University of Nairobi

School of Engineering

Assessment of Energy Potential of biogas from Ongata Rongai Slaughter House

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Declaration

I **Nazarene Kathambi Kirimi** declare that this report is my original work, and except where acknowledgements and references are made to previous work, the work has not been submitted for examination in any other University.

Signature.................................... Date..................................

Approval by supervisors

I confirm that the study was carried out under our supervision and has been submitted for examination with our approval as University supervisors.

Prof. J. A. Nyang'aya Signature.......................... Date...........................

Prof. F. M. Luti Signature.......................... Date...........................

Dedication

I dedicate this work to God almighty that the knowledge achieved through it may be for the glory of His name and for the betterment of our environment.

Acknowledgement

I acknowledge the support, assistance and wise guidance of my supervisors; Prof. J.A. Nyang'aya and Prof. F.M. Luti who have been very helpful and patient with me even when it seemed grim.

My Husband Charles, who encouraged and urged me on to ensure that I completed the work on time, as well as my children Eric, Joy and Victor for the patience and understanding when it was difficult to be with them as they would have wished.

My colleagues at work who supported me with the information I required to assist me in executing the work and the researchers whose past studies I heavily depended on for the foundation of my work.

Special acknowledgement goes to the management and staff of Ongata Rongai slaughter house and Sinai hospital for availing information to aid the success of this study.

Abstract

This study focused on quantifying the amount of waste generated at Ongata Rongai slaughterhouse in order to identify a better way of disposal. Generation of biogas was explored in the study in relation to meeting the cooking energy needs of the neighbouring Sinai Hospital.

The slaughter house currently spends Ksh.2,800.00 fortnightly to dispose the waste produced during the slaughtering process which includes the stomach and intestinal contents. Manure collects in the animal holding area/pen and waste water is channelled to soak pits that occupy more than half an acre of land.

The neighbouring Sinai hospital uses 30kg of LPG for cooking in a month at a cost of Ksh.7,000.00.

In order to quantify the amount of energy potential of the slaughterhouse, records of the number of animals slaughtered in the month of February 2014 were obtained and the amount of waste expected at the slaughterhouse estimated at 458.9kg/day. The biogas digester was sized, designed and bill of quantities generated with an estimated cost of Ksh.393,813.20.

Information on the energy used in the Hospital for cooking was obtained through interviews with the Hospital and from electricity consumption records. The amount of biogas that could be generated from the slaughterhouse was 495m^3/month, equivalent to 10,890MJ/month and enough to provide for cooking needs of the Hospital and about 33 households.

To encourage use of biogas from the slaughterhouse, an affordable tariff was worked out. This tariff would make use of biogas to be preferred to other cooking energy sources like LPG, charcoal or electricity. Two tariffs were derived as Ksh1.95/m^3 and ksh21.84/m^3 for payback periods of 5 and 2 years respectively.

By venturing into biogas production, the slaughter house would generate income, save ksh2,800.00 fortnightly from eliminating hired services and improve the general hygiene of the slaughterhouse.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

REA	Rural Electrification Authority
NEMA	National Environmental Management Authority
FAO	Food and Agriculture Organization of the United Nations
UNIDO	United Nations Industrial Development Organization
LPG	Liquified Petroleum Gas
MJ	Mega Joules
kWh	Kilowatt hour
EU	European Union
Mtoe	Million tons of oil equivalent
KIRDI	Kenya Industrial Research and Development Institute
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Society for International Cooperation)
kg	Kilogram
HRT	Hydraulic Retention Time
TS	Total Solids
Vf	Volume of Fermentation chamber
Vgs	Volume of Gas Storage
Q	Total waste
SRM	Specified Risk Material
PSDA	Promotion of Private Sector Development in Agriculture
UNEP	United Nations Environment Program
KPLC	Kenya Power & Lighting Company
BOQ	Bill of Quantities

1.0. INTRODUCTION

1.1 Background

Production of biogas from waste is one of the most common methods to generate energy and at the same time good waste reduction method. Biogas production can be practiced either for the purpose of energy production or waste reduction. (Tefera, 2009).

Most processes in slaughterhouses, tanneries and dairy plants require the use of water. This water and water used for general cleaning purposes will produce wastewater. The level of pollution in the wastewater depends on the nature of the processes involved and chemicals used. Discharge of wastewater to surface water affects the water quality in three ways:

1. The discharge of biodegradable organic compounds (BOC's) may cause a strong reduction of the amount of dissolved oxygen, which in turn may lead to reduced levels of activity or even death of aquatic life.

2. Macro-nutrients (N, P) may cause eutrophication of the receiving water bodies. Excessive algae growth and subsequent dying off and mineralisation of these algae, may lead to the death of aquatic life because of oxygen depletion.

Eutrophication means water rich in mineral and organic nutrients that promote a proliferation of plant life, especially algae, which reduces the dissolved oxygen content and often causes the extinction of other organisms.

3. Agro-industrial effluents may contain compounds that are directly toxic to aquatic life (e.g. tannins and chromium in tannery effluents; un-ionized ammonia). (FAO website, 2013)

Slaughterhouses in Kenya are required to follow National Environment Management Authority (NEMA) laws of waste disposal to curb surface disposal that contaminates water bodies, air and soil.

Use of slaughterhouse waste for biogas is one of the methods of useful waste disposal for energy. In Kenya, biogas generation from slaughter house waste is limited with a few units established by United Nations Industrial Development Organization (UNIDO) to address waste management and compliment energy requirements in the slaughter house.

UNIDO has initiated several pilot projects in Dagoreti, Kiserian, Bungoma and Homabay to address the problem of waste disposal. Electricity is generated using biogas from the waste to light up the abattoirs. The gas is also used to heat water for cleaning the abattoirs. Ongata Rongai slaughter house was not included in the pilot project.

1.2 Problem statement

The study sought to address the problem of waste disposal at Ongata Rongai slaughter house. As Koech puts it, although slaughterhouses are an important economic activity to the operators as well as livestock producers they represent a major environmental challenge particularly water, soil and land pollution. (Koech, et al, 2012). The activities of Ongata Rongai slaughter house thus pose challenges to the surrounding environment in various ways.

The slaughter house currently generates waste in the form of dung(manure), stomach contents(rumen waste), and waste water. The manure is accumulated in the animal holding area/pen encouraging flies to thrive, compromising the general hygiene conditions of the slaughter house and its immediate environs. Methane and ammonia gases from the decomposing manure contribute to increased greenhouse effect and air pollution.

The shed for temporary storage of semi-digested grass and other plants from the slaughtered animals is not fully covered. When it rains, the stored waste is splashed over the incomplete walls and spreads onto the compound making it difficult to maintain cleanliness. The cost of disposing this waste matter every fortnight by hired services is an unnecessary financial burden to the slaughterhouse.

Waste water channelled to soak pits occupying more than half an acre of land deprives the opportunity to perform any other economic activity there, like building of commercial houses or farming.

Better disposal of these forms of waste is therefore a necessity for more benefits to the slaughter house and the environment. The proposal to achieve this is by generation of biogas.

The photos in figures 1.1 to 1.4 show the general representation of waste disposal system in the slaughter house.

Fig. 1.1 Ongata Rongai Slaughter house waste drainage and filtering system

Fig. 1.2 Ongata Rongai Slaughter house digestive system waste collection shed

Fig. 1.3 Ongata Rongai Slaughter house first soak pit inlet point

Fig. 1.4 Ongata Rongai Slaughter house animal holding pen

1.3 Objectives

Overall Objective

The objective of this study was to determine the energy potential of biogas from Ongata Rongai slaughterhouse and how it would benefit the neighbouring Sinai Hospital.

Specific Objective

1. To determine the amount waste generated from the slaughter house.
2. To determine the amount of energy used for cooking at Sinai Hospital
3. To determine the amount of biogas that the waste from the slaughterhouse can generate
4. To design the biogas digester to handle the waste and generate Bill of quantities (BOQ).

v. To determine the ability of the slaughterhouse biogas to cater for cooking energy needs at the Hospital

1.4 Justification for the study

Use of slaughter house waste to generate biogas is not very common in Kenya. The few slaughterhouses where this has been done have proved advantageous for the needs of the slaughterhouse especially for lighting and water heating.

Ongata Rongai slaughterhouse operates only during the day and does not require lighting. No electric equipment are used there either.

The slaughter house all the same generates waste that needs to be managed in accordance with the NEMA requirements. This puts a financial burden on the slaughter house to dispose of the waste.

By using this waste to generate biogas, the slaughterhouse would save by minimizing the cost of disposal and could generate income by selling cheaper cooking energy to the Hospital.

The study seeks to utilize the digestive system waste, the waste water and manure to generate biogas that can be utilized for cooking in the neighbouring Sinai Hospital. The slaughterhouse will benefit in reducing the cost of disposal and to generate extra income in selling the biogas to the hospital. The hospital could make savings by using biogas for cooking which may be cheaper than LPG and/or electricity that the Hospital has been using in the past.

Currently, the Hospital is mainly using LPG for cooking after electricity became too expensive. It consumes 2 cylinders of 15kg a month on average. This approximates to Ksh.7000 per month.

Previously the Hospital used to consume about 1 cylinder of 15kg for one and a half months and 455 kWh of electrical power per month. The expenditure then was Ksh11,271.45 per month on average.

Therefore the study is aimed at determining the potential of generating biogas from the slaughter house and its economic benefit to the slaughterhouse itself and the Hospital.

1.5 Scope

The project scope covers the slaughter house area and the Hospital that are located 200m apart. The location of the two establishments is shown in figure 1.5.

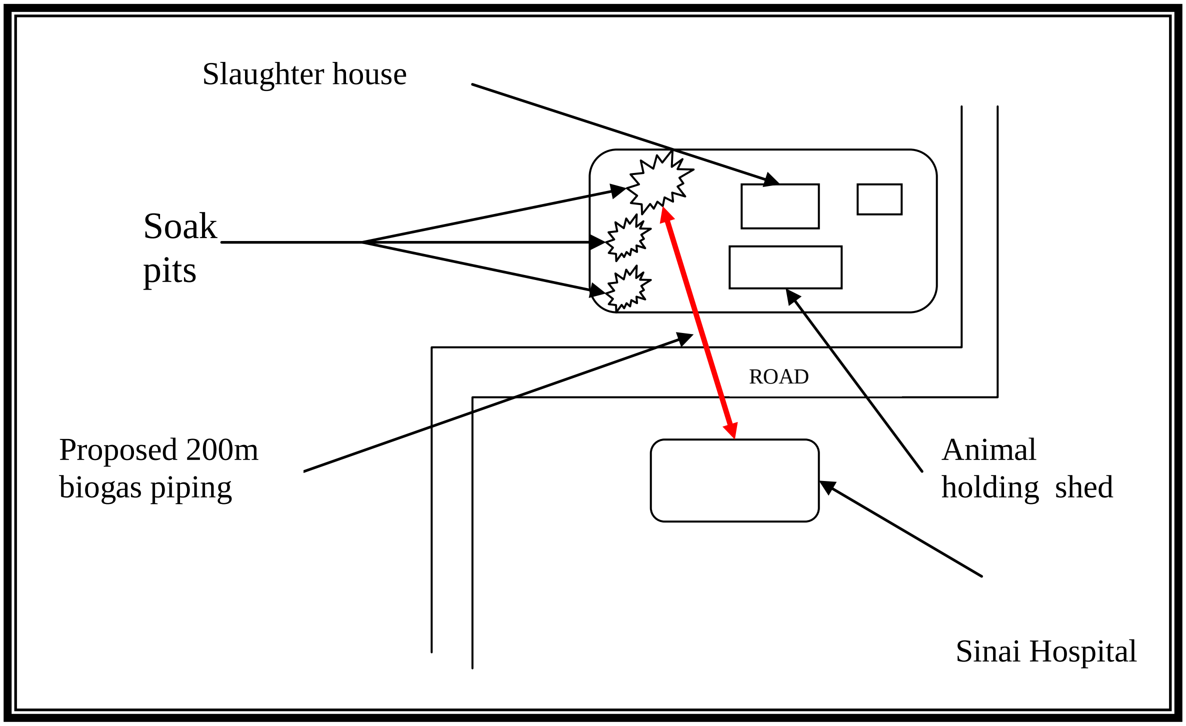


Fig.1.5. Sketch of the relative location of Ongata Rongai slaughter house and Sinai Hospital (not to scale)

The current process of waste disposal at the slaughter house is illustrated in fig. 1.6

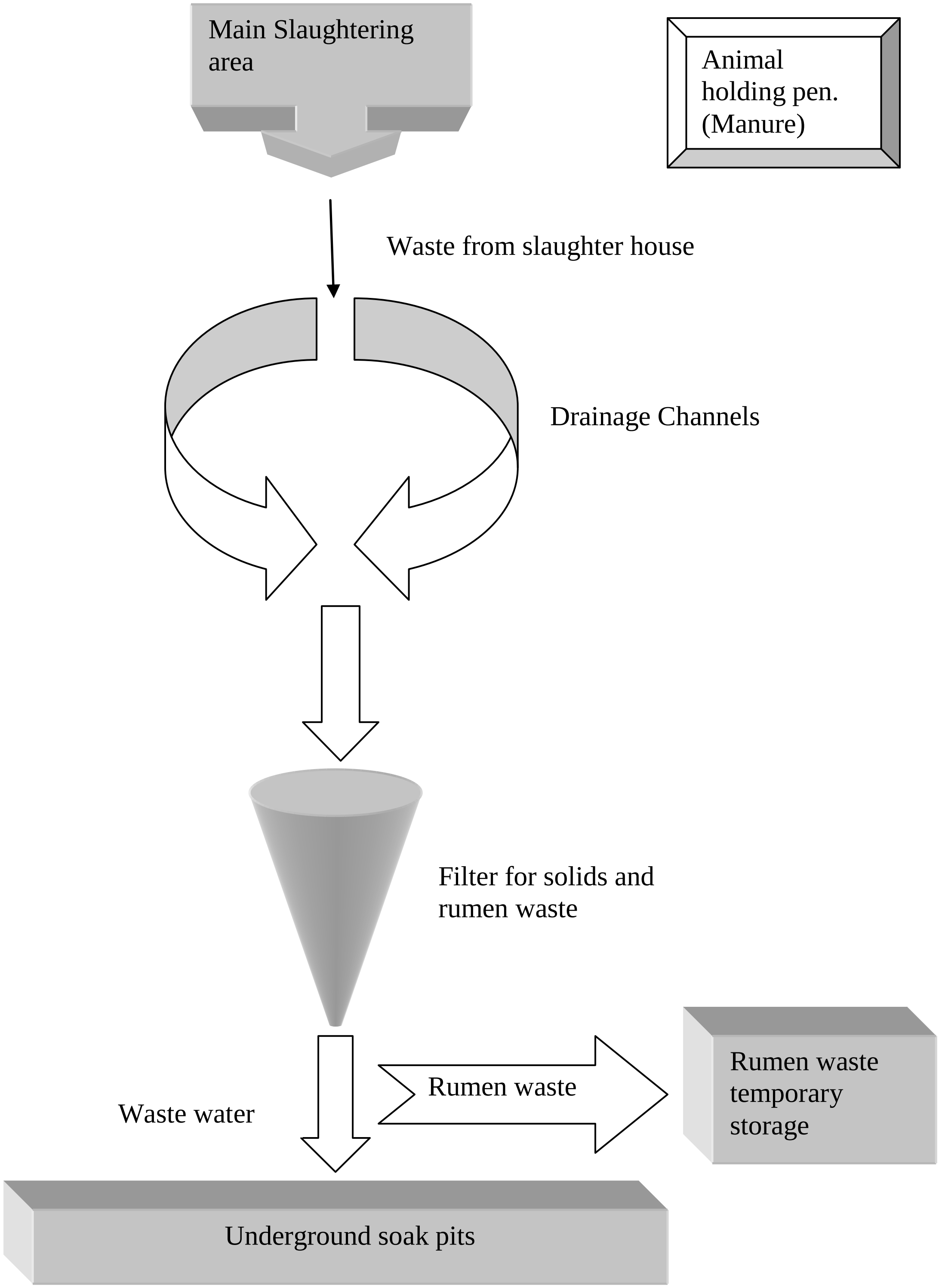


Fig. 1.6 Flowchart of current waste management process at Ongata Rongai slaughter house

The process anticipated by the project would utilize both the products of the slaughter house itself and the contents of the holding pen.

