressure will vary from quite high when the container is full, to quite low when it is nearly empty. A gasometer combines the functions of storage, over-pressure safety valve and pressure regulation in one structure - an ideal permaculture device! This is achieved by having one gas-tight tank float upside-down in another tank of water with the gas being stored beneath the floating tank. As more gas is produced, it is stored in the gasometer and the floating tank rises to accommodate the increased volume. Conversely, as gas is consumed, the floating tank floats lower. In this way, the gas pressure is kept constant at a pressure determined by the weight of the floating tank no matter what the volume of the stored gas.

The safety function of the floating tank system works like this: if the gas volume produced is too much, the floating tank lifts up until the bottom edge is clear of the water and the excess simply blows out from under the lower lip to release over-pressure conditions and then allowing the floating tank to settle back down again in the water. A bit like a monstrous mechanical burp when it happens. It's fairly obvious that the two functions of digester and gasometer can be combined in the one device by having the floating tank float in the (mainly liquid) digester contents. This represents a substantial savings in construction costs but it does mean that the floating tank will have to be acid-proofed both inside and out since both surfaces come into contact with the (mildly) corrosive digester contents. The disadvantage of the floating tank gasometer system is that it wont shut off the supply at low pressures. For that safety feature you will need a supply pressure regulator of the spring-loaded diaphragm type plumbed into the gas supply-line before the appliances and after the gasometer. [1]

2.11. USING METHANE GAS

Energy content of biogas can also be transformed into various other forms such as mechanical energy (for running machines) and heat energy (for cooking and lighting) depending on the need and availability of the technology.

Methane gas can either be burned directly as a source of energy for heating or cooking or it can be compressed and used for fuel for internal combustion engines. Methane is fairly high-grade source of energy. It can provide intense localised heat compared to energy from solar panels. The important uses of high-grade energy are for heating, lighting, cooking and fuel for internal combustion engines.

If biogas provides energy for cooking, lighting and fuel, it also replaces wood for fires. Thus leads to conservation of forests, less labour requirement and fertile soil for farming, creates new businesses and is of course much cleaner for air contamination.

Direct Combustion; Methane burns well in burners that were made for coal and LPG, but those for natural gas need modification. Basically a large jet opening and a slow flame speed are required. Pressure of between 1 to 1.5 kPa is required for a slow flame speed.

Fuel for Internal Combustion Engines; Both petrol and diesel engines will run on methane gas. Gas carburetors are available for most engines and no other modification is needed for a spark ignition (petrol) engine.

It is also possible to fit a gas carburetor on the intake and still use the diesel injectors to fire the mixture, using 10% diesel fuel.

The obvious use for methane as a fuel on a farm is in engines producing electricity and pumping. It is a simple matter to have a gasometer along side the plant to fuel the engines. [5]

2.12 REMOVING IMPURITIES FROM THE METHANE GAS

When a digester is working well, the contents are alkaline rather than acid, with a pH of 7.5 -8.0. The gas has fewer impurities when this condition is reached, just carbon dioxide and a small amount of hydrogen sulphide.

It is better to remove the impurities, particularly hydrogen sulphide, which can cause corrosion of metals and create a foul smell if allowed to accumulate. Hydrogen sulphide (H_2S) can be removed by several different methods.

Two effective methods suggested are:

1. To pass the gas through a solution of copper sulphate (bluestone) and water. H_2S combines with the copper and settles out in a black precipitate.

2. To pass gas through a 51mm P.V.C pipe filled with steel wool. The indication of effectiveness is that the steel wool becomes corroded at the inlet but not at the outlet.

The main culprit to be scrubbed will be Hydrogen Sulphide, or 'Rotten Egg' gas, because this will combine with the moisture in the biogas to form sulphurous acids and these can corrode almost anything. The way to get rid of it is to give it something to corrode that you don't want; like some steel wool, for instance, in a wide-necked bottle or flagon. It must be of clear glass with the gas inlet pipe running down to the bottom of the container and an outlet pipe coming away near the top. Of course, the whole thing needs to be gas-tight. As you use the gas, the steel wool will corrode from the bottom upwards taking up the hydrogen sulphide by conversion to black iron sulphide which can later be reused after being oxidised to rust (ferric oxide) by exposure to air, although the process is slower than the initial scrubbing one was. When the black corrosion reaches 75% of the height of the container, or so, it's time to change the steel wool or ferric oxide for fresh, sacrificial stuff. It's probably better to run two or more similar bottles or containers connected one after the other to give some flexibility by providing some 'back-up' scrubbing capability if you are away for a period. [1]

To get rid of the Carbon Dioxide (CO_2) requires that the digester biogas be diffused through a water (or lime-water) spray tower. This action dissolves the CO_2 in the water which is then collected at the bottom of that tower and then sprayed down a second column to release the carbon dioxide gas from the water which is then vented to atmosphere, preferably via your greenhouse to give the plants a boost. The water is then recycled back to pick up another load of carbon dioxide.

It is not absolutely necessary to eliminate Carbon Dioxide from the methane, but CO_2 has no intrinsic fuel value and can complicate the jet and air settings of user appliances. The reason is that CO_2 percentage can vary considerably from week to week of normal operation, particularly where differing feedstock constituents are used from time to time. This can vary appliance performance from 'not at all' to 'explosive', neither of which is desirable.

CHAPTER III

DESIGN AND CONSTRUCTION OF EXPERIMENTAL SET UP

3.1. PROJECT WORK

The objective of this project is to build a small scale "Batch" anaerobic digester and operate with cow wastes and make some experiments to see effect of mixing, temperature, additives and dilution of the manure on biogas production.

Animal wastes contain large quantities of organic matter, which if processed by anaerobic digestion and it produces significant quantities of methane gas. The methane gas can be captured and used as a fuel.

A Batch digester operates on a single charge until the methane gas is exhausted. At the end of the digestion cycle, the Batch Digester is emptied, cleaned, recharged and restarted for a new cycle then left until done. Operating the batch digestion system requires that any body have two or more digesters to be able to have a more or less continuous gas supply. Batch digesters have the quality of predicability because once started they are not disturbed or interrupted.

3.2. EXPERIMENTAL METHOD

System has been designed to accommodate the enough mixing of water and waste and to economize the manufacturing of the system and to standardize the system. Therefore the dimensions and materials must be selected under these conditions.

Firstly, before beginning of the project we considered the following points.

- The mixing of water and waste are accommodated in the digester. Maintaining biogas digesters consists mainly of regular cleaning and the inspection for, and replacement of, corroded metal fittings and components. Digester operates in a warm moist environment. The digester which is used to accommodate the enough mixing of water and waste resists to corrosion. The collected biogas is stored in the gas depot. The gas depot can resist on high pressure. This is necessary to supply safety and long life of the project. The biodigester is made water proof and air tight.

- A compresor is used in the system. The resisting of connection pipe of compresor is considered. The connection pipe resists on the high pressure in the digester and gas depot.

- The connection of pipe and screw is suitable to prevent the escaping of biogas.

- The temperatures of the experiment region and the manure in the digester are controlled during the experiments. Therefore the thermometres and a special heater are used.

- The system works with pressurized gas. Therefore the manometers are used to supply safety and to measure the amount of collected biogas in the depot.

- A checkvalve is used to prevent the leakage of collected biogas in the digester.

- The air ratio is important in the burning of the biogas. Therefore the system contains a burner which can arrange the ratio of air when the biogas is burned.

- The silicon sealant is used on around the connection points and opening surface (cover) to provide air tight and water proof conditions all together.

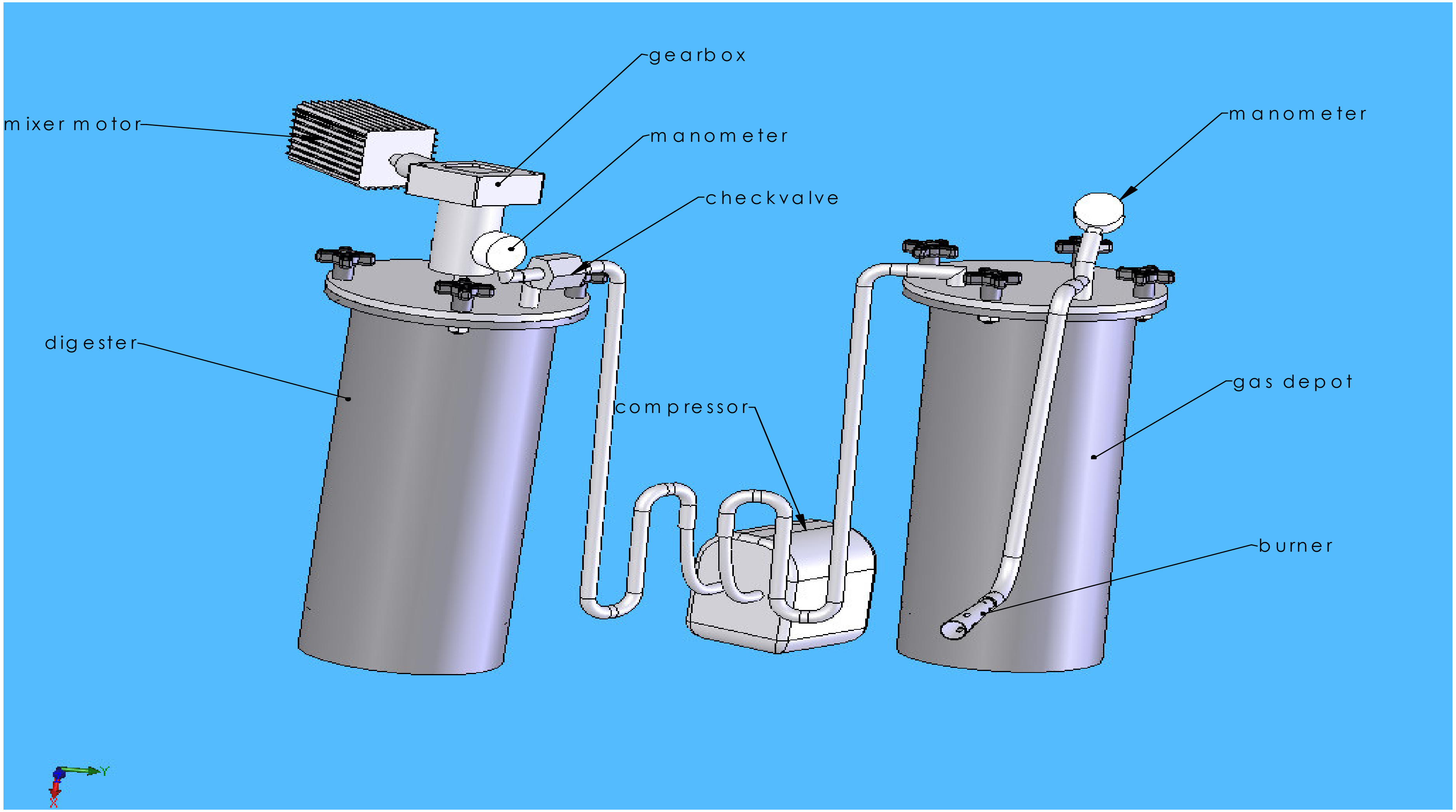


Figure 3.1. Assembly of System

3.3. MATERIALS USED TO CONSTRUCT A BIODIGESTER

The equipments that are necessary to construct a biodigester are listed below,

1. Two high alloy steel container with the volume capacity of approximately 26 litres for digester and gas depot.

2. One electrical motor to mix the mixture in the digester.

3. One compressor to compress the biogas which is collected in the digester to the gas depot.

4. Five meters of 12mm plastic irrigation pipe, four elbows, one cross joint.

5. A gas stove burner.

6. One checkvalve to prevent the leakage of collected biogas in the digester.

7. Two manometers, one of them is for the digester, the other is for the gas depot.

8. Three thermometers to measure the temperatures of room, digester and gas depot.

9. One heater to supply constant temperature in the digester.

10. Silicone sealant to supply air and water tight condition in the digester.

The economics of the system and the easy availability of the materials and the parts are important in choosing of the system's materials and parts.

3.4. EXPERIMENTAL SET UP

When choosing a suitable location for a biodigester to be placed, a site close to the shed holding the livestock (cows) is preferable. But this project work was carried out at A.E.L. Business Administration in Kahramanmaraş. The experimental set up was designed and mounted in the atelier of A.E.L. Business Administration. The study was performed in six sets of experiments to observe and control the temperature and collected gas.

Firstly; the mixing motor was installed on the digester cover. Then a suitable connection between motor shaft and mixer shaft was assembled. A small hole was made on the digester cover for the gas outlet. The checkvalve and manometer were connected to a “cross” joint at this gas outlet hole on the digester cover. One side of the cross joint was then put into the manometer. The gas collection pipe was fitted to the other side of the cross joint and the other end of the gas collection pipe was fitted to the compressor inlet which sucked the gas for compressing into the gas depot.

Next, the biogas depot was placed beside the digester. Two small holes were made on the gas depot cover for biogas inlet that was connected the compressor outlet and biogas outlet that was connected the biogas burner to burn the biogas. The compressor outlet was fitted to the inlet hole of depot with gas collection pipe. All of the gas collection pipe connections were sealed off with water and gas proof tape.

The mixture of water and cow waste was put into the digester. Then the cover of the digester was closed. All of the screw and pipe connections and digester and gas depot surfaces were sealed off with silicon to prevent escape of gas.

The heater was used to keep the temperature at 28 ^{o}C continuously by a thermostat. After these arrangements, the experiments were conducted.

3.5. EXPERIMENTS

The reported study was performed in six sets of experiments using the batch type digester having a working volume of 26 L were operated at a controlled temperature. Digesters were made of high alloy steel and had hopper bottoms with a 25 ^{o} slope angle. The cover of the digester was fixed with four butterfly bolt. The cover surface and bolt connection of digester were sealed with liquid gasket (silicone sealant). Biogas generated in the digesters was collected in the gas depot.

Some experiments were done to observe the performance characteristics of project work and to produce biogas at different experiments condition.

For this reason six experiments were made by using this experiment's set. The conditions and procedure of these experiments and experimental results are explained below.

3.5.1. Experiment 1

The main purpose of this experiment is to observe the amount of gas production rate at the determined optimum conditions and to compare the result of this experiment with the other experimental results at different conditions.