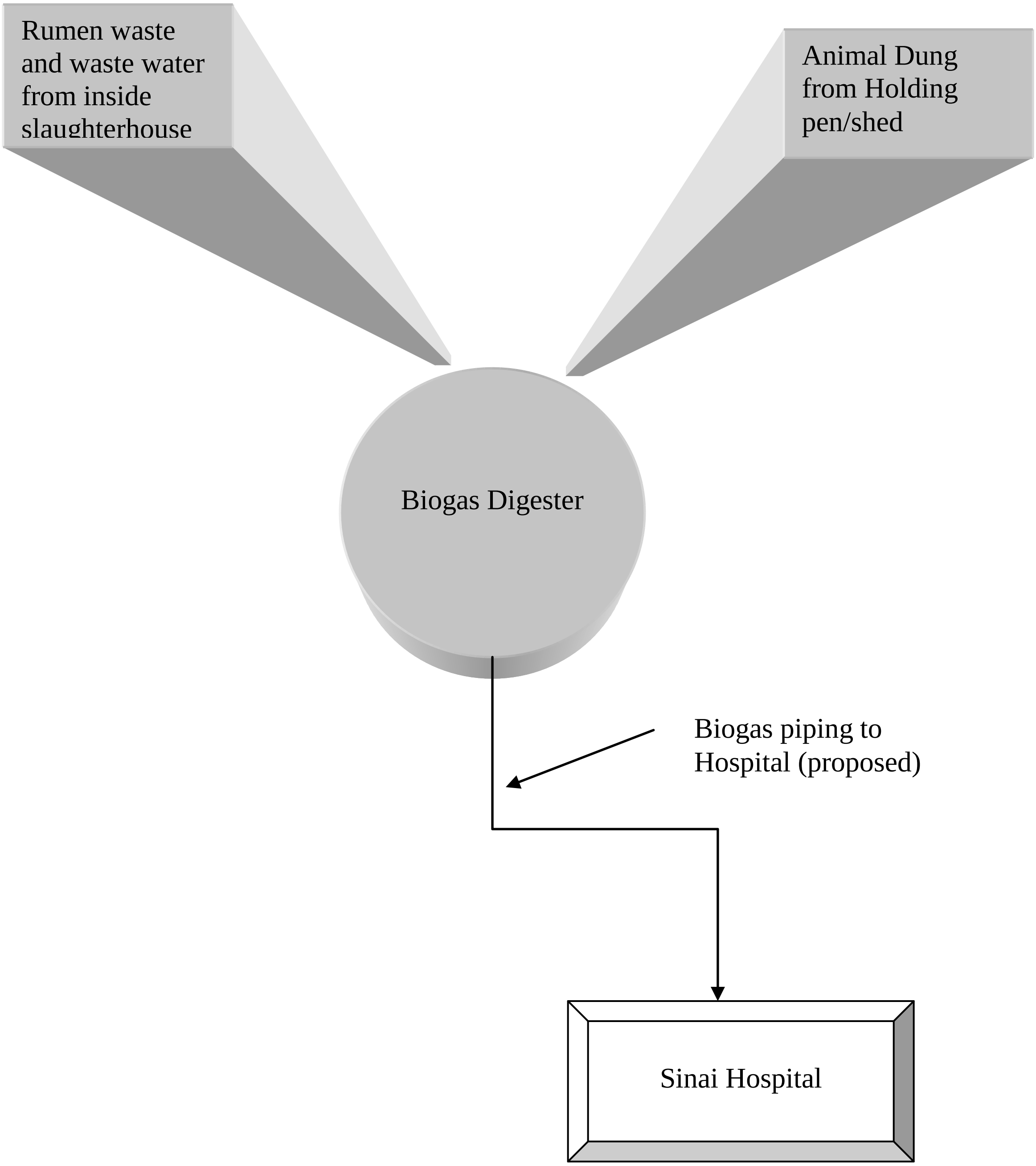


Fig. 1.7 Flow chart of waste management through biogas generation

2.0. LITERATURE REVIEW

2.1. Biogas general information

Biogas is a methane-rich gas that is produced from the anaerobic digestion of organic materials. It’s a colourless, blue burning gas that can be used for cooking, heating and lighting. It has a heating value of 22MJ/m^3. (Itodo, et al, 2007).

The requirements for biogas production are; the presence of organic matter, bacteria and right anaerobic conditions. One type of bacteria converts fats, carbohydrates and proteins into simple acids and another type converts the acid into methane.

Anaerobic digestion is a bio-chemical process that occurs in different steps. It is driven by many different bacteria; each step has specialized bacteria. Anaerobic digestion happens in the absence of oxygen. To perform anaerobic digestion, the substrate should not have contact with air. (PSDA, 2011). Figure 1.7 shows the chemical process of anaerobic digestion. The two products of anaerobic digestion are biogas and bio-slurry.

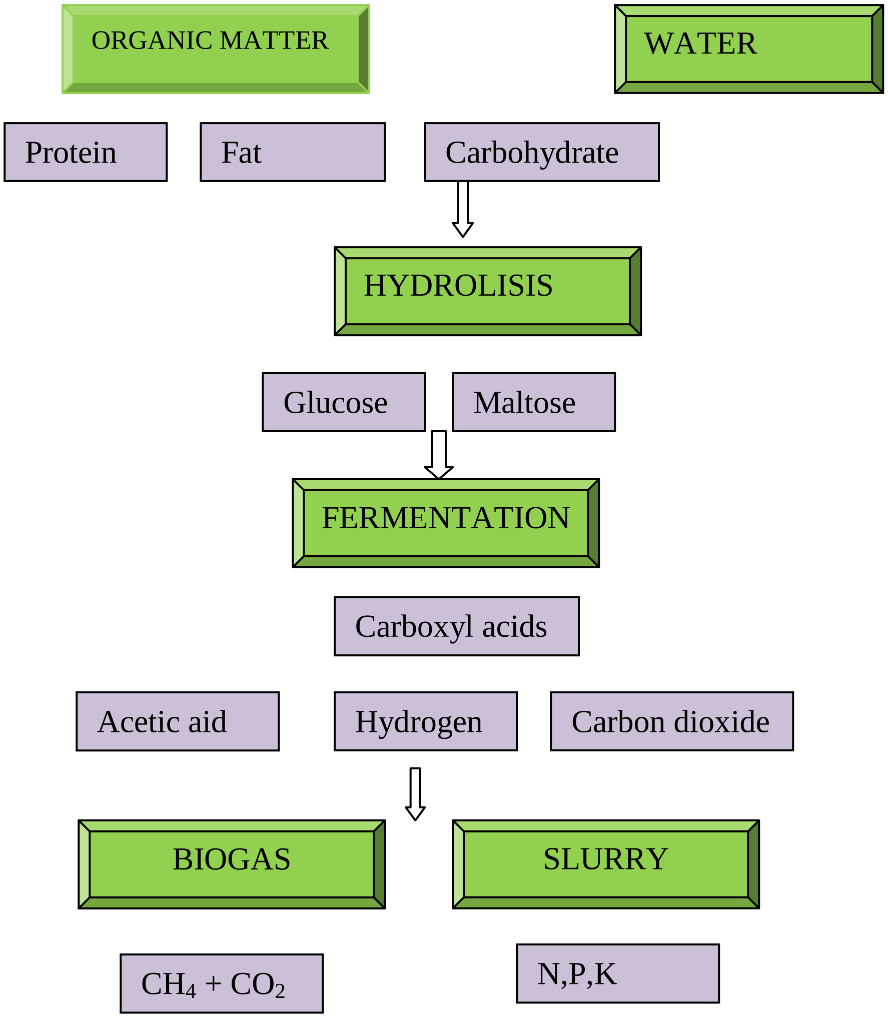
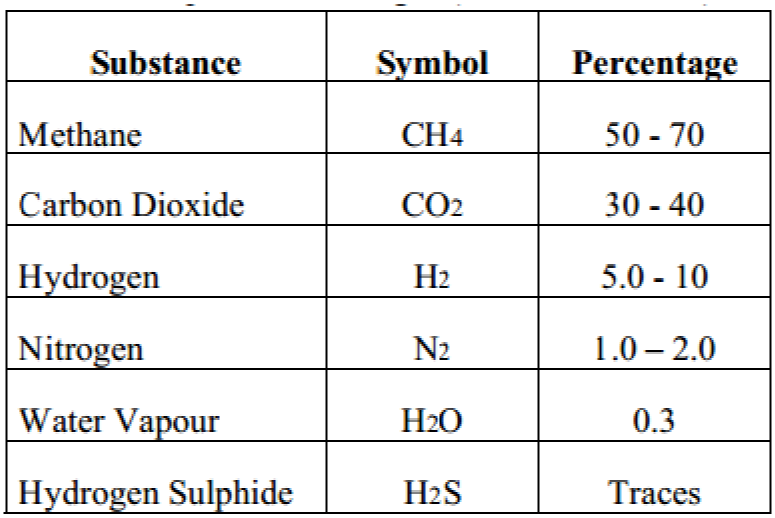


Fig. 2.1 The biochemical process of anaerobic digestion (Sasse, 1998)

Biogas consists mainly of methane(CH_4) and carbon dioxide(CO_2). Other components are Nitrogen(N_2), Hydrogen(H_2), water vapour(H_2O) and traces of hydrogen sulphide(H_2S). Biogas is combustible if methane content is more than 50%.(PSDA, 2011). The methane component of biogas ranges between 55% and 65% while that of Carbon Dioxide ranges between 35% and 45%. Table 2.1 shows the ratios of the constituent substances found in biogas.

Table 2.1. Components of biogas (Hassan, 2004)



Substance	Symbol	Percentage
Methane	CH_4	50 - 70
Carbon Dioxide	CO_2	30 - 40
Hydrogen	H_2	5.0 - 10
Nitrogen	N_2	1.0 – 2.0
Water Vapour	H_2O	0.3
Hydrogen Sulphide	H_2S	Traces

After producing biogas from the feed material, the remnant is bio-slurry. The Bio-slurry is a paste-like liquid of a greenish-brown colour that is nearly odourless. Its main component is water (around 95%). The rest is undigested organic matter and dissolved inorganic components. The slurry is more liquid than the mixed feed material, since most of the organic content has been converted to biogas. The slurry is a high-potential organic fertilizer, with all the nutrients of the dung but none of toxins. It is much better than mineral fertilizer because it also improves the condition of the soil. (PSDA, 2011).

The other component of biogas is water vapour that can be trapped as condensate within the piping network. Other trace gases including Hydrogen sulphide are also found in biogas. Hydrogen sulphide (H_2S) is a colourless, very poisonous gas. It forms explosive mixtures with air (oxygen). It has the smell of rotten eggs and gives biogas its characteristic smell. (GTZ, 1985)

The presence of Hydrogen Sulphide in biogas causes corrosion to metal parts of the biogas system. The combustion product SO_2 combines with water vapour and badly corrodes the exhaust side of burners, gas lamps and engines. Burning biogas in stoves and boilers can also result in damage to the chimney. When biogas is used in internal combustion engines it requires purification to remove the SO_2. (GTZ, 1985).

Hydrogen sulphide is formed in the biogas plant by the transformation of sulphur-containing protein. This can be protein from plants and fodder residues. However, when animal and human faeces are used, bacteria excreted in the intestines is the main source of protein. Inorganic sulphur, particularly sulphates, can also be biochemically converted to H_2S in the fermentation chamber. Plant material introduces little H_2S into biogas. On the other hand, poultry droppings introduce, on average, up to 0.5 vol. % H_2S, cattle and pig manure about 0.3 vol. % H_2S. **(**GTZ, 1985).

There are various methods that are used to purify biogas to remove Hydrogen sulphide .

i. Desulphurization using Lime process

This is only used in small scale. Its limitation is the formation of large amounts of odourous residue that is a challenge to dispose. Also, the presence of CO_2 causes a reaction with the lime and uses it up quickly. The $Ca(HCO_3)_2$ formed reacts with $Ca(SH)_2$ which is formed by the reaction of H_2S with $Ca(OH)_2$ thus resulting in the reoccurrence of H_2S.

ii. Desulphurization using Ferrous material

The ferrous material can be in the form of natural soils or iron ore. This ferrous material is placed in a gas-tight container and the gas passed through it from the bottom leaving through the top. The agent absorbs the Hydrogen sulphide from the gas. Regeneration can be done by treating the sulphidized absorbent with atmospheric oxygen, the iron can be returned to the active oxide form required for the purification of the gas.

2.2 . Conditions for Biogas generation

Generation of biogas requires specific conditions. These include presence of organic matter, anaerobic environment and right temperatures. Generally, the bacteria prefer constant conditions ─ constant feeding, the same feed material, the same temperature. (PSDA, 2011).

Organic matter for use in biogas generation can be in various forms. Fruit and vegetable wastes, flower, eggshells, coffee and other organic leftovers except wood(lignin) can be used for biogas digestion. Treated sewage waste that is free from harmful chemicals and heavy metals, animal manure, wastes from food industry and human waste make feedstock for biogas generation.

Gas production depends on volume of the digester and temperature. The temperature inside the digester depends mainly on the ambient temperature (temperature of the surrounding soil). Soil temperature depends on the average year temperatures above ground, but below the ground it fluctuates far less. In tropical countries the soil temperature at a depth of 1m is nearly constant. (PSDA, 2011).

The volume of the digester and feed material determines retention time. Gas production increases with increase in the time that feed material remains in the digester. Figure 2.2 shows the relationship between retention period and biogas production.

The retention time is calculated by dividing the digester volume (m^3) by the volume of daily feed material (m^3).(PSDA, 2011).This is assuming that the amount of daily feed material is constant every day. Simple Biogas plants in tropical regions operate within an ambient temperature range of 15°C to 25°C and a retention time of 30 to 60 days. (PSDA, 2011).

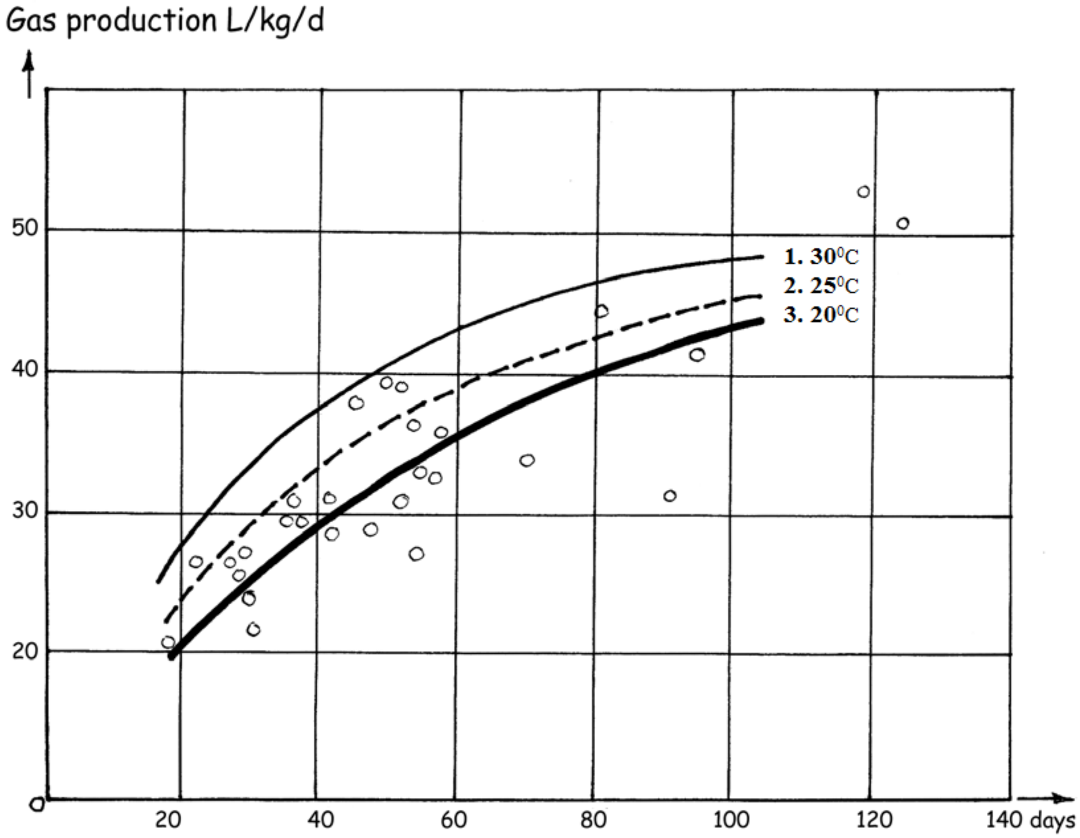


Fig. 2.2. Relation between retention time and gas production (Sasse, 1998)

The process that were described in figure 2.1 run parallel in time and space, in the digester tank. The speed of the total decomposition process is determined by the slowest reaction of the chain. In the case of biogas plants, processing vegetable substrates containing cellulose, hemi-cellulose and lignin, hydrolysis is the speed determining process. During hydrolysis, relatively small amounts of biogas are produced. Biogas production reaches its peak during methanogenesis(formation of methane by microbes known as methanogens). (Seadi, 2008).