In this experiment, the cattle wastes were used. The mixing motor was not worked in this experiment. The digestion of the slurries was undertaken in a batch operation.

The conditions of experiment were observed as follows:

1. Cattle dung was mixed with water at the ratio of 1:1 on a unit volume basis. The amount of cattle dung was 10 lt in the first experiment.
2. The temperature of digester was set to 28 ± 2 ^{o}C.
3. The lag time was 20 days.

The digester was a batch type digester. Therefore the animal waste and water were put in the digester one time. The feed manure slurry was not used during the experiment. Because of the mixing motor was not operated in this experiment, the animal waste and water was mixed one times before starting the example. Then the cover of digester was closed. The silicon sealant was used on all of surfaces of the cover to prevent escape of collected gas, when it was closed. The temperature of digester was kept about 28 ^{o}C.

The compressor was run at the 17th day and the gas was compressed to about 0,2 bar. But the compressed gas was not burned. The collected gas was not compressed in 2 days. When the lag time was 20 days, the compressor was started again and the gas was compressed to about 0,25 bar. At this time the collected gas was burned. The wastes started to produce combustible gas 20 days after they were charged. After the compressor was operated, the gas was compressed regularly everday until the gas production finished. Daily biogas production during the first experiment is shown in the Figure 3.2.

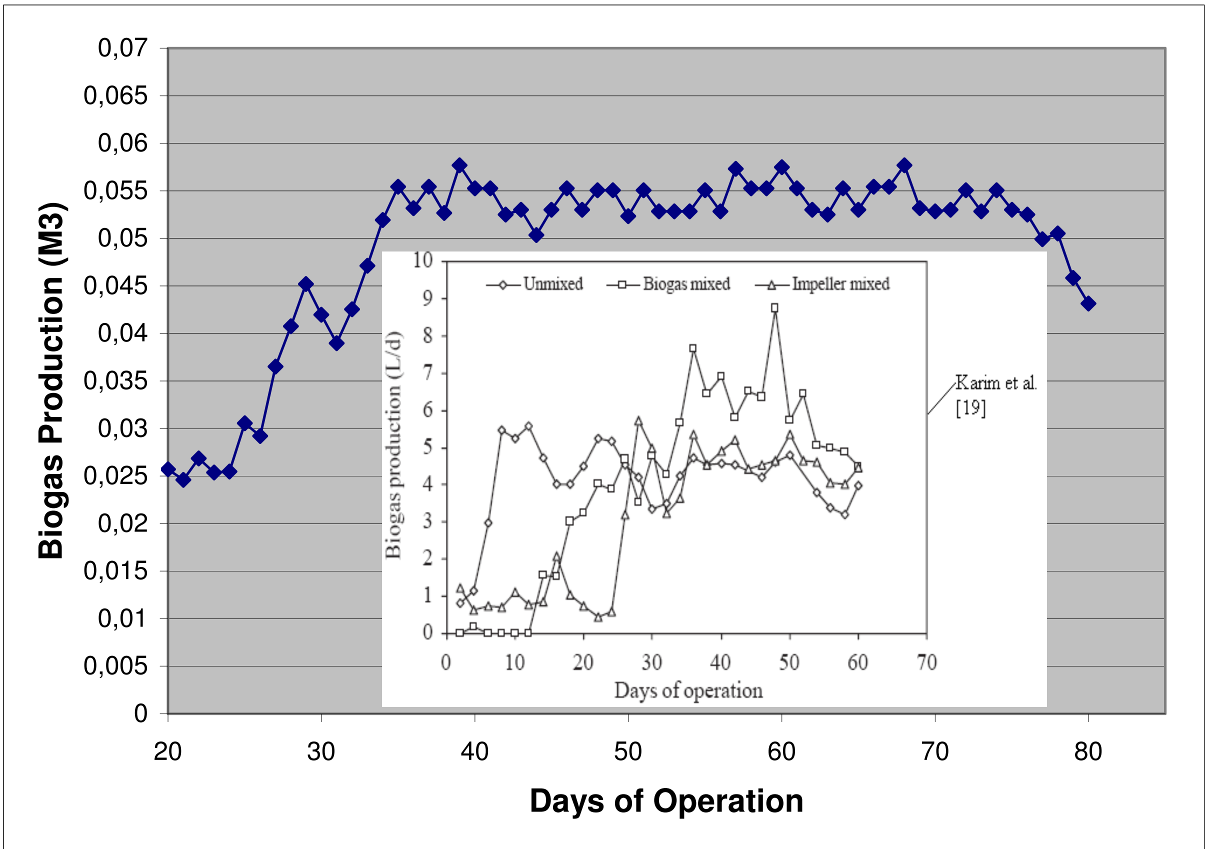


Figure 3.2. Daily Biogas Production During the First Experiment

The sum of daily collected biogas production was 2,998 ± 0,034 m^3 at this experiment. ± shows the error of manometer reading. The manometer which ranges from 0 – 2,5 bars was used. It has 0,05 bar scale interval. The gas was compressed regularly in 61 days.

3.5.2. Experiment 2

Mixing of the mixture can be accomplished through various methods, including mechanical mixers, recirculation of digester contents, or by recirculating the produced biogas to the bottom of the digester using pumps.

The main purpose of this experiment is to study the effect of mixing with mechanical mixers. Two other important aspects are the intensity and duration of mixing. The mixing motor was worked during this experiment. The speed of mixer shaft was 4 rpm. The digester was mixed by two 65*140 mm rectangular fin.

The conditions of Experiment 2 were observed as the same as those for Experiment 1.

The compressor was operated at the 17^{th} day, but there was not collected gas in the digester. The compressor was run again at the 20^{th} day and the gas was compressed about 0,15 bar. But the compressed gas was not burned. Then the collected gas was not compressed in 3 days. When the lag time was 24 days, the compressor was started again and the gas was compressed about 0,35 bar. At this time the collected gas was burned. After the compressor was operated, the gas was compressed regularly everday until the gas production finished.

Daily biogas production during the second experiment is presented in the Figure 3.3.

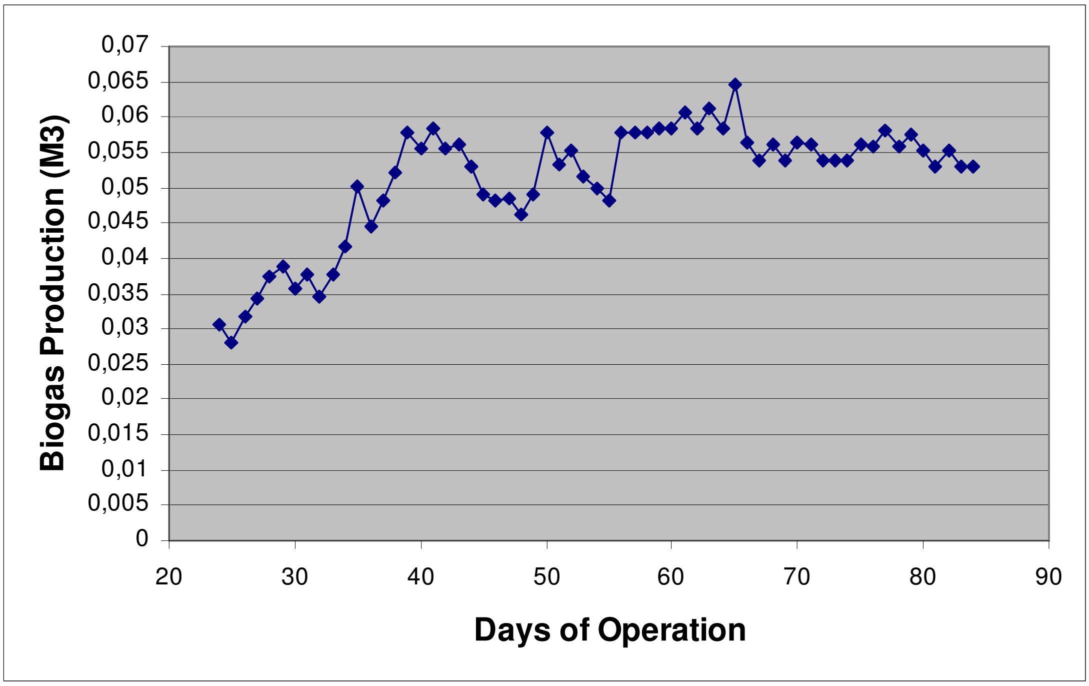


Figure 3.3. Daily Biogas Production During the Second Experiment

The sum of daily collected biogas production was 3,115 ± 0,034 m^3 in this experiment.

3.5.3. Experiment 3

The main purpose of this experiment is to observe the effect of ratio of water and waste in the mixing on the biogas production rate of digester. The mixing motor was not operated in this experiment.

In this experiment the cattle dung was mixed with water as a ratio of 1:0,6 on a unit volume basis. The amount of cattle dung was 12,5 litres and the amount of water was 7,5 litres.

The other conditions of experiment:

1. The temperature of digester was kept as 28 ± 2 ^{o}C.
2. The lag time was 20 days.

The compressor was worked at the 20th day and the gas was compressed about 0,35 bar. But the compressed gas was burned with very low flame height. Then the collected gas was compressed about 6 days but the gas was not burned. After the compressor was worked again, at this time the collected gas was burned and the gas was compressed regularly everday until the gas production finished. But, the biogas was not burned exactly.

Daily biogas production during the third experiment is available in the Figure 3.4.

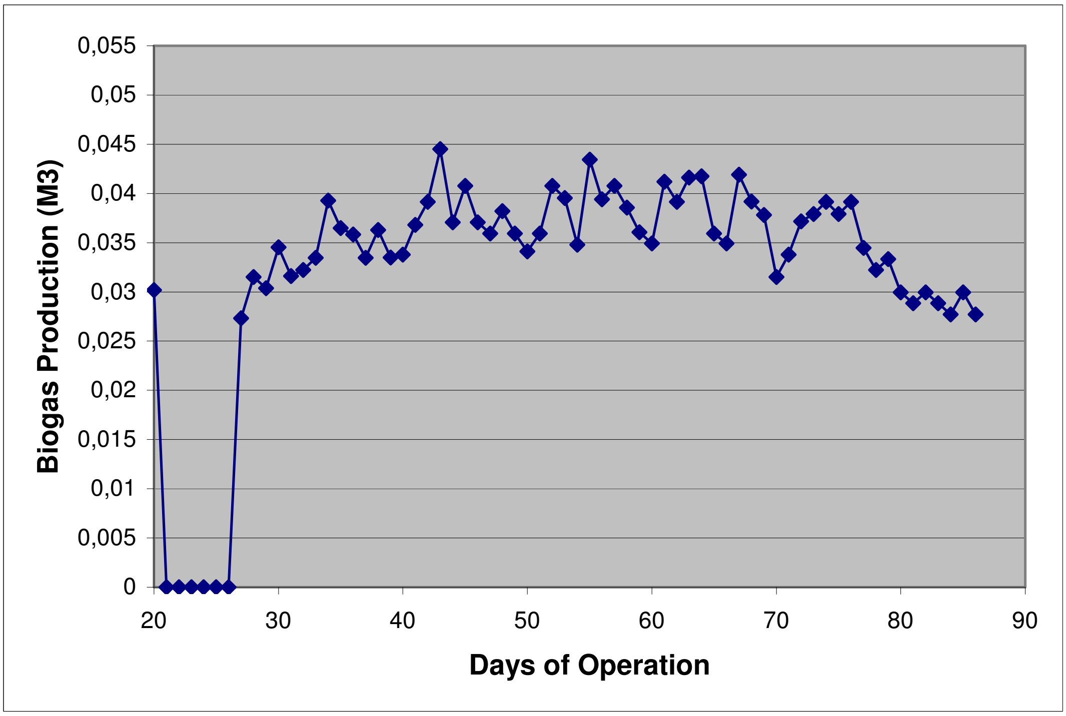


Figure 3.4. Daily Biogas Production During the Third Experiment

The sum of daily collected biogas production was 2,176 ± 0,034 m^3 at this experiment.

3.5.4. Experiment 4

The main purpose of this experiment is to evaulate the effect of temperature of digester. The mixing motor was not operated in this experiment.

The conditions of experiment was observed as follow:

1. Cattle dung was mixed with water at the ratio of 1:1 on a unit volume basis.
2. The temperature of digester was set to 20 ± 2 ^{o}C.

The compressor was run at the 20th day and the gas was compressed to about 0,3 bar. But the compressed gas was not burned. The collected gas was not compressed in 10 days. The compressor was operated again at the 30th day and the gas was compressed to about 0,35 bar. But the compressed gas was not flammable at this time. The compressor was started again at the 40th day and the gas was compressed to about 0,35 bar, the compressed gas was not burned. The compressed gas that was about 0,20 bar was burned at the lag time 57th day. After, the compressor was operated, the gas was compressed regularly everday until the gas production finished.

Daily biogas production during the fourth experiment is showed in the Figure 3.5.