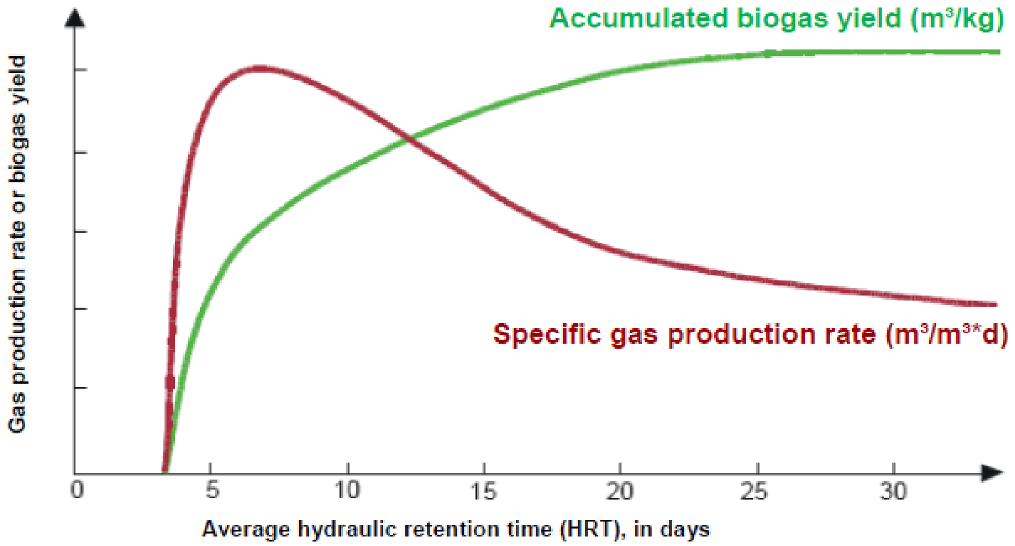


Fig. 2.3. Biogas production after addition of substrate (Seadi, 2008).

The calorific value of biogas is dependent on both temperature and altitude. At sea level and 20°C it is 6 kWh/m³ with 60% of methane (CH4). Calorific value of Biogas at 1,000 m above sea level and 20°C is only 5.36 kWh/m³. (PSDA, 2011).

The three typical temperature ranges used for biogas production are:

a) Psychrophilic, temperature from 10°C to 25°C
b) Mesophilic, temperature from 25°C to 35°C
c) Thermophilic, temperature from 49°C to 60°C

The three temperature ranges are identified by the type of bacteria in action in the particular range. Psychrophilic range is associated with psychrophiles, mesophilic range with mesophiles and thermophilic range is associated with thermophiles.

The temperature ranges and activity of the various microorganisms associated with them are not clearly distinct but do overlap as shown in the figure 2.3. The growth of the methanogens varies . It increases with temperature such that it is lowest for psychrophiles and highest for thermophiles. (Tefera 2009).

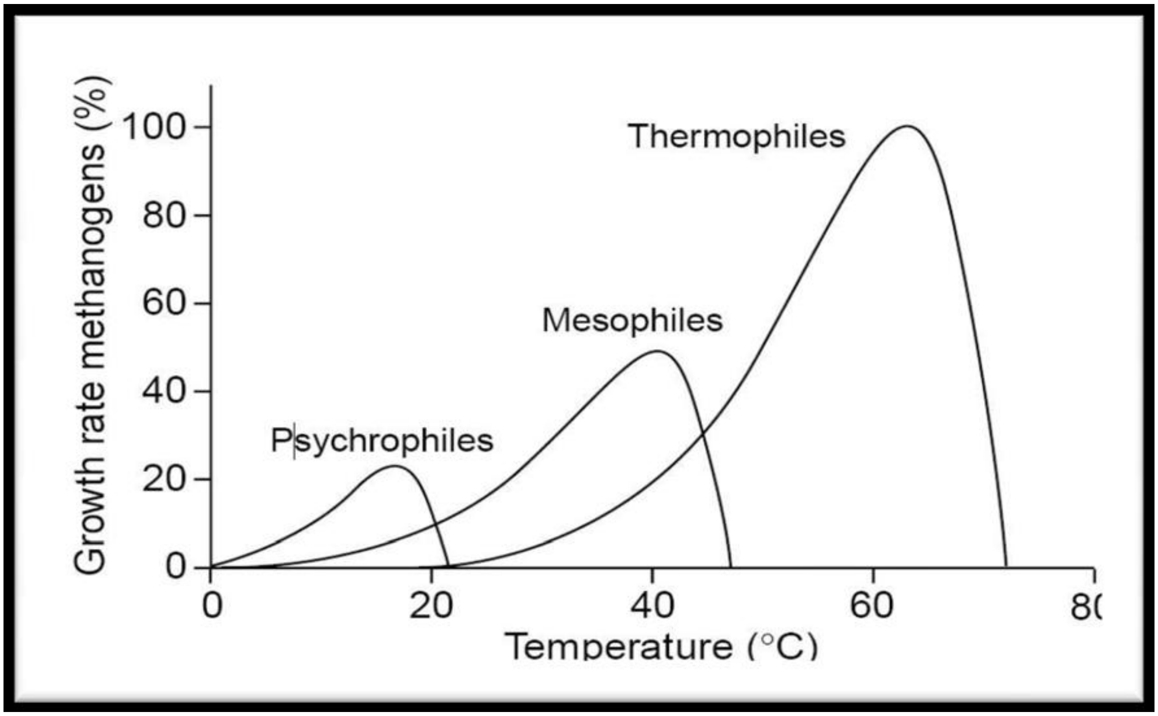


Fig. 2.4. Relative growth rates of Psychrophilic, Mesophilic and Thermophilic Methanogens (Van L. 1997)

The methanogenic bacteria are available in all kinds of environments and survive a wide temperature range. This makes it not surprising to find that the change from Mesophilic to Thermophilic temperatures or vice versa is not a problem in anaerobic digesters as long as the change occurs smoothly (slow change, low loading). However, it might take months before mesophilic cultures are adapted to psychrophilic temperatures. Once the adaptation to low temperatures is complete, the system reacts very well to stress situations. (Wellinger, 1985).

2.3. Potency of slaughter house waste to produce biogas.

Production of biogas from slaughter house waste has been found to be very potent with attractive yields from both solid waste and also waste water. Waste water can produce biogas amounting to 2.472 m^3/m^3 of wastewater and cattle manure can produce a total of 618,90 L/kg. (Budiyono, et al, 2011)

The main feed stock for a slaughter-house-waste biogas is animal dung and stomach/intestinal contents. These include semi-digested plant matter as well as digested contents in the digestive system.

Organic matter in slaughterhouse waste has a special characteristic of being highly biodegradable and easily used by micro organisms either in aerobic or anaerobic condition. Anaerobic digestion has the following advantages:

i low sludge production of only 5% to 20% of that generated by aerobic systems;
ii yields usable energy in the form of methane;
iii Requires no aeration energy;
iv the biomass can remain unfed for long periods without deterioration (Speece, 1996).

2.4. Biogas from various sources

Generally biogas use remains significantly low in comparison to other forms of energy and especially conventional sources of energy. It is more commonly used in domestic setup than industrial and commercial applications.

The use of biogas in the EU is mainly contributed by 13 countries with Germany leading with 60% contribution of the total. In the other countries biogas plays a marginal or no role. (Foreest, 2012). Figures 2.1 and 2.2 illustrate the level of biogas production among various countries in Europe.

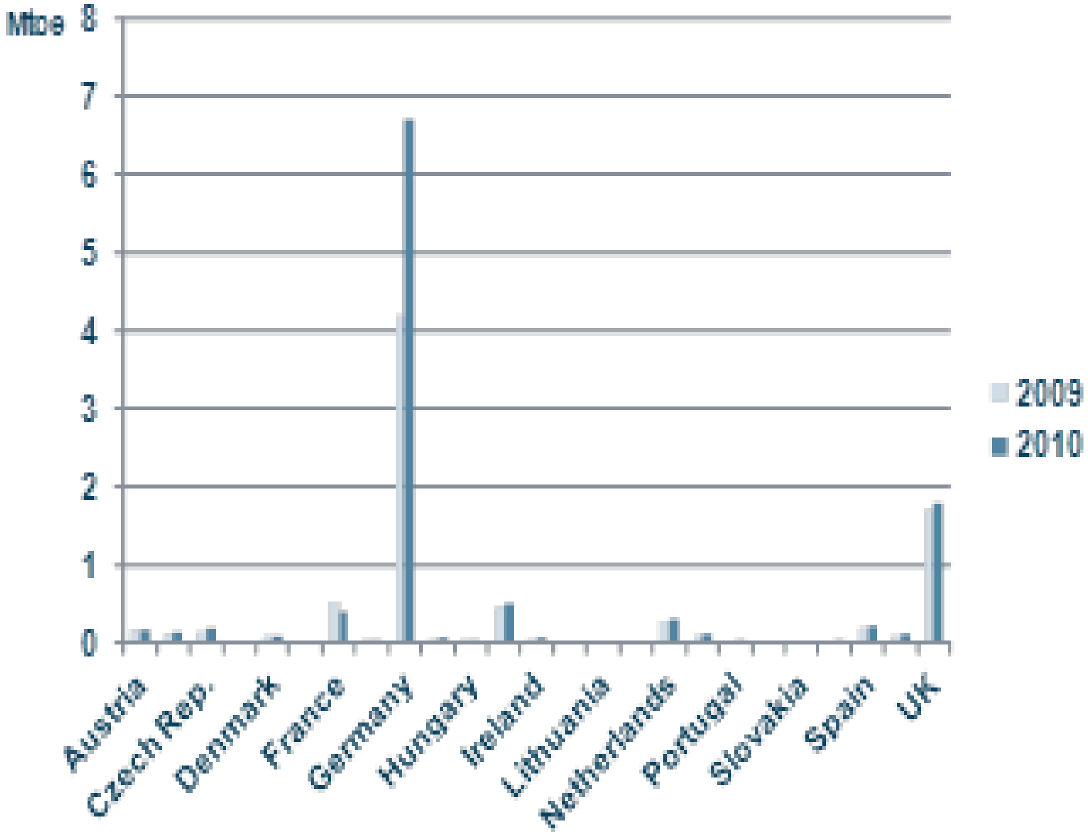


Fig. 2.5: Biogas production in Europe 2009-2010 (Foreest, 2012)

Germany is the highest producer of biogas at 60% of the total while some countries produce no biogas like Portugal, Lithuania among others. Amounts of Landfill and sewage sludge based biogas seem to have stabilized in Europe. Others sources that include agricultural industries - where slaughter house belongs - seems to have been growing steadily between 2007 and 2010.

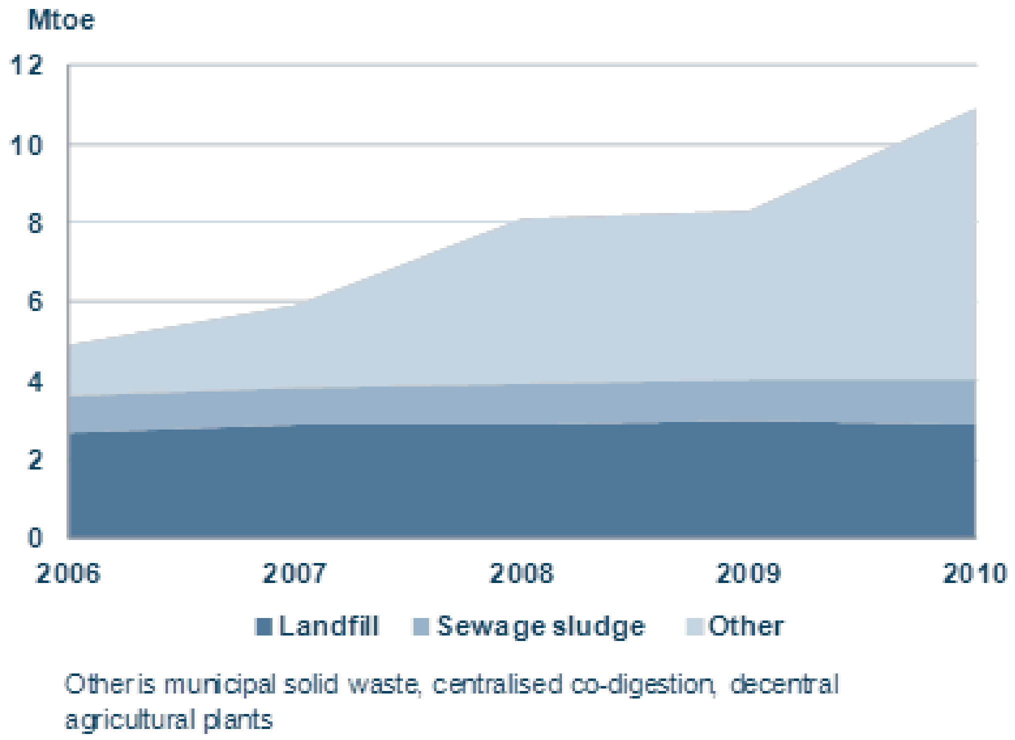


Fig. 2.6. Biogas production in Europe 2006-2010 by source (Foreest, 2012)

Use of household biogas is most widespread in Asia with China having over 15 million households on biogas by 2004 (Wim, 2006). The biogas is generated mainly from livestock farms as well as household waste water. The initiative being made in China is to replace septic tanks with waste water digesters for biogas.

The general observation is that slaughter house biogas has not been highlighted much compared to other sources of biogas like agricultural waste and animal dung.

2.5. Biogas in Kenya

Biogas use was introduced in Kenya in 1957 by Tim Hutchinson who had built one biogas digester for his personal use. (Shell foundation, 2007).

It is estimated that up to 2000 units have been installed in the country to date but it is not possible to estimate the actual number or proportion of those that are functional due to the dispersed and sometimes uncontrolled and informal nature of installations. The majority of systems were installed in the 1980s and 1990s. (Shell foundation, 2007).

Biogas technology penetration rate in the country remains very low because it has acquired a less favourable reputation. (Shell foundation, 2007).

However there is good potential for household biogas in Kenya. There are 35 districts in the country with very high potential for household biogas with the highest potential areas being in Nyanza, Western, and Central provinces, and more limited scope in parts of Rift Valley and Eastern provinces. The prospected capacity of domestic biogas in Kenya is 38,000 units. (Shell foundation, 2007).

Although biogas has been a proven technology in Kenya, having been promoted since the 1950s, there is a general lack of awareness of the relevance of biogas technology at household level. (Shell foundation, 2007).