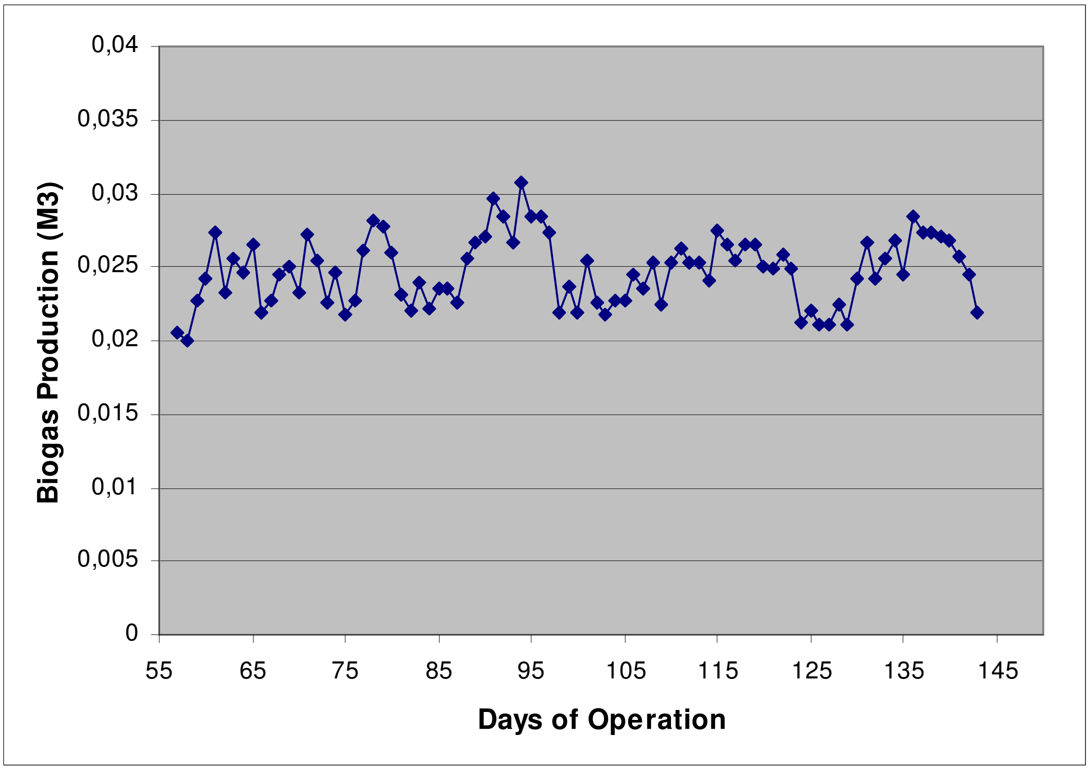


Figure 3.5. Daily Biogas Production During the Fourth Experiment

The sum of daily collected biogas production was 2,152 ± 0,049 m^3 in this experiment. The gas was compressed regularly 87 days in this experiment.

The biogas production is plotted according to different temperatures in the Figure 3.6. The values of the graphic were taken from the first experiment for 30 ^oC and 25 ^oC temperatures. The values of 20 ^oC temperature were taken from the results of the fourth experiment. The biogas production increases with high digester temperature. The biogas production was about between 0,6 to 0,8 bar when the temperature was 30 ^oC. The minimum biogas production was obtained when the temperature was 20 ^oC. The pressure of the produced gas was about between 0,3 to 0,4 bar at the 20 ^oC.

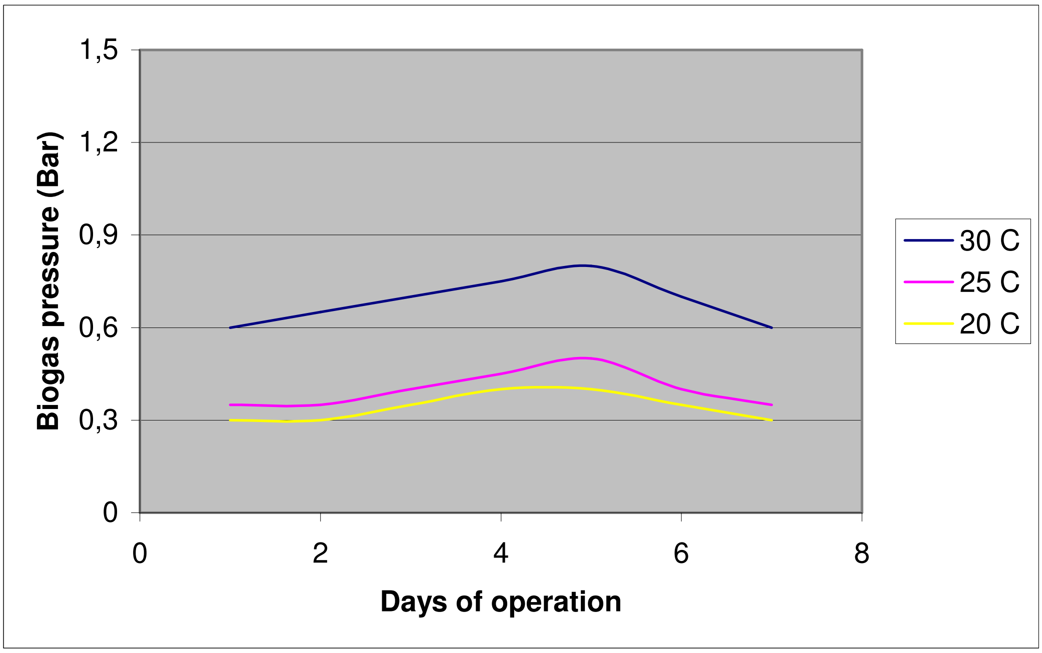


Figure 3.6. Biogas Production at Different Temperatures

3.5.5. Experiment 5

The main purpose of this experiment is to evaulate the effect of thermophilic bacterias and straw on biogas production. Therefore, the heater and thermostat were added to obtain thermophilic conditions in the system. The mixing motor and fin were dismantled. The resistance heater that has thermostat were mounted on centre of the digester.

In this experiment the cattle dung was mixed with straw as a ratio of 1:0,25 on a unit weight basis. The amount of cattle dung was 4 kg and the amount of straw was 1 kg. The water was added at the ratio of 1:1 for dung and 4:1 for straw. The amount of water was 8 kg. The temperature of thermostat was adjusted to 55 ^{o}C.

Seven days could be considered as the average production lag time. Flammability tests were conducted on the gas produced from the 8th day and it was discovered not to be flammable. But, when the temperature of the digester was controlled from outside the temperature of the centre of digester was higher than the other region of digester. Therefore the digester was opened, because the heater could not heat all digester. When the digester was opened we saw that the dung was in dry form, it was too thick, the particles could imped the flow of gas formed at the lower part of digester. The around of heater only could be heated to 55 ^{o}C. The straw and dung sticked on the resistance heater and they impeded the heat transfer to the other region of digester.

3.5.6. Experiment 6

The main purpose of this experiment is to evaulate the effect of thermophilic bacterias and blood on biogas production. The same experiment set up was used in this experiment.

In this experiment the cattle dung was mixed with blood at the ratio of 1:0,25 on a unit weight basis. The amount of cattle dung was 6 kg and the amount of blood was 1,5 kg. The water was added at the ratio of 1:1. The amount of water was 7,5 kg. The temperature of thermostat was adjusted to 55 ^{o}C.

Nine days could be considered as the average production lag time. Flammability tests were conducted on the gas produced from the 10th day and it was discovered not to be flammable. But, there were the same problem of experiment 5 at this experiment. The heat transfer could not catched perfectly in the digester.

Flammability tests were conducted on the gas produced from the 14th day again and it was discovered not to be flammable also. The cattle dung sticked on the resistance heater. There was a thermostat in between the resistances. When the cattle dung sticked on resistances, the dung only was heated to 55 ^{o}C. After, the thermostat stoped the heater. For this reason, the temperature of other regions of digester could not reached to 55 ^{o}C.

3.6. EXPERIMENT FOR DETERMINATION OF HIGHER HEATING VALUE OF BIOGAS

The main purpose of this experiment is to evaulate the high heating value of biogas. The LPG (liquefied petroleum gas) was used to compare high heating values. In the experiment 250 ml water was used. The first temperature of water was 21,6 ^{o}C. The digital thermometer was used to meausure the temperature.

Firstly, the water was heated with biogas. The temperature of water increased to 26,7 ^{o}C in the one minute. The same heater and same water was used for the LPG. The temperature water increased to 35,1 ^{o}C in the one minute when the LPG was used. From these conclusions;

Temperature difference of water : 26,7 – 21,6 : 5,1 ^{o}C heating with biogas

Temperature difference of water : 35,1 – 21,6 : 13,5 ^{o}C heating with LPG

We know that the high heating value of LPG is 49,90 Mj / kg. When the rate of temperature differences are used the high heating value of biogas is found 18,85 Mj / kg.

18,85 Mj / kg * 1,21 kg/m^3 : 22,80 Mj / m^3

The high heating value of methane gas is 37,68 Mj / m^3. The methane percentage of biogas was found according to this value.

The methane percentage of biogas : (22,80 / 37,68) * 100 : 60,51 %

Biogas consists of methane (CH_4) 55-65%. [21] The methane percentage of experiment biogas is medium. Temperature is important for the methane percentage of biogas. The methanogens are inactive in extreme high and low temperatures.

3.7. EXAMPLE OF BIOGAS CALCULATION

In the experiments, digester biogas was compressed in the gas depot. Because of the manometer was used to calculated the digester biogas on the gas depot, the unit of produced biogas in bars. The mass of the biogas produced can be calculated as follows :

Digester Volume : 26 lt (dm^3) : 0,026 m^3

Ru : 8,314 kj / kmolK

Molar mass of Biogas : 26,18 kg / kmol (from Ref. [21])

Density of Biogas : 1,21 kg / m^3

R : Ru / M

R : 8,314 / 26,81 : 0,3176 kj / kgK

1 Bar : 10^5 N / m^2 : 10^2 kj / m^3

For example : P : 0,35 bar (Gauge Pressure), T : 25 ^oC

P_{atm} : 0,883250 bar at 1300 m altitude (from Ref. [27])

PV : mRT $\Longrightarrow$ (0,35+0,883250)*(10^2)*(0,026) : m*(0,3176)*(298)

m : 0,033878 kg

The amount of produced biogas : m / ρ : 0,033878 / 1,21 : 0,027998 m^3

3.8. ECONOMIC ANALYSIS OF BIOGAS SYSTEM

An ideal biogas system should be as low-cost as possible and the design should be simple not only for construction but also for operation and maintenance. When the necessary skill and materials are not readily available, this may require a higher initial investment. The design should be compatible with the type of inputs that would be used. According to plant materials batch or continuous feeding systems may be used.

The impact of the low-cost biodigester is variable. Adoption of the technique and successful results depend on aspects such as location (availability of traditional fuel) and the way in which the technology is introduced, adapted and improved according to local conditions.

Available local materials were used in this experimental study. The special materials were used for experimental study. Therefore, the initial investment may be higher according to system capacity. The digester and gas depot that resist on 6 bars were used in the experiment. But maximum pressure was 0,9 bar in the experiment. The investment cost for this system is $985 (Table 3.1.). This is based on actual installation cost for experimental set up.

Table 3.1. Investment Cost for Experimental Set Up

Item	Investment
Digester Tank with Mixer	$ 220
Gas Depot	$ 120
Compressor	$ 45
Electrical Motor with Gear Box	$ 340
Heater	$ 80
Manometer	$ 20
Connection Pipes, Burner, Thermometer	$ 70
Labor for installation	$ 90
TOTAL	**$ 985**

The maximum biogas production was 0,916 m^3 at second experiment. The electricity equivalence of this value is 4,3052 kwh. The second experiment was 90 days. The four experiments can be operated in the one year.

Electric Equivalence of Total Biogas : 4 * 4,3052 : 17,2208 kwh in the one year

According to electric cost in Turkey 1 kWh : $ 0,1218

Annual Cost of Biogas : 17,2208 * 0,1218 : $ 2,097

We can see that the annual cost of biogas is very low according to initial investment. Since this is an experimental set up, the capacity of system is very low and therefore, initial investment is high. But, high capacity biogas systems which are extremely simplified and has low-cost so that they may be installed for a commercial plants. On the other hand, small capacity biogas system can be applied in small farmers because of low installation cost and also because of environmental advantages. The technology can be applied in rural or urban areas. For example, transparent polyethylene tubular film digesters provide a cheap and simple way to produce gas.

CHAPTER IV

DISCUSSION AND CONCLUSION

4.1. DISCUSSION

In this study, six experiments were made. The first experiment conditions were ‘cattle dung was mixed with water at the ratio of 1:1 on a unit volume basis, the temperature of digester were 28 ^{o}C ± 2, the lag time was 20 days’ in the first experiment. According to these conditions the total biogas was 2,998 m^3 in the first experiment. The measured daily biogas production of experiment is shown in Fig. 3.2. We can see that the biogas production was nearly stable after the 35^{th} day and until 74^{th} day. The methane concentration before this day was probably low. The graphics has same characteristics with the study of Karim et al. and Alvarez et al. [19,24]. This value is significant. Because there was about 10 kg animal manure in the experiment. The quantities are comparable to the published value (1,13 ± 0,14 L/L/d) with methane contents of 64 %, by [19]. It is also clear that the experimental value is high. Because, the experimental set up was a typical batch type digester.

The amount of biogas production from animal manure by anaerobic digestion has been addressed by several researchers. Gürçin [6] reported gas production potential of cattle dung (0,023 – 0,040 m^3/kg dung). Hammad et al. [26] compared cattle, poultry, sheep and horse manure for biogas production and obtained the highest productivity of biogas with cattle manure (0,28 $m^3/d.m^3$). This value represents the daily production in m^3 for each m^3 of the unit volume. Karim et al. [19] researched effect of mode of mixing using cow manure slurry and obtained the highest unmixed biogas production with 15 % manure slurry feed (1,13 ± 0,14 L/L/d).

The experimental set up was a typical batch type digester. The all of bacterias were used in the batch type digester because of we finished experiment until biogas production stopped. At the continuous systems, the retention time can be selected long to prevent escape or washed out of bacterias. Öztürk [25], reports around 70-80 % of the nutrition organisms are biodegradable at the continuous digesters. Jenangi [5], reports if retention time is too short the microbes are “washed out” of the digester and digestion process fails, while a long retention time requires a large digester.

In the second experiment, the mixing motor was worked during the experiment. All other conditions were kept the same, as described in the first set of experiments. The second set of performance experiments was conducted to compare the performance of mixing as well as to check the reproducibility of the performance data obtained in the first set of experiments. The two very important aspects of digester mixing are the intensity and duration of mixing. Most of the literature on anaerobic digestion emphasizes the importance of adequate mixing to improve the distribution of substrates, enzymes and microorganisms throughout the digester.

The maximum amount of biogas was collected at the second experiment because of the effect of mixing on the biogas production. Thorough mixing of the substrate in the digester distributes organisms uniformly and also transfers heat, and thus is regarded as essential in high-rate anaerobic digesters. Furthermore, agitation helps to reduce particle size as digestion progresses and to release biogas from the mixture.