In Kenya, attempts have been made by United Nations Industrial Development Organization (UNIDO) to help some few slaughter house owners to generate biogas as a way of waste management and disposal. In their audit done in 50 establishments UNIDO found that 2% of the establishments were slaughter houses and they generated the biogas for use within the institution. (Kirai, et al, 2009).

This has been tried in slaughter houses located in Dagoretii Nyongara, Kiserian, Bungoma and Homabay.

Among the objectives of UNIDO in these projects is to target the local communities and provide them with alternative cooking energy in form of biogas to prevent further destruction of environment from charcoal burning and firewood exploitation. However, this objective is yet to be achieved because the projects are still in testing stage.

One such example is the partnership between Kenya Industrial Research and Development Institute (KIRDI) and one of the largest abattoirs in Dagoretiti to set up a biogas unit, that was hypothesized to allow for the distribution of biogas to nearby shops. (Kirai, et al, 2009).

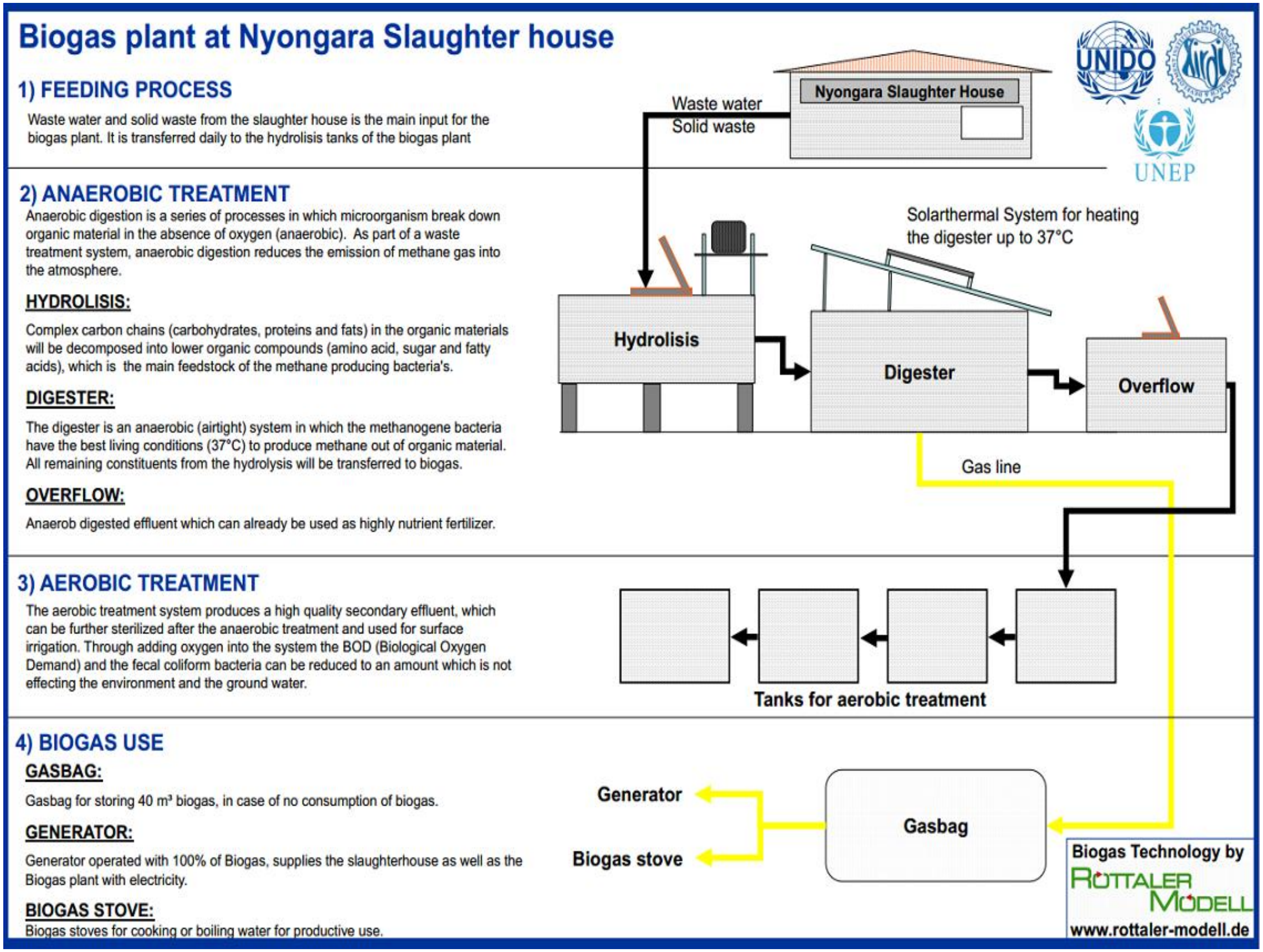
Biogas Generation at Dagoreti Slaughterhouses

The project at four Dagoreti slaughterhouses was a joint initiative of UNIDO-Kenya and UNEP-Kenya with KIRDI as the consultant. It was aimed at resolving environmental problems arising from the slaughterhouses polluting Kabuthi - Nairobi river. (KIRDI, 2008)

According to a feasibility study done in 2008 by KIRDI, an average of 360 cattle and 100 small animals(sheep/goats) are slaughtered daily in the slaughterhouses and meat distributed to Nairobi markets. Average live weight of one cattle slaughtered is 380kg. Daily amounts of waste generated from the slaughterhouses that could be used as feedstock for biogas is 17.9 tonnes. Water used in the slaughterhouses per day is about 20,000 litres. (KIRDI, 2008)

Anaerobic digestion of slaughterhouse waste from the Dagoreti slaughterhouses was found most suitable for rendering the waste harmless. The digestion was made in phases; Hydrolysis, methanation and aerobic digestion of overflow. Hydrolysis tanks were used to induce the process of digestion to quicken the process. Methanation in the digester was also quickened by raising temperatures to $37^{o}C$ through use of solar heaters and hence retention period was reduced to ten days. By doing so, it was possible to have more waste treated within a shorter period hence reduce the size of digester.

The resultant gas from the process comprises approximately between 65% and 70% methane and the rest is mainly Carbon dioxide with traces of other unwanted gases. (KIRDI, 2008). The Nyongara slaughterhouse biogas flow diagram is shown in figure 2.8.



Biogas plant at Nyongara Slaughter house

1) FEEDING PROCESS

Waste water and solid waste from the slaughter house is the main input for the biogas plant. It is transferred daily to the hydrolisis tanks of the biogas plant

2) ANAEROBIC TREATMENT

Anaerobic digestion is a series of processes in which microorganism break down organic material in the absence of oxygen (anaerobic). As part of a waste treatment system, anaerobic digestion reduces the emission of methane gas into the atmosphere.

HYDROLISIS:

Complex carbon chains (carbohydrates, proteins and fats) in the organic materials will be decomposed into lower organic compounds (amino acid, sugar and fatty acids), which is the main feedstock of the methane producing bacteria's.

DIGESTER:

The digester is an anaerobic (airtight) system in which the methanogene bacteria have the best living conditions (37°C) to produce methane out of organic material. All remaining constituents from the hydrolysis will be transferred to biogas.

OVERFLOW:

Anaerob digested effluent which can already be used as highly nutrient fertilizer.

3) AEROBIC TREATMENT

The aerobic treatment system produces a high quality secondary effluent, which can be further sterilized after the anaerobic treatment and used for surface irrigation. Through adding oxygen into the system the BOD (Biological Oxygen Demand) and the fecal coliform bacteria can be reduced to an amount which is not effecting the environment and the ground water.

4) BIOGAS USE

GASBAG:

Gasbag for storing 40 m^3 biogas, in case of no consumption of biogas.

GENERATOR:

Generator operated with 100% of Biogas, supplies the slaughterhouse as well as the Biogas plant with electricity.

BIOGAS STOVE:

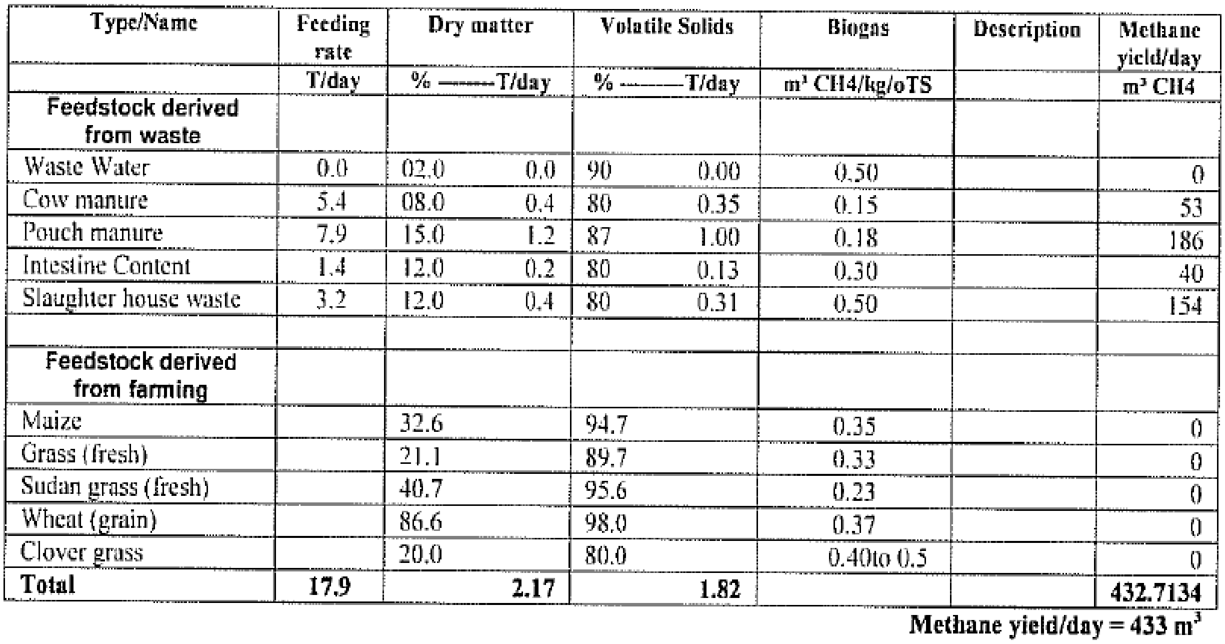
Biogas stoves for cooking or boiling water for productive use.

Fig. 2.7. Flow diagram of Nyongara slaughterhouse biogas in Dagoreti (KIRDI website, 2014)

The categories of wastes from the slaughterhouse and the calculated biogas yield at the final phase of the project is shown in the table 2.2. Blood is isolated and dried for use as addition to animal feed.

The slurry from the anaerobic digestion could be sold to the farmers as fertilizer and also could be used by the slaughter house to grow napier grass for the animals.

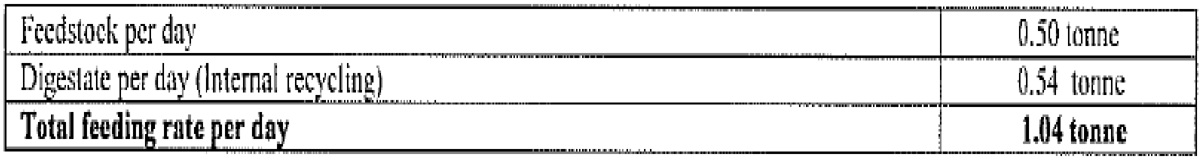
Table 2.2. Biogas calculation (KIRDI, 2008)



Type/Name	Feeding rate	Dry matter		Volatile Solids		Biogas	Description	Methane yield/day
	T/day	%	T/day	%	T/day	m³ CH4/kg/oTS		m³ CH4
Feedstock derived from waste								
Waste Water	0.0	02.0	0.0	90	0.00	0.50		0
Cow manure	5.4	08.0	0.4	80	0.35	0.15		53
Pouch manure	7.9	15.0	1.2	87	1.00	0.18		186
Intestine Content	1.4	12.0	0.2	80	0.13	0.30		40
Slaughter house waste	3.2	12.0	0.4	80	0.31	0.50		154
Feedstock derived from farming								
Maize		32.6		94.7		0.35		0
Grass (fresh)		21.1		89.7		0.33		0
Sudan grass (fresh)		40.7		95.6		0.23		0
Wheat (grain)		86.6		98.0		0.37		0
Clover grass		20.0		80.0		0.40to 0.5		0
Total	**17.9**		**2.17**		**1.82**			**432.7134**

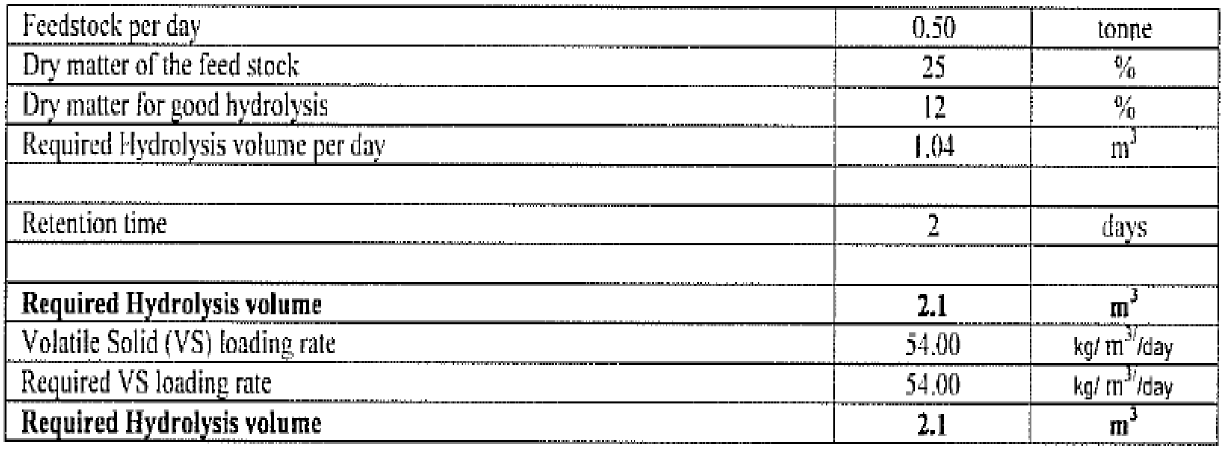
Methane yield/day = 433 m³

Table 2.3. Feeding rate per day (KIRDI, 2008)



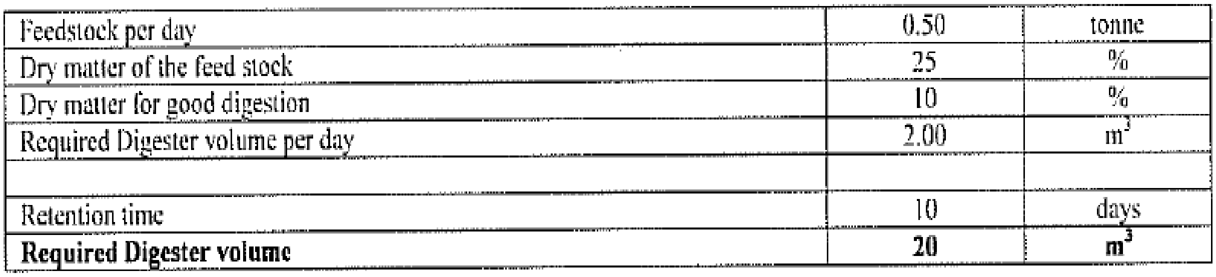
Feedstock per day	0.50 tonne
Digestate per day (Internal recycling)	0.54 tonne
Total feeding rate per day	**1.04 tonne**

Table 2.4. Hydrolysis capacity calculation (KIRDI, 2008)