The mixer obtained uniform temperature and uniform distrubution of water and waste mixture. But, the lag time was 24 days seen in Figure 3.3. Because of the mixer provide constant temperature, it prevented the different local temperatures. In the first experiment, the temperature could be reach to digestion temperature anywhere of the digester tank, then biogas production could be started at this local place. But in the second experiment, the gas production did not occur until the temperature of digester has reached to the digestion temperature uniformly. For this reason, the lag time of the second experiment was higher than that for the first experiment. The total biogas was 3,115 m^3 in the second experiment. The effect of mixing in the anaeorobic digestion has been reported by several researchers. Karim et al. [12,19], reported that mixing improved the biogas production when a thicker manure slurry (10 % and 15 %) was fed. Karim et al. [19] researched effect of mode of mixing using cow manure slurry and obtained the highest biogas-mixed and impeller-mixed biogas productions with 15 % manure slurry feed (1,64 ± 0,32 L/L/d) and (1,25 ± 0,12 L/L/d). The graphics in the Figure 3.3. has the same characteristics with the study of Karim et al. [19]. We can see that the biogas production was not stable as in the Figure 3.3.

Mechanical mixing adds a complexity to the system, but can aid thermal uniformity, reduce settling, and break up crust formation. Mechanical mixing may be necessary for certain manure handling systems such as flush systems where solid and liquid portions may separate easily into distinct layers within the digester. One of the role that mixing play inside a digester is to minimize stratification and accumulation of inert solids, especially if the feed manure has a high concentration of inert solids, such as sand from bedding material. Mixing seems that it helps segregate volatile solids from inert solids, which would help to keep light-weight biodegradable deposits at the top of the heavier inert deposits, furthering biodegradation. Based on the findings of this study, it can be concluded that the mixing becomes more critical with thicker manure slurries.

Results of the second set of performance studies, showed no significant difference in their start-ups and performance when the electric power of mixing motor was considered.

At the third experiment, the effect of percentage of manure in the slurry was seen. The amount of collected biogas in the third experiment was higher than that for the first experiment. Unfortunately, the burning of the biogas was not perfectly at the third experiment. The flame height of the burning of gas was very small. The length of time that volatile solids remain in an anaerobic digester is an important factor in the digestion process. Because of more manure in mixture, the solid retention time is high at the third experiment. Therefore, the collected gas was compressed about 6 days but the gas was not burned after first day of gas burned.

The dilution should be made to maintain the total solids from 7 to 10 percent. But the total solids were more than 10 percent in the third experiment. For this reason, the dung was too thick. The particles impede the flow of gas formed at the lower part of digester in this experiment. In the initial period of fermentation, as large amount of organic acids were produced by acid forming bacteria because there were large amounts of manure in the digester. The pH inside the digester could be decreased. This can inhibit the digestion or fermentation process. Methanogenic bacteria are very sensitive to pH and do not thrive below a value of 6,5. Therefore, the burning of the biogas was not completed. The compressed gas was burned with a very low flame height in the third experiment.

The effect of temperature on the produced biogas was seen in the fourth experiment. The lag time was 57 days in the experiment. Because, the lag time is also dependent on the temperature, the higher temperature, the lower lag time. The temperature was about 20 ^{o}C in the experiment. Therefore the retention time was higher than the other experiment. There are mesophilic bacterias in the manure. The optimum temperature of mesophilic bacterias is between 25 to 38 ^{o}C. The methanogens are inactive in extreme high and low temperatures. When the ambient temperature goes down to 10 ^{o}C, gas production virtually stops. The production of biogas delayed according to experiment temperature. Therefore the amount of produced biogas was low in the fourth experiment.

The effects of thermophilic bacterias were required to see in the fifth and sixth experiments. But, the problem of heat transfer was occured during these experiments. The resistance heater was used and the animal waste sticked to resistances. The sticked waste prevented the heat transfer in the digester. In the Experiment 5, the dung was too thick. The particles impeded the flow of gas formed at the lower part of digester. The digester must be heated inside a insulated chamber where temperature must be constant by a heating device. The heating device or heating surface must not be touch to the dung and the digester wall in order to perform such experiment.

4.2. CONCLUSION

Biodigesters can play a vital role in integrated farming systems by contributing to the control of pollution and at the same time add a value to livestock manure. The impact of the low-cost biodigester is variable. Adoption of the technique and successful results depend on aspects such as location (availability of traditional fuel) and the way in which the technology is introduced, adapted and improved according to local conditions.

The technology has been developed sufficiently to justify large - scale implementation in countries where socio-economic conditions facilitate its rapid adoption, such as has occurred in Vietnam and Cambodia. Nevertheless, research should continue in close consultation with users so that the technology continues to improve.

In recent years, increasing awareness that anaerobic digesters can help control the disposal and odor of animal waste has stimulated renewed interest in the technology. Dairy farmers faced with increasing federal and state regulation of the waste their animals produce are looking for ways to comply. New digesters now are being built because they effectively eliminate the environmental hazards of dairy farms and other animal feedlots.

It is often the environmental reasons rather than the digester´s electrical and thermal energy generation potential that motivate farmers to use digester technology. This is especially true in areas where electric power costs are low.

Anaerobic digester systems can reduce fecal coliform bacteria in manure by more than 99 percent, virtually eliminating a major source of water pollution. Separation of the solids during the digester process removes about 25 percent of the nutrients from manure.

In addition, the digester´s ability to produce and capture methane from the manure reduces the amount of methane that otherwise would enter the atmosphere.

Scientists have targeted methane gas in the atmosphere as a contributor to global climate change.

Another environmental benefit from using biogas as an energy resource is that there is no net production of greenhouse gases. The carbon dioxide released during biogas combustion originally was organic plant material and so is just completing a cycle from atmosphere to plant to animal and back to the atmosphere. Methane is a more severe greenhouse gas than carbon dioxide and capture of biogas as a fuel prevents the release of methane into the atmosphere. Land application of solids and anaerobic lagoon treatment of liquid wastes releases a substantial amount of methane to the atmosphere.

Turkey is an energy importing country and more than half of the energy requirements have been supplied through imports that have caused financial problems. Because of the economical problems in Turkey today, the Turkish energy policy should be concentrated on assurance of energy supply; reliability, domestic sufficiency, in time, in economic terms, and renewability. Therefore as a renewable energy source, biomass seems interesting. On the other hand, biomass may, however, see greatly expanded use in response to the environmental problems caused by fossil fuel use in the country. Biomass has been proposed to have a central role to play in future, more sustainable energy scenarios. For this, to become a reality several real problems need to be overcome. In Turkey, as in other developing countries, modernization of biomass energy provision is an urgent necessity for the sake of human health, protection of the environment, and climate change abatement. Given sufficient recognition, resources and research biomass could become the environment conscious fuel of the future.

After reviewing the energy structure of Turkey, it seems necessary to take measures toward the optimum utilization of biomass as an energy source. Since animal husbandry and agriculture are highly developed in Turkey, a substantial amount of animal wastes and agricultural crop residues are produced each year. Organic wastes are of vital importance for the soil, but in Turkey most of these organic wastes are used as fuel through direct combustion. Animal wastes are mixed with straw to increase the calorific value, and are then dried for use. This is the principal fuel of many villages in rural region of Turkey, especially in mountainous regions.

Anaerobic digestion for methane production is a possible solution to recover the wastes as fertilizers and produce energy. In Turkey, much effort has been put into biogas research and projects were developed since the 1960s. In addition to feasibility studies on biogas utilization, many digesters have been constructed at different places in the country. Universities, national research institutes, companies and international organizations have actively been involved with the subject. Unfortunately, due to lack of collaboration and organization between these different projects, further development was not resulted.

Past experience indicates the necessity of reorganizing the biogas programmes and the development of a digester for the conditions of Turkey. It should also be taken into account that livestock farming mostly occurs in central and eastern Anatolia, where winters are very cold. As the digester temperatures should be at least 20°C, a good design should be developed to operate well under these climatic conditions.

REFERENCES

1. Shannon Ron, (1996). Biogas. Sixth International Permaculture Conference&Convergence, Perth&Bridgetown, Western Australia.

2. Sahlström Leena, (2003). A Review of Survival of Pathogenic Bacteria in organic Waste Used in Biogas Plant, *Bioresource Technology,* **87**, 161-166.

3. Kaygusuz K., Türker M.F., (2002). Biomass Energy Potential in Turkey *Renewable Energy,* **26**, 661–678

4. Hoogwijka Monique, Faaija Andr'e, Broeka Richard Van Den, Berndesb Goran, Gielenc Dolf, Turkenburga Wim, (2003). Exploration of the Ranges of the Global Potential of Biomass for Energy. *Biomass and Bioenergy* **25**, 119 – 133.

5. Jenangi L., (2001). Producing Methane Gas From Effluent. Adelaide University Diploma in Agricultural Production, Individual Project.

6. Gürçin E., (2003). Design and Construction of a Biogas System for Domestic Use. Graduation Project. Central Library, University of Gaziantep.

7. Lapp H.M., Schulte D.D., Sparling A.B., Buchanan L.C., (1975). Methane Production from Animal Wastes. Fundamental Considerations. *Canadian Agricultural Engineering,* **17(2)**, 97-102.

8. Bilgin N., (2003). "Biyogaz Nedir?". Tarım ve Köy İşleri Bakanlığı Köy Hizmetleri Genel Müdürlüğü Ankara Araştırma Enstitüsü, Ankara.

9. Hayes T.D., Jewell WJ, Dell Orto S, Fanfoni KJ, Leuschner AP, Sherman DF. (1997). Anaerobic Digestion of Cattle Manure. London, Applied Science Publishers.

10. Leggett J., Graves Robert E., Lanyon Les E., (2000). Anaerobic Digestion: Biogas Production and Odor Reduction from Manure, Agricultural and Biological Engineering. Pennsylvania State University.

11. Karim K., Hoffmann R., Klasson T., Al-Dahhan M.H., (2005). Anaerobic Digestion of Animal Waste: Waste Strength Versus Impact of Mixing. *Elsevier*, *Appl. Sci. Pub*., pp. 1771–1781.

12. Karim K., Hoffmann R., Klasson T., Al-Dahhan M.H, Drescher S. R., David W. DePaoli D. W. (2005). Anaerobic Digestion of Animal Waste: Effect of mixing. *Bioresource Technology,* **96**, 1607–1612

13. Engler Cady R., Jordan Ellen R., McFarland Marshall J., Lacewell Ronald D., (2003). Economics and Environmental Impact of Biogas Production as a Manure Management Strategy. *Biomass and Bioenergy,* **58**, 109 – 114.

14. Safley M.L., Westerman P.W. (1988). Biogas Production from Anaerobic Lagoons. *Biological Wastes* **23**: pp. 181-193.

15. Kossmann W., Pönitz U., Habermehl S., Hoerz T., Kramer P., Klingler B., Kellner C., Wittur T., Klopotek F., Krieg A., Euler H. (2000). Biogas Digest, Volume 1, Biogas Basics. Information and Advisory Service on Appropriate Technology(ISAT). Eschborn, Federal Republic of Germany.

16. Wright P., (2002). Manure Treatment Specialist Scott Inglis. Research Associate Department of Biological and Environmental Engineering, Cornell University.

17. Köse F., Dinçer K., (2000). Biogas Production from Organic Wastes. In: 12th National Congress of Heat Science and Technique, 28–29 February, Sakarya (Turkey).

18. Acaroğlu M., Aksoy A.S., Öğüt H., (1999). The Potential of Biomass and Animal Waste of Turkey and the Possibilities of these as Fuel in Thermal Generating Stations. *Energy Sources,* **21**, pp. 339–45.

19. Karim K., Hoffmann R., Klasson T., Al-Dahhan M.H., (2005). Anaerobic Digestion of Animal Waste: Effect of Mode of Mixing. *Water Research,* **39**, pp. 3597–3606.

20. Piccinini S., Fabbri C., Verzellesi F., (1998). Integrated Bio-systems for Biogas Recovery from Pig Slurry: Two Examples of Simplidfied Plants in Italy. Research Center for Animal Production.

21. Gülen J., Arslan H., (2005). Biogas. *Journal of Engineering and Natural Sciences,* pp. 121 -129.

22. Biyogaz [Internet]. Available from http: // www.enerji.gov.tr/biyogaz.htm

23. Elektrik İşleri Etüt İdaresi Genel Müdürlüğü (2005). Biyogaz [Internet] Available from www.eie.gov.tr/biyogaz.

24. Alvarez R., Villca S., Liden G., (2006). Biogas Production from Llama and Cow Manure at High Altitude. *Biomass and Bioenergy,* **30**, 66-75.

25. Öztürk M., (2005). "Hayvan Gübresinden Biogaz Üretimi". Çevre ve Orman Bakanlığı, Ankara.

26. Hammad M., Badarneh D., Tahboub K., (1999). Evaluating Variable Organic Waste to Produce Methane. *Energy Conversion & Management* **40**, pp. 1463-1475.

27. Aksoy B., (2003). Deney Yöntemi ile Atmosfer Basıncı Konusunun Öğretimi Üzerine Bir Model. *G.Ü. Gazi Eğitim Fakültesi Dergisi*, Cilt **23**, Sayı 3, 207-226.

APPENDIX

PHOTOGRAPHS

Photograph 1 : Cover of digester with mixer

Photograph 2 : Sealing of cover

Photograph 3 : Assembly of mixer motor

Photograph 4 : Final setup of gas depot

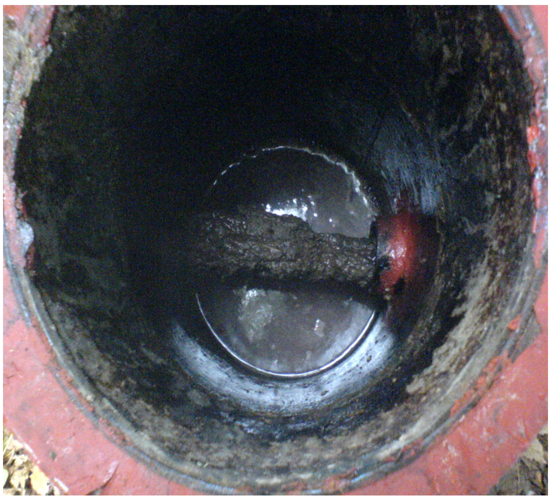
Photograph 5 : Connections of compressor **Photograph 6** : Slurry in the digester

Photograph 7 : Sealed of digester

Photograph 8 : Residue of slurry after experiment

Photograph 9 : Resistance heater of digester **Photograph 10** : Residue slurry Exp.5

Photograph 11 : Slurry with blood for Exp.6 **Photograph 12** : Residue slurry Exp.6



Photograph 13 : Resistance heater after experiment