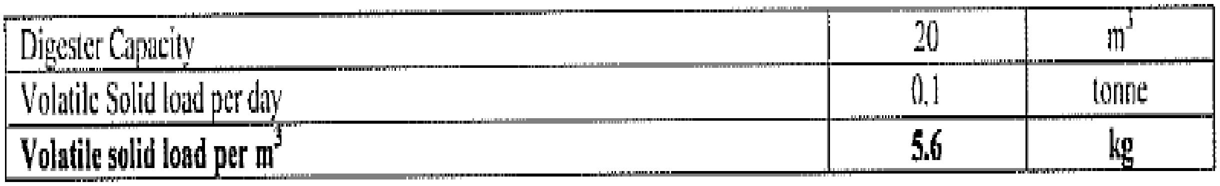
Feedstock per day	0.50	tonne
Dry matter of the feed stock	25	%
Dry matter for good hydrolysis	12	%
Required Hydrolysis volume per day	1.04	m^3
Retention time	2	days
Required Hydrolysis volume	**2.1**	**m^3**
Volatile Solid (VS) loading rate	54.00	kg/ m^{3}/day
Required VS loading rate	54.00	kg/ m^{3}/day
Required Hydrolysis volume	**2.1**	**m^3**

Table 2.5. Required digester volume (KIRDI, 2008)



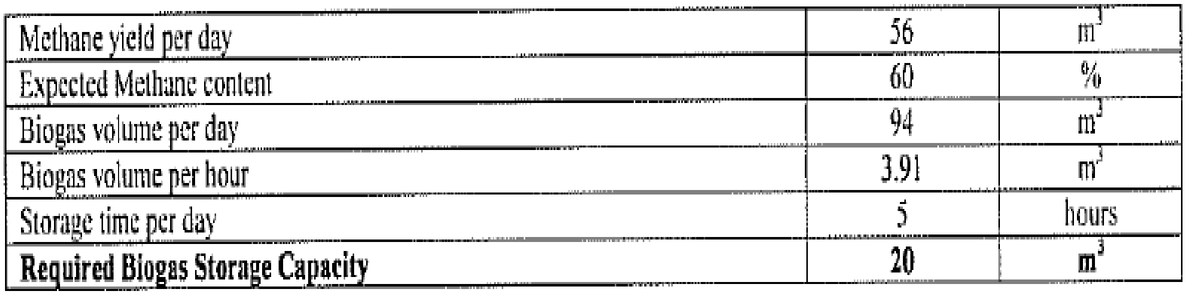
Feedstock per day	0.50	tonne
Dry matter of the feed stock	25	%
Dry matter for good digestion	10	%
Required Digester volume per day	2.00	m^3
Retention time	10	days
Required Digester volume	**20**	**m^3**

Table 2.6. Digester loading rate calculation (KIRDI, 2008)



Digester Capacity	20	m^3
Volatile Solid load per day	0.1	tonne
Volatile solid load per m^3	**5.6**	**kg**

Table 2.7. Biogas storage capacity (KIRDI, 2008)



Methane yield per day	56	m^3
Expected Methane content	60	%
Biogas volume per day	94	m^3
Biogas volume per hour	3.91	m^3
Storage time per day	5	hours
Required Biogas Storage Capacity	**20**	**m^3**

The waste estimate from Dagoreti slaughter houses for an average of 360 heads of cattle and 100 sheep and goats was 17.9 tonnes per day. Using the ratio of dung production for cattle and small animals as 20kg and 2kg per head of cattle and small animal respectively, the waste contribution by cattle would be 17.416 tonnes and that of small animals would be 0.483T. This translates to 48.37kg per cattle and 4.83kg per small animal.

2.6. Slaughter house activities and waste management

Slaughter houses generate a lot of waste in the form of manure, rumen content, blood and waste water. This waste should be handled within the provisions of the law to avoid pollution.

NEMA in waste management regulation 2006 states that:

(1) No person shall dispose of any waste on a public highway, street, road, recreational area or in any public place except in a designated waste receptacle.

(2) Any person whose activities generate waste shall collect, segregate and dispose or cause to be disposed off such waste in the manner provided for under these Regulations.

(3) Without prejudice to the foregoing, any person whose activities generates waste has an obligation to ensure that such waste is transferred to a person who is licensed to transport and dispose off such waste in a designated waste disposal facility.

5. (1) Any person whose activities generate waste, shall segregate such waste by separating hazardous waste from non-hazardous waste and shall dispose of such wastes in such facility as is provided for by the relevant Local Authority.

17. (1) Every trade or industrial undertaking shall install at its premises anti-pollution technology for the treatment of waste emanating from such trade or industrial undertaking;

(2) Anti-pollution technology installed pursuant to 8

Regulation 17(1) shall be based on the best available technology not entailing excessive costs or other measures as may be prescribed by the Authority.

18. No owner or operator of a trade or industrial undertaking shall discharge or dispose of any waste in any state into the environment, unless the waste has been treated in a treatment facility and in a manner prescribed by the Authority in consultation with the relevant lead agency. (NEMA waste management Act 2006)

In order to meet these requirements, slaughter houses incur costs to dispose and generally manage the wastes generated.

2.7. Biogas Digester Types and Designs

A standard Biogas plant is a continuous running plant with automatic discharge through overflow. (PSDA, 2011). From the standpoint of fluid dynamics and structural strength, an egg-shaped vessel is about the best possible solution. This type of construction, however, is comparatively expensive, so that its use is usually restricted to large-scale sewage treatment plants. The Chinese fixed-dome designs are of similar shape, but less expensive.

Simplified versions of such digester designs include cylinders with conical covers and bottoms. They are much easier to build and are sometimes available on the market as prefabricated units. Their disadvantage lies in their less favourable surface-volume ratio. The cylinder should have a height equal to its diameter. Cuboid digesters are often employed in batch-fed systems used primarily for fermenting solid material, so that fluid dynamics are of little interest.(Energypedia, 2014).

Industrial Digester types

The designs are selected in a way that all the typical elements of modern biogas technology appear at least once. All designs are above-ground, which is common in Europe. (Energypedia, 2014).

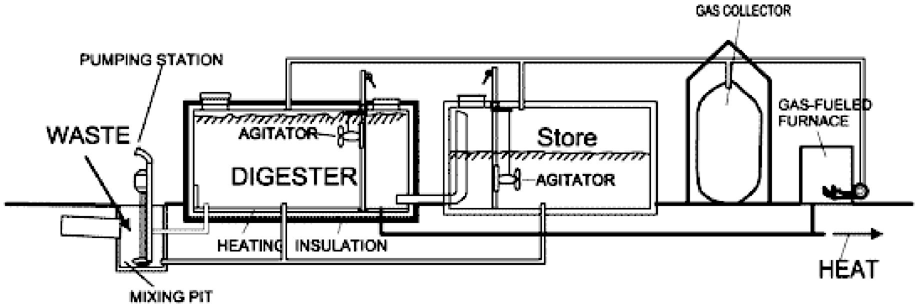


Fig. 2.8. Concrete digester with two chambers (one heated, one unheated for storage) (Energypedia, 2014).

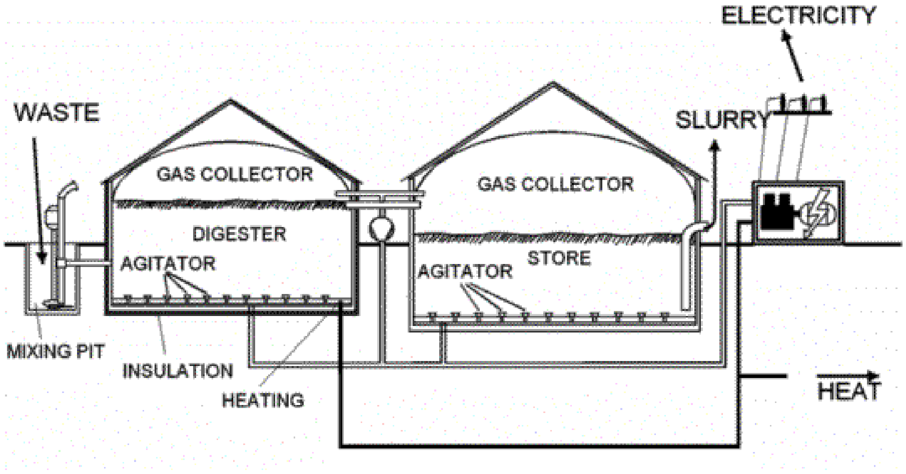


Fig. 2.9. Concrete digester with integrated plastic gas-holder(Energypedia, 2014).

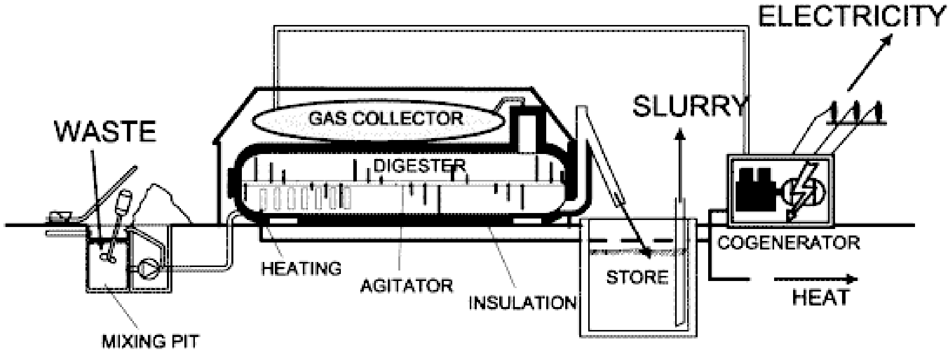


Fig. 2.10. Steel vessel fermenter with separate balloon gas-holder(Energypedia, 2014).

Batch Plants

Batch plants are filled and then emptied completely after a fixed retention time. Each design and each fermentation material is suitable for batch filling, but batch plants require high labour input. As a major disadvantage, their gas-output is not steady. (Energypedia, 2014).

Small Scale Digester Types

Fixed-Dome Digesters

Fixed-dome digester design is one of the two well proven designs that are suitable for rural households (the other design being the floating drum design). (PSDA, 2011).

A fixed-dome plant comprises of a closed, dome-shaped digester with an immovable, rigid gas-holder and a displacement pit, also named 'compensation tank'. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. Gas pressure increases with the volume of gas stored, i.e. with the height difference between the two slurry levels. If there is little gas in the gas-holder, the gas pressure is low. (Energypedia, 2014). The maximum pressure of a fixed dome digester is the difference between the overflow level at the expansion chamber and the maximum gas storage level. (PSDA, 2011).

Fixed dome plants produce just as much gas as floating-drum plants, if they are gas-tight. However, utilization of the gas is less effective as the gas pressure fluctuates substantially. Burners and other simple appliances cannot be set in an optimal way. If the gas is required at constant pressure (e.g., for engines), a gas pressure regulator or a floating gas-holder is necessary. (Energypedia, 2014). Figure 2.7 shows the layout of a fixed dome digester.

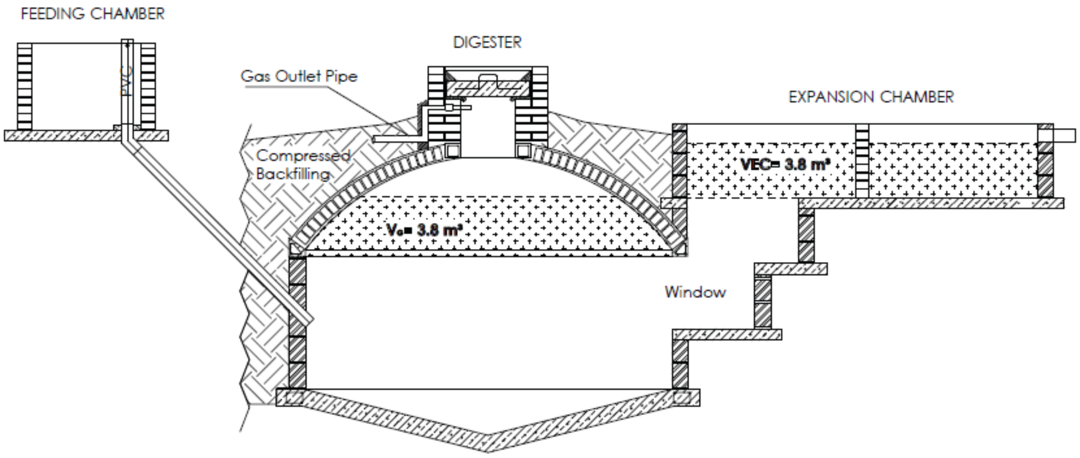


Fig. 2.11. Layout of fixed-dome digester(PSDA, 2011).

Floating Drum Digesters

Floating-drum plants consist of an underground digester and a moving gas-holder. The gas-holder 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. (Energypedia, 2014).

The drum in which the biogas collects has an internal and/or external guide frame that provides stability and keeps the drum upright. If biogas is produced, the drum moves up, if gas is consumed, the gas-holder sinks back. (Energypedia, 2014).

Floating-drum plants are used most frequently by small- to middle-sized farms (digester size: 5-15m^3) or in institutions and larger agro-industrial estates (digester size: 20-100m^3). The disadvantage of this design is that the drum has a short lifespan of about 15years. It also requires regular maintenance to remove rust and to paint. (Energypedia, 2014).

There are various types of floating drum digesters and vary in shape and materials used especially for the drum.

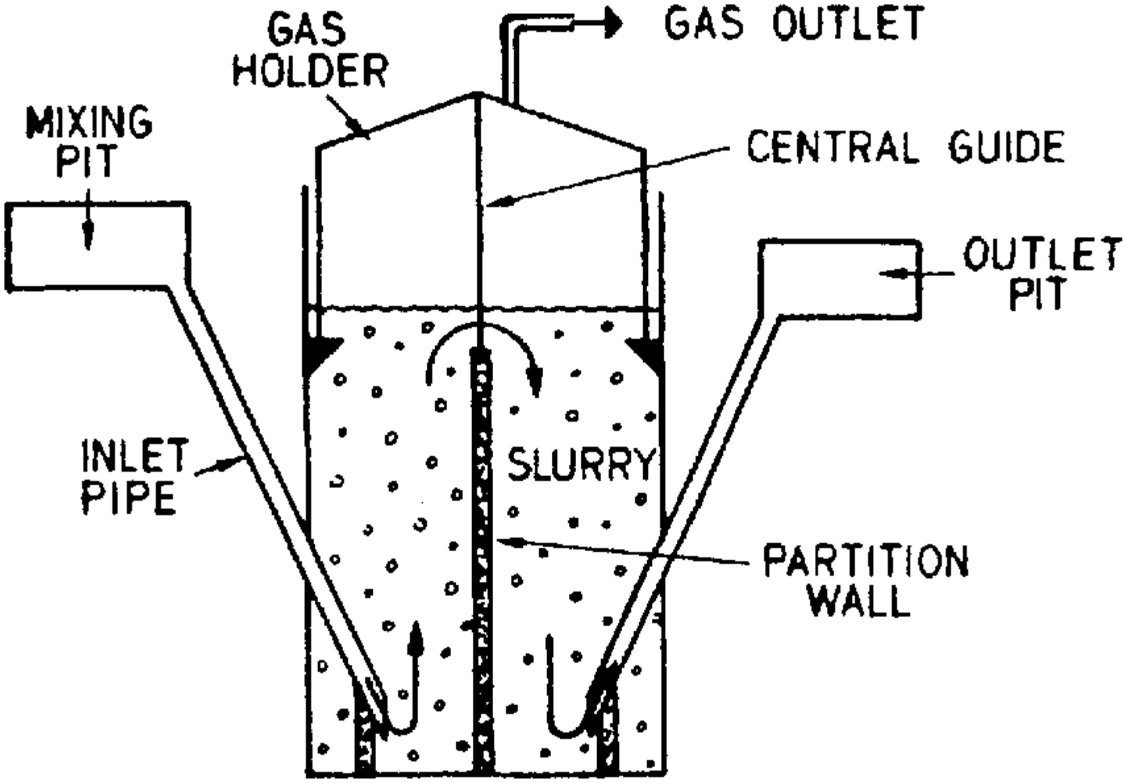


Fig. 2.12. Schematic diagram of floating drum design (FAO website)

Low-cost Polyethylene Tube Digester

The low-cost polyethylene tube digester uses a tubular polyethylene film (two coats of 300 microns) that is bent at each end around a 6 inch PVC drainpipe and is wound with rubber strap of recycled tire-tubes.

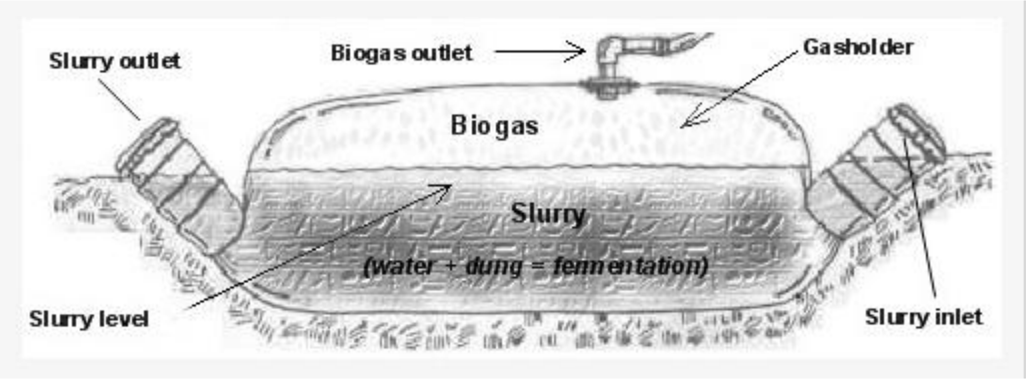


Fig. 2.13. Low Cost Polyethylene Tube Digester Scheme (Energypedia, 2014).

Balloon Plants

A balloon plant consists of a heat-sealed plastic or rubber bag (balloon), combining digester and gas-holder. The gas is stored in the upper part of the balloon. The inlet and outlet are attached directly to the skin of the balloon. Gas pressure can be increased by placing weights on the balloon. If the gas pressure exceeds a limit that the balloon can withstand, it may damage the skin. Therefore, safety valves are required. If higher gas pressures are needed, a gas pump is required. (Energypedia, 2014).

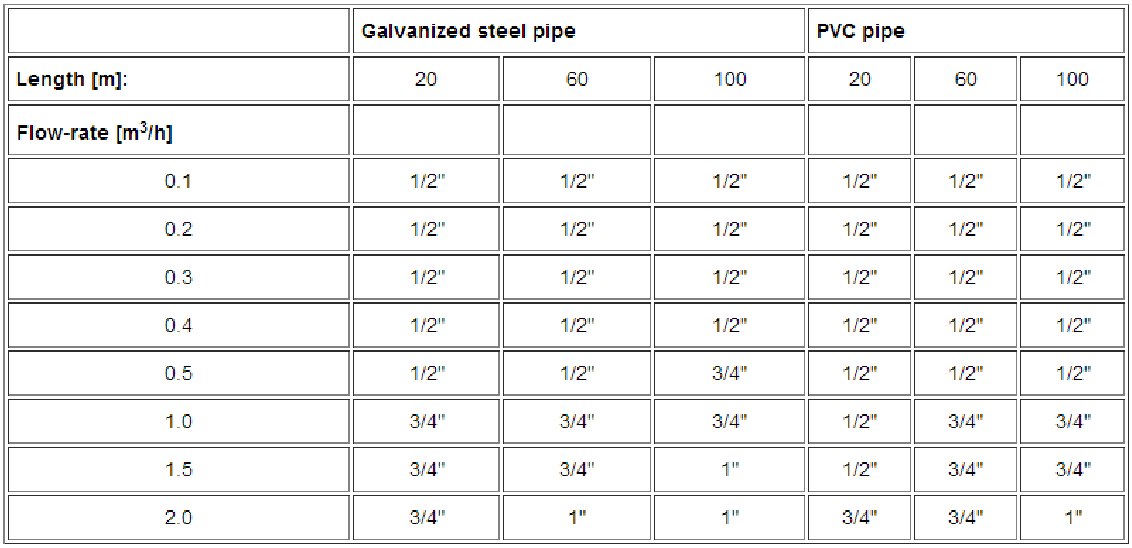
2.8. Biogas storage and piping

All biogas storage facilities must be gas tight and pressure-resistant and must be UV-, temperature- and weather proof. For safety reasons, they must be equipped with safety valves to prevent damages and safety risks. Explosion protection must also be guaranteed. The gas storage facility must have the minimum capacity corresponding to one fourth of the daily biogas production. Normally, a capacity of one or two days gas production is recommended. (Seadi, 2008)

There are three types of biogas storage facilities; low pressure, medium pressure and high pressure. Low pressure tanks have an overpressure range of 0,05 to 0,5 mbar and are made of special membranes, which must meet a number of safety requirements. The membrane tanks are installed as external gas reservoirs or as gas domes/covers on top of the digester. Medium and high pressure reservoirs operate at pressures between 5 and 250 bar, in steel pressure tanks and bottles. These kinds of storage types have high operation costs and high energy consumption. For gas reservoirs up to 10 bar, energy requirements of up to 0.22 kWh/m³ must be considered and for high pressure reservoirs with 200 to 300 bar, the energy requirement is of about 0.31 kWh/m³. Because of their high costs, these kinds of biogas storage are rarely used in agricultural biogas plants. . (Seadi, 2008)

Two types of pipes preferred and commonly used for biogas piping are Galvanized steel(G.I) pipes and Polyvinyl Chloride (PVC) pipes. G.I. pipes are recommended for exposed piping network while PVC should be used for underground to prevent exposure to direct sunlight. G.I. pipes are more expensive than PVC pipes and hence it is a necessary consideration when making a choice. The longer the distance and the higher the flow rate, the higher the pressure drops due to friction. Bends and fittings increase the pressure losses. G.I. pipes show higher pressure losses than PVC pipes. (Energypedia, 2014).

Table 2.9. Values for appropriate pipe diameters and corresponding flowrates (Energypedia, 2014)

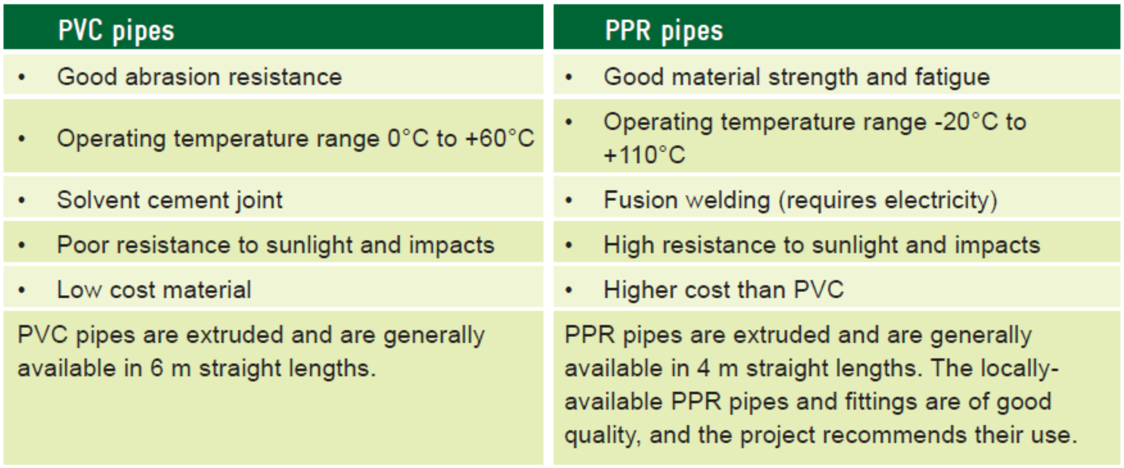


	Galvanized steel pipe			**PVC pipe**		
Length [m]:	20	60	100	20	60	100
Flow-rate [m^3/h]						
0.1	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"
0.2	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"
0.3	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"
0.4	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"
0.5	1/2"	1/2"	3/4"	1/2"	1/2"	1/2"
1.0	3/4"	3/4"	3/4"	1/2"	3/4"	3/4"
1.5	3/4"	3/4"	1"	1/2"	3/4"	3/4"
2.0	3/4"	1"	1"	3/4"	3/4"	1"

Among plastic pipes that could be used for biogas distribution are polyvinyle chloride (PVC) and polypropylene(PPR). Polypropylene pipes are of better quality and more durable than PVC pipes. (PSDA, 2011)

The characteristics of the two types of plastic pipes are shown on table 2.10.

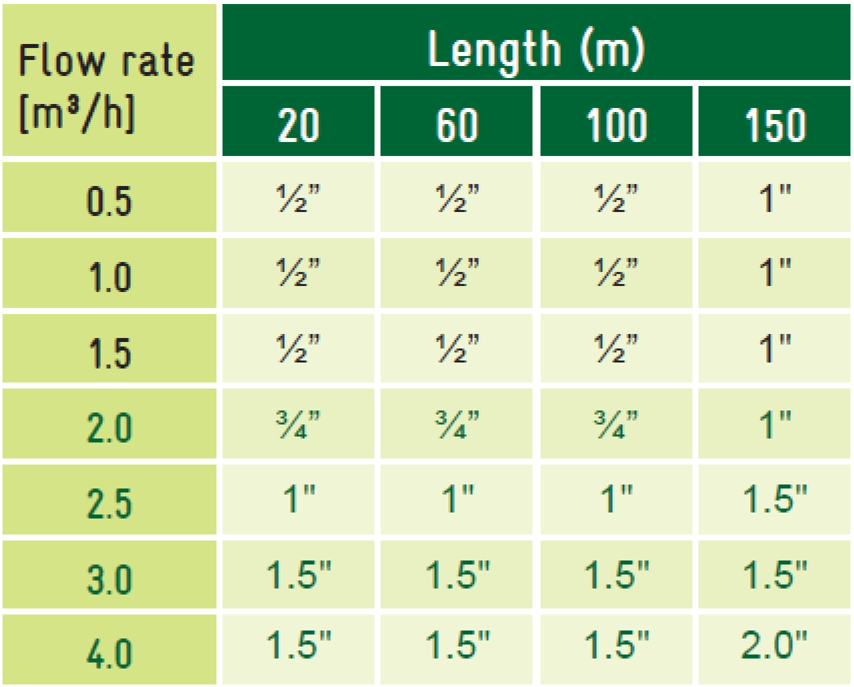
Table 2.10. Comparison of material characteristics of PVC and PPR (PSDA, 2011)



PVC pipes	PPR pipes
• Good abrasion resistance	• Good material strength and fatigue
• Operating temperature range 0°C to +60°C	• Operating temperature range -20°C to +110°C
• Solvent cement joint	• Fusion welding (requires electricity)
• Poor resistance to sunlight and impacts	• High resistance to sunlight and impacts
• Low cost material	• Higher cost than PVC
PVC pipes are extruded and are generally available in 6 m straight lengths.	PPR pipes are extruded and are generally available in 4 m straight lengths. The locally-available PPR pipes and fittings are of good quality, and the project recommends their use.

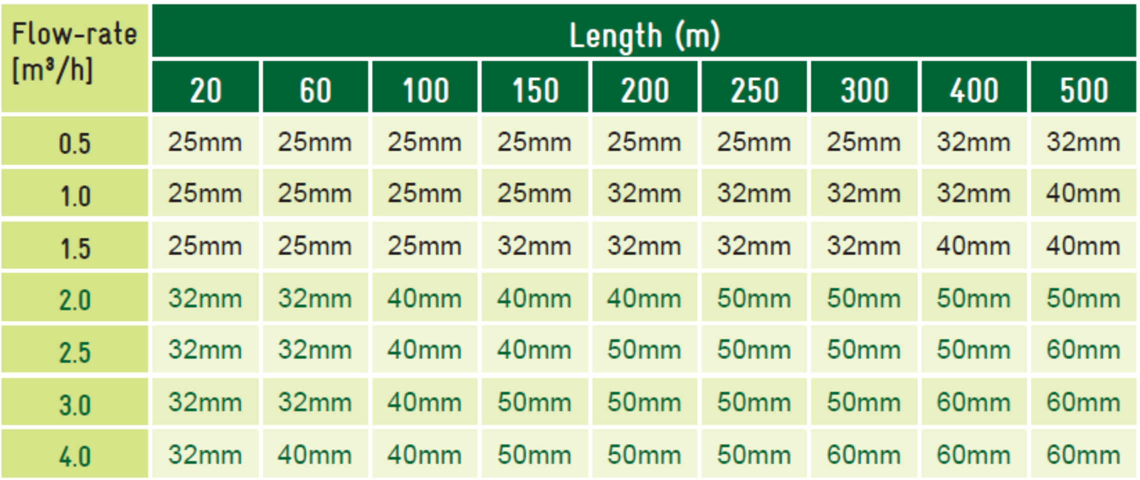
Tables 2.11 and 2.12 show the recommended pipe diameters for various flow rates for both PVC and PPR pipes.

Table 2.11. Recommended pipe sizes for different flow rates for PVC pipes (PSDA, 2011)



Flow rate [m^3/h]	Length (m)			
	20	60	100	150
0.5	½"	½"	½"	1"
1.0	½"	½"	½"	1"
1.5	½"	½"	½"	1"
2.0	¾"	¾"	¾"	1"
2.5	1"	1"	1"	1.5"
3.0	1.5"	1.5"	1.5"	1.5"
4.0	1.5"	1.5"	1.5"	2.0"

Table 2.12. Recommended pipe sizes for different flow rates for PPR pipes (PSDA, 2011)



Flow-rate [m³/h]	Length (m)								
	20	60	100	150	200	250	300	400	500
0.5	25mm	25mm	25mm	25mm	25mm	25mm	25mm	32mm	32mm
1.0	25mm	25mm	25mm	25mm	32mm	32mm	32mm	32mm	40mm
1.5	25mm	25mm	25mm	32mm	32mm	32mm	32mm	40mm	40mm
2.0	32mm	32mm	40mm	40mm	40mm	50mm	50mm	50mm	50mm
2.5	32mm	32mm	40mm	40mm	50mm	50mm	50mm	50mm	60mm
3.0	32mm	32mm	40mm	50mm	50mm	50mm	50mm	60mm	60mm
4.0	32mm	40mm	40mm	50mm	50mm	50mm	60mm	60mm	60mm

Table 2.13. Biogas plant sizes and maximum plant pressure (PSDA, 2011).

Plant Size (m^3)	8	12	16	24	32	48	59	71	91	124
Max. pressure (cm)	94	97	105	115	125	125	127	133	135	140

2.9. Biogas Digester sizing

From the amount of waste generated in the slaughter house, sizing of pipe diameters can be done using table 2.14 as provided by GIZ guidelines.

Table 2.14. Estimated digester sizes and their gas yield expected. (PSDA, 2011).

Design Parameters for Biogas Digesters			
A	B	C	D
Digestor Size m^3	Waste/day (kg)	Heads of cattle	Gas production (m^3)
8	100	5	3
12	150	7	4.5
16	200	9	6
24	300	13	9
32	400	17	12
48	600	25	18
59	740	31	22
71	900	38	28
80	1100	46	34
124	1500	63	46

The biogas so generated can be used directly for cooking or can be used to generate electricity. To utilize biogas produced from slaughterhouse for cooking, it would be necessary to establish the consumption of the fuel being used that needs to be substituted. Biogas typically has a calorific value of about 22 MJ/m^3 (Banks, 2009) and density of approximately 1.2 kg/m^3 at ambient condition. (Barik et al, 2013).

Assuming temperatures of 25^oC and atmospheric pressure of 1021mb (of Nairobi weather), density of biogas could be estimated. The ratio of methane to carbon dioxide is assummed to be 60% and 40% respectively.

Using the ideal gas formular;

$PV=nRT$ (2.1)

For methane in $1m^3$:

$T= 25^oC=298K$

$P=1021mb=1.000765atm$

$V = 60\%$ of $1 m^3 = 600 L$

Molar mass of methane =16.04g/mole

From equation (1.2),

$n = PV/RT$

$= (1.00765 x 600)/(0.8206)(298)$

=24.724 moles

The mass in 600L of methane

=n x molar mass

=24.724moles x16.04g

=396.6g

For Carbon dioxide in $1 m^3$:

$T = 25^{o}C = 298K$

P=1021mb=1.000765atm

$V = 40\%$ of $1 m^3 = 400 L$

Molar mass of Carbon dioxide =44.01g/mole

From equation (1.2),

$n = PV/RT$

$= (1.00765 x 400)/(0.8206)(298)$

=16.59 moles

The mass in 400L of Carbon dioxide

=n x molar mass

=16.59moles x 44.01g

=730.294g

Total weight of biogas

=396.6+730.294

=1.126kg/m^3

Therefore calorific value of biogas could be estimated at (22/1.126)MJ/kg or 19.5MJ/kg. The thermal value of LPG according to the energy fuel data ranges between 47.7MJ/Kg and 46.0MJ/kg. (Staffell, 2011).

Therefore to substitute 1kg of LPG for the average calorific value of 46.85, (46.85/19.5)kg or 2.4kg of biogas would be required, which is equivalent to (2.4/1.13) or 2.1m^3.

3.0. METHODOLOGY

Materials and methods

3.1. Oral Interviews

Several visits were made to the slaughter house and the hospital during which oral interviews were conducted. At the slaughter house the interview sessions established the method of waste disposal, the frequency of disposal and the cost of doing it. This information was to be used to determine the need for alternative method of disposal that would be cheaper and of better economic value than the existing.

At the hospital the oral interview conducted established the type and history of energy used for cooking in the hospital. It established the average amount of cooking energy used since the hospital had no formal record kept on this. According to the information availed, during one period the hospital used both electricity and LPG and during another, it was using LPG only.

For the LPG usage, the hospital kept no record of amounts used but had general knowledge on the amounts consumed every month for the two periods, information volunteered during the interview. For the amount of electricity usage, it was possible to obtain the billing record from KPLC.

3.2. Manual Data Recording

In order to estimate the waste generated by the slaughter house, the number of animals slaughtered there was important. The slaughterhouse though could not avail the books of record for perusal, so manual data recording was used. The number of animals and dates of slaughter were dictated and noted down. This method was limited in that only data for the month of February 2014 was offered.

3.3. Digester Design

To be able to estimate the size of the digester to be designed, the rate of waste generation in the slaughter house was estimated using the data that was obtained regarding animals slaughtered in the month of February 2014 (table 4.3). Waste estimation was calculated on the basis of the estimates for Dagoreti slaughter house in the assumption that the animals slaughtered at Rongai and Dagoreti slaughter houses were comparable in size and dung production.

Waste estimation

Equivalent waste production for animals derived from Dagoreti slaughterhouse values were:

Total heads of cattle slaughtered per day = 360

Total number of sheep/goats slaughtered per day = 100

Total waste per day = 17.9 tonnes

For live animals, dung per day is estimated at 20kg and 2kg for cattle and sheep/goats respectively.

The ratio of waste discharge for slaughtered animals was calculated based on this ratio of dung production.

The ratio of waste discharge is (360x20):(100x2) of 17900kg

This gives 17416kg:483.8kg for cattle and sheep/goats respectively

Therefore for 10 heads of cattle and 11.75 sheep/goats total waste expected would be

10/360x17416 and 11.75/100x438.8

=483.8kg and 51.56kg for cattle and goats respectively

Therefore total waste expected at the Ongata Rongai slaughterhouse would be

483.8kg + 51.56kg

=535.36kg/day for 24 days out of 28days of February

On average for the entire month daily waste would be

535.36x24/28

=458.88kg/day

Biogas and digester size estimation

The average waste production of 458.88 per day could not be used as the daily rate of feeding the digester because of the significant variations in the numbers of animals slaughtered daily. Therefore the waste would have to be fed into the digester in a uniform manner to sustain proper digestion and maintain relatively constant pressure. A pre-digester storage tank would be introduced to allow for regulated feeding of the waste into the digester.

Various waste quantities were tried for daily digester feeding to identify the optimum amount that would guarantee continuous feeding and minimum size of holding tank. Waste quantity of 439kg/day would give the maximum waste balance in the waste holding tank as 1117.86kg and minimum as 5.96kg as shown in table 4.3.

Using a daily feeding rate of 439kg,

Dry matter from feedstock as 25%,

Dry matter for good digestion as 10%,

Total waste for digestion = 439x0.25/0.1

=1097.5

=1097.5kg per day

For retention period of 40 days,

Total waste = 1097.5kgx40days

=43900kg

Working volume of digester = volume of gas storage (*Vgs*) + volume of fermentation chamber (*Vf*).

$$Vgs + Vf = Q.HRT \qquad (4.6)$$

For every 1000kg of waste an equivalent of $1m^3$ of digester volume is required (PSDA, 2011)

Therefore 43900kg would require $43.9m^3$ digester.

This is approximately $44m^3$.

Design and costing

According to the literature reviewed, the two commonly used designs for small and domestic digesters are floating drum and fixed dome digesters. Of the two designs, floating drum is more expensive, requires a lot of maintenance and has a short lifespan. It however, has the advantage of constant biogas pressure because of self-adjusting drum. This would make it appropriate to compensate for the irregular feeding of the waste that would fluctuate with the number of animals being slaughtered daily.

The fixed dome type of digester on the other hand is more durable and requires minimal maintenance. The disadvantage in slaughterhouse application is the fluctuation of gas pressure with the waste feeding rate.

Comparing the advantages and disadvantages of the two models, it was found that the fixed dome type was more appropriate if there was a way of controlling and sustaining constant pressure. To address this problem, the feeding to the tank would have to be regulated by introducing a storage tank preceding the digester for short term accumulation of waste in order to discharge it in regular and equal quantities. Excess waste would be held in the tank during days of more slaughters and would back up for the deficit during less slaughters.

A schematic diagram of the proposed biogas plant layout is shown on figure 3.1.

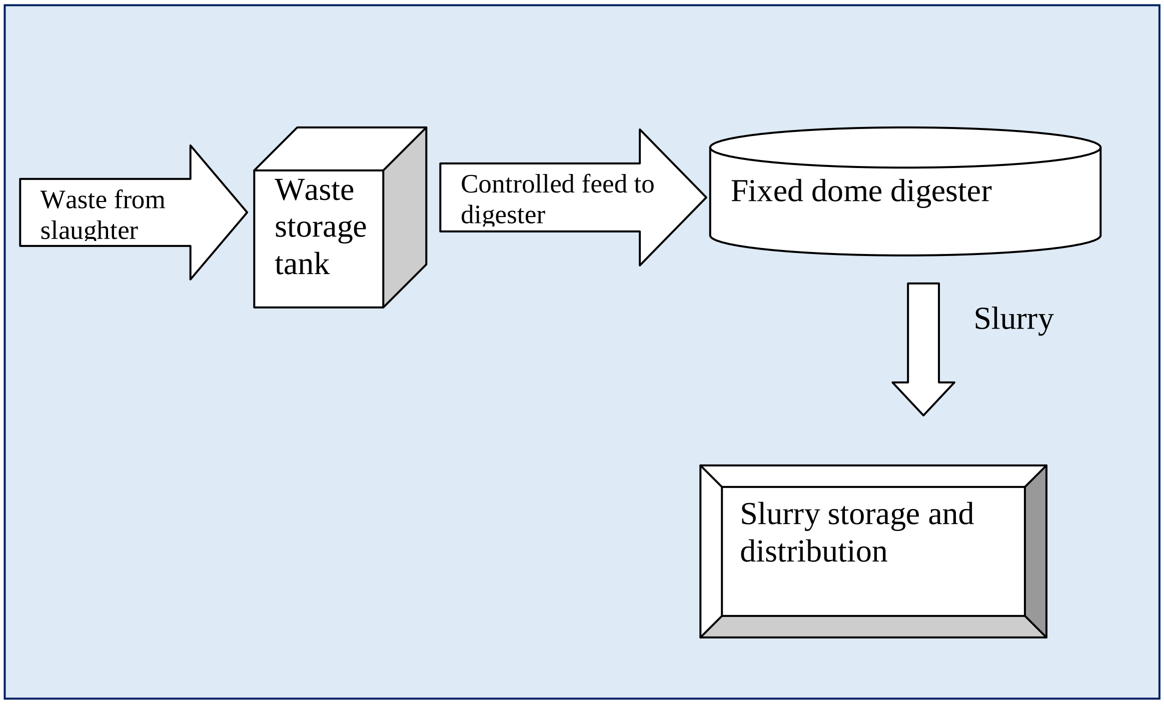


Fig. 3.1. Schematic diagram of biogas plant for Ongata Rongai slaughterhouse

Waste storage tank

The structure for this tank would be done by quarry stones and plastered with waterproof cement. It should have a volume enough to hold 1,500kg to accommodate for the highest momentary waste storage of 1,117.86kg (table 4.4). Since 1000kg of waste would require 1m^3 of space in digester(PSDA, 2011), 1.5m^3 of storage volume would be adequate for the storage tank. Therefore the storage tank would have dimensions shown in fig 3.2.

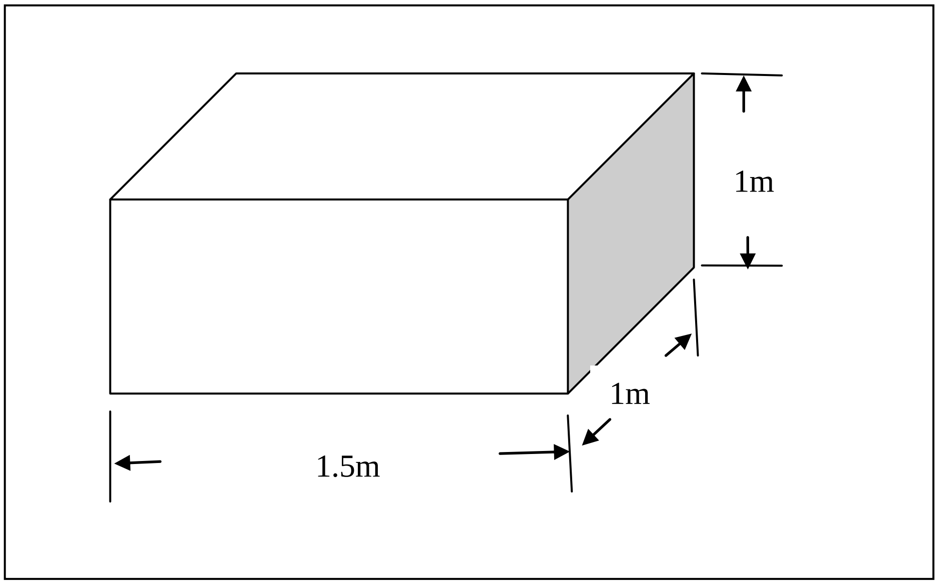


Fig. 3.2. Storage tank dimensions

Digester

The size of the digester is $44m^3$. This volume includes the digestate volume and the gas storage space. The main digester is divided into various sections; base cone, cylindrical tank and the gas storage dome.

General layout of the digester

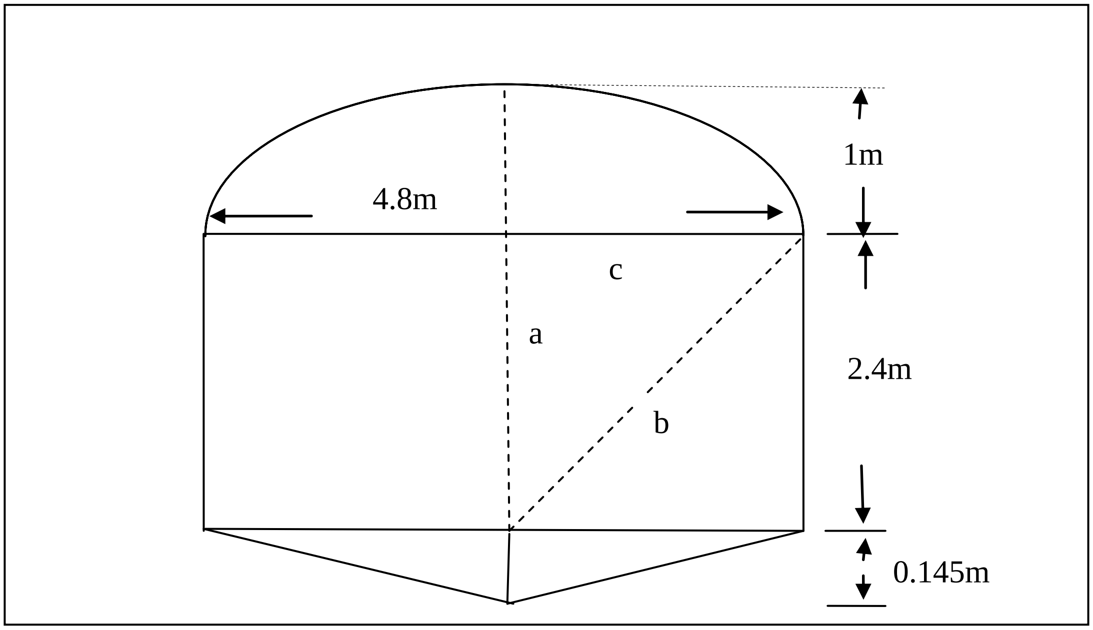


Fig. 3.3. Digester dimensions

General digester layout

The volume of the digester is 44m3. The general layout is such that the diameter is about twice the height of the digester to avoid digging too deep and to make construction work easier because of better lighting and sufficient room to accommodate the construction workers, equipment and construction manoeuvres. Therefore the height of the cylindrical part was determined using the formula:

$$\Pi r^2 h = \text{volume of (waste total waste-waste in the cone).} \qquad (4.7)$$

Waste in the cone is estimated as the twice the daily feeding waste of 878kg.

Waste in the cylinder =43900-(439x2)=43022kg

This is equivalent to 43022/1000=43.022m^3.

Therefore

$$\Pi r^2 h = 43.022\text{m}^3 = \Pi r^3 = 3.14\, r^3 \qquad (4.8)$$

and,

$$r = \sqrt[3]{(43.022/3.14)}$$

$$= 2.39\text{m}$$

$$\approx 2.4\text{m}$$

The cone

The base of the digester should be cone-shaped to increase static resistance of the whole structure(PSDA, 2011). The capacity of the cone will be approximately equal to the volume of twice the daily feedstock of 439kg, which is 878kg. The equivalent volume to hold this amount of waste is 878/1000=0.878m^3. The height of the cone is determined by the formula:

$$\text{Volume}(V) \text{ of cone} = \tfrac{1}{3}\pi r^2 h \qquad (4.9)$$

$$V = 3.14/3 \text{x} 2.4^2\, h = 0.878$$

$$h = 0.145\text{m}$$

The dome

The dome is constructed with its radius from the centre of the cone base to the top of the wall of the cylinder. Thus the radii a and b of figure 4.6 are equal.

$$b = \sqrt{(a^2+c^2)} \qquad (4.10)$$

$$= \sqrt{(2.4^2+2.4^2)}$$

$$= 3.4\text{m}$$

Thus the height of the dome from the cylinder top is the hypotenuse of triangle abc minus the height of the cylinder.

$$\text{Dome height} = 3.4\text{-}2.4$$

$$=1.0\text{m}$$

The expansion chamber

The recommended maximum pressure of a 44m^3 digester is equivalent to 125cm of water (from table 2.13), which is the distance between the overflow of the expansion chamber and the maximum level of the gas (the level of the digestate in the digester).

Therefore the height between the steps of the expansion chamber and the expansion chamber itself is 125cm. The expansion chamber is estimated to hold twice the displaced slurry of daily feedstock (approximately 0.44m^3). The height of each the two steps is estimated to be the same as the height of the expansion chamber. The height of the second step and expansion chamber make up the height of maximum pressure of 125cm.

Therefore the dimensions of a circular expansion chamber are determined by the formula:

$$\Pi r^2 h = 0.88\text{m}^3 \qquad (4.11)$$

$$= 3.14 r^2 \text{x} 1.25/2 = 0.88$$

$$r = \sqrt{}\ (0.88/3.14/1.25\text{x}2)$$

$$= \sqrt{0.658} = 0.81\text{m}$$

The steps extend to the centre of the chamber at equal length of 0.4m and width of 0.4m.

The horizontal layout of the complete digester with all the sections is shown in figure 4.7.

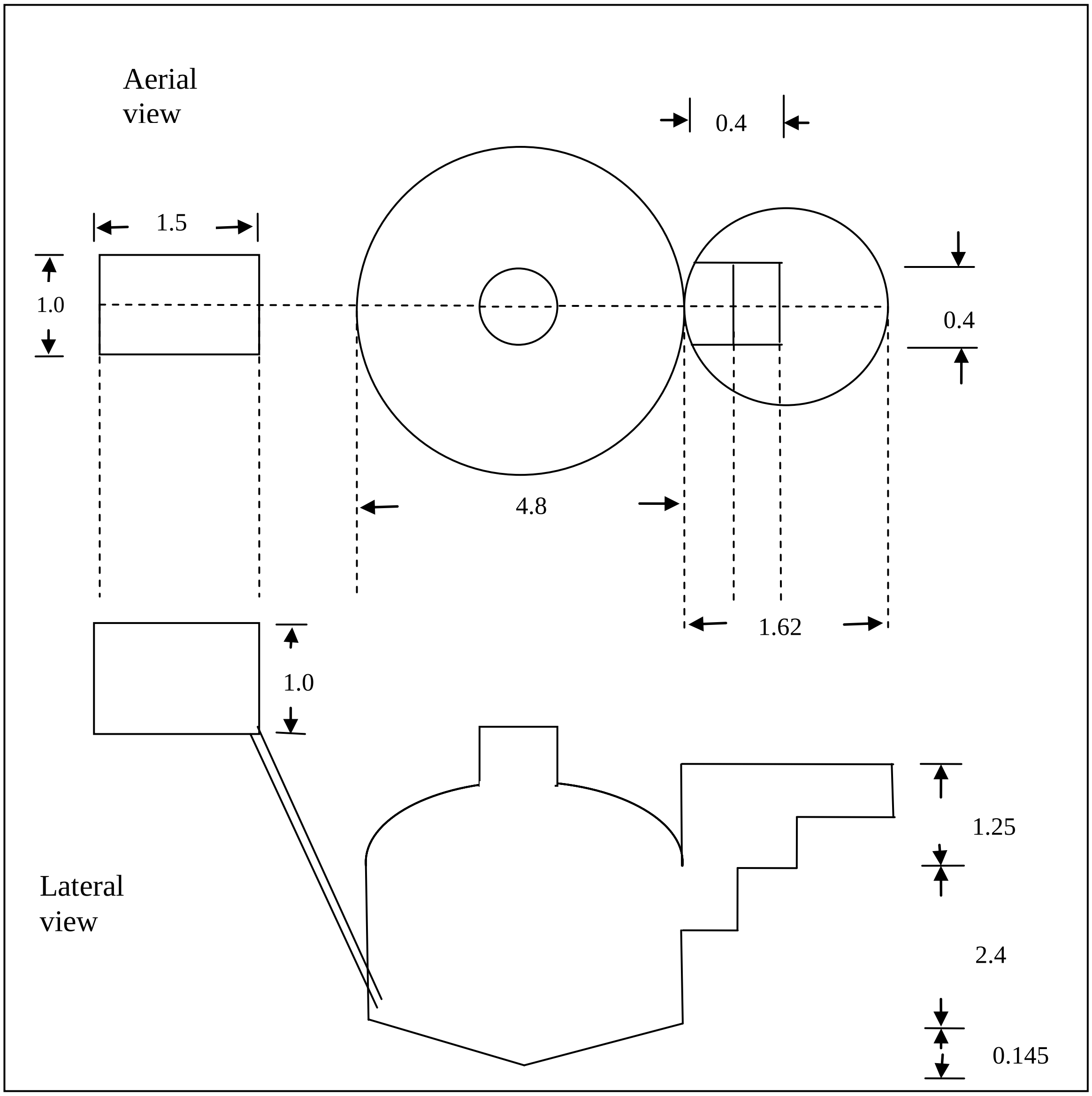


Fig. 3.4. Aerial and lateral view of the digester layout complete with inlet and expansion chamber (all dimensions are in metres)

Piping system

The type of pipe chosen for the piping is plastic pipe of polypropylene(PPR) because it is weather resistant, cheaper than metal, corrosion-free and light. To determine the size of the pipe the flow rate of biogas from the digester to the Hospital was identified. A straight path though the slaughterhouse plot would be chosen to avoid joints and thus reduce pressure loss.

The amount of biogas required to substitute 1kg of LPG is 2.1m^3. Each day, the Hospital requires 1kg of LPG on average for cooking. This translates to 2.1m^3 per day. Assuming that the cumulative amount of time the Hospital uses to do total cooking in a day is 6hrs, then the flow rate of the gas would be 2.1/6 = 0.35m^3/hr. The pipe recommended for this flow rate according to table 2.12 is 25mm diameter PPR pipe.

3.4. Bill of Quantities of the digester and piping

Table 3.1. Bill of quantities for the digester

BILL OF QUANTITIES FOR 44M^3 DIGESTER					
NO.	**ITEM DESCRIPTION**	**UNIT**	**QTY**	**PRICE PER UNIT**	**TOTAL COST**
Earth moving					
1	Excavation and backfilling for biogas plant	m^3	73	230	16,790.00
2	Trenching and backfilling for pipes	m	200	40	8,000.00
3	Landscaping				
Material					
4	Cement	50kg bags	77	720	55,440.00
5	Bricks for dome, 24x11x9cm, made on site	No.	1275	40	51,000.00
6	Ballast 6mm (1/4") for brick making	Tones	5	1500	7,500.00
7	River sand , washed	Tones	17	1800	30,600.00
8	Ballast 3/4"x1/2"	Tones	12	1300	15,600.00
9	Quarry stones 6"x9"	feet	675	17	11,475.00
10	Water proof additive	kg	14	150	2,100.00
11	Round bars R8 12m	pcs	16	820	13,120.00
12	Round bars R6 12m	pcs	6	610	3,660.00
13	Binding wire	kg	6	4200	25,200.00
14	Clay	Bucket 20ltrs	1		1,000.00
15	PVC pipe 4"	m	6	1600	9,600.00
16	PVC elbow, 4", 45^o	pcs	1	200	200.00
17	Nails 3"	kg	3	140	420.00

18	Nails 2"	kg	4	140	560.00
19	Coffee tray wire	m^2	1	250	250.00
20	Timber 6"x1"	feet	180	23	4,140.00
21	Timber 4"x2"	feet	120	40	4,800.00
22	Timber 2"x2"	feet	18	20	360.00
23	Plywood	pcs	4	600	2,400.00
24	Galvanized pipe, 1"	pcs	1	2,387.00	2,387.00
25	paint brush 6"	pcs	2	420	840.00
26	Wire brush	pcs	2	80	160.00
Gas Piping manhole					
27	PPR ball cock	pcs	2	950.00	1,900.00
28	PPR t-joint fitting with male thread	pcs	1	60.00	60.00
29	PPR cap and nipple	pcs	1	50.00	50.00
30	PPR elbow, 1", 45^{o}	pcs	4	60.00	240
Gas Piping to user point					
31	PPR pipe 25mm(1" x4m)	pcs	52	450.00	23,400.00
32	Manometer	pcs	1		5,000.00
Subtotal for materials					298,012.00
Labour(per day)		days	20	3,000.00	60,000.00
Sub total					**358,012.00**
10% contingency					**35,801.20**
Total					**393,813.20**

3.5 Electricity bills

Since the Hospital was not maintaining record specifically on energy used for cooking it was necessary to source for the data from elsewhere. Therefore electricity consumption for the period between January 1st 2013 and January 31st 2014 was obtained from KPLC (Table 4.1).

Using the consumption trend it was possible to determine the time that the Hospital stopped use of electricity for cooking.

4.0. RESULTS AND DISCUSSION

4.1. Sinai Hospital Energy consumption

Data obtained for electricity consumption between January 2013 and January 2014 was used to compute monthly average consumption and deviation from this average for each of the months considered. This was presented in form of a table (table 4.1). The first period had the months with positive deviations because the consumption was below the monthly average for each of the months. The second period had negative deviations for all the months because the consumption was more than the average monthly consumption for each of the months in the period.

Table 4.1. Electricity consumption for Sinai Hospital between Jan. 1st 2013 and Jan. 31st 2014

Month	Consumption (kWh)	Monthly average for the period (kWh)	Deviation from average (kWh)	Monthly bill (Ksh)
Jan-13	1153	1,018.50	134.50	22,644.92
Feb-13	1069	1,018.50	50.50	20,995.16
Mar-13	1184	1,018.50	165.50	23,253.76
Apr-13	1020	1,018.50	1.50	20,032.80
May-13	1158	1,018.50	139.50	22,743.12
Jun-13	1230	1,018.50	211.50	24,157.20
Jul-13	1478	1,018.50	459.50	29,027.92
Aug-13	1256	1,018.50	237.50	24,667.84
Sep-13	686	1,018.50	-332.50	13,473.04
Oct-13	705	1,018.50	-313.50	13,846.20
Nov-13	695	1,018.50	-323.50	13,649.80
Dec-13	745	1,018.50	-273.50	14,631.80
Jan-14	861	1,018.50	-157.50	16,910.04

From the electricity consumption trend of Sinai Hospital, there was a significant distinction between the period; January 2013 to August 2013 and September 2013 to January 2014.

This represented the two energy consumption patterns/energy sources that the Hospital used for cooking during the period.

The first period represented the time that the Hospital was using a combination of LPG and electricity while the second period represented the time the Hospital was using only LPG for cooking.

The monthly bills for the first period ranged between Ksh20,032.80 and Ksh29,027.92 . It was however noted that the consumption and the bill in the month of July 2013 was exceptionally higher than the rest of the months in the first period. This could therefore have contributed to the hospital's decision to stop use of electricity for cooking. After this high bill, it only took one more month and the consumption of electricity and bills fell sharply in the month of September 2013.

For the next consumption period the Hospital bills ranged between Ksh16,910.04 and Ksh13,473.04.

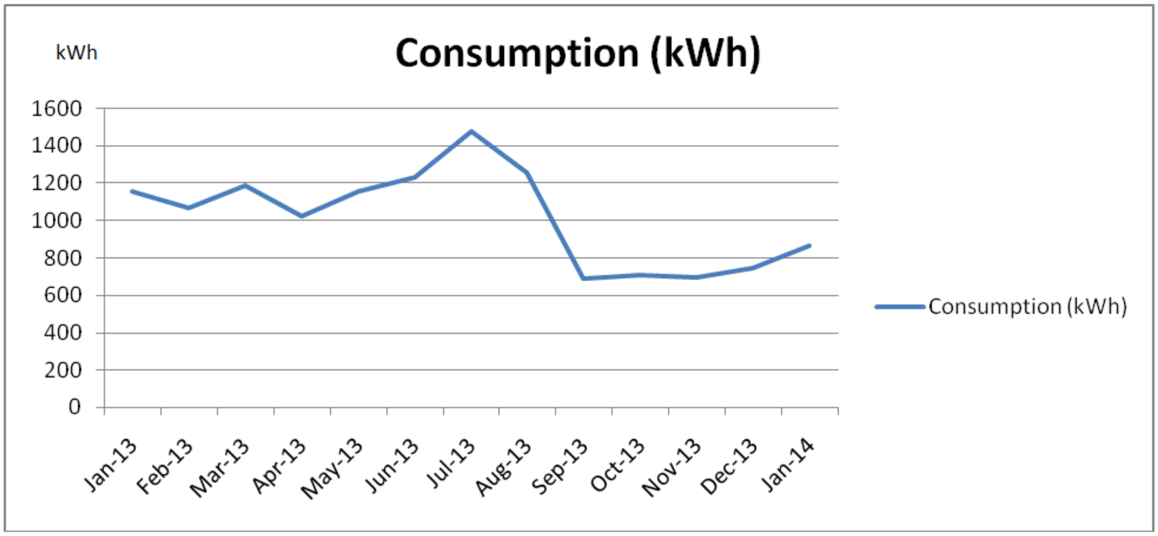


Fig. 4.1. Electricity Consumption(kWh) at Sinai Hospital between 1st January 2013 and 31st January 2014

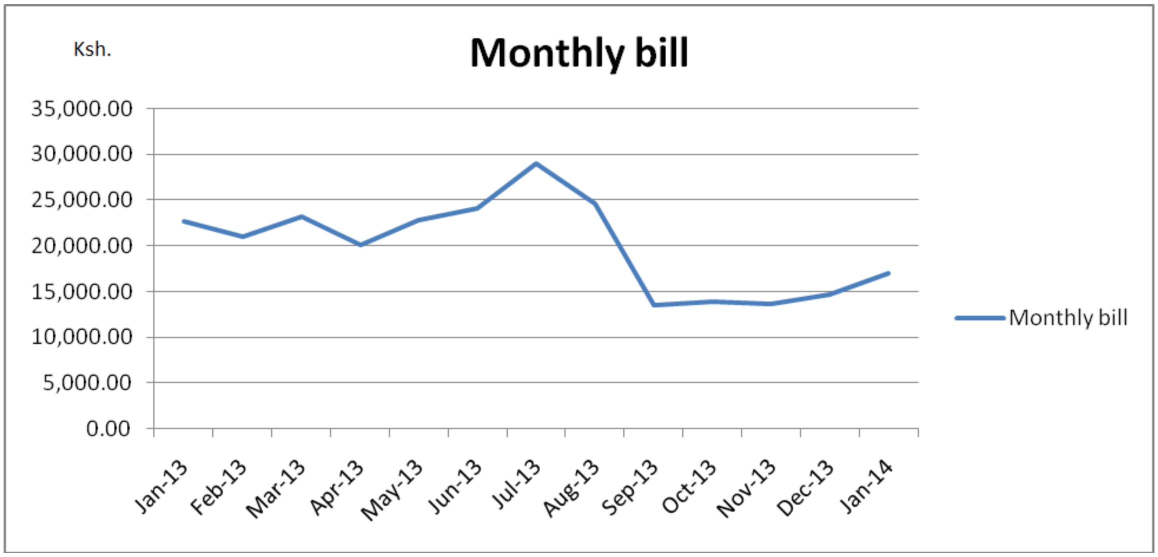


Fig. 4.2. Graph of bills for Sinai Hospital between January 1st 2013 and January 31st 2014

In order to be able to estimate the amount of electricity that the Hospital had been using for cooking, and that was later substituted with LPG, average consumption figures were used for three different periods.

- Average consumption for entire period evaluated.
- Average consumption for first period during use of energy mix of electricity and LPG.
- Average consumption for the second period during use of LPG only.

The monthly average consumption for the entire period evaluated (between January 2013 and January 2014) was computed as follows:

$$EMAC = (\text{Sum of } MC)/13 \text{ months} \qquad (4.1)$$

$$= 13{,}240.00/13$$

$$=1{,}018.5 \text{ kWh/month}$$

Where:

EMAC is Monthly average consumption for the entire period evaluated

MC is actual monthly consumption

The monthly average consumption for the first period (between January 2013 and August 2013) was computed as follows:

$$FMAC = (\text{Sum of } FMC)/8 \text{ months} \qquad (4.2)$$

$$=9{,}548/8$$

$$=1{,}193.5 \text{ kWh/month}$$

Where:

FMAC is Monthly average consumption for the first period

FMC is actual monthly consumption for the first period

The monthly average consumption for the first period (between January 2013 and August 2013) was computed as follows:

$$SMAC = (\text{Sum of } SMC)/5 \text{ months} \qquad (4.3)$$

$$= 3{,}692/5$$

$$= 738.4 \text{ kWh/month}$$

Where:

SMAC is Monthly average consumption for the second period

SMC is actual monthly consumption for the second period

From the computations above the summary of averages for the three periods is:

Entire period - 1,018.5 kWh /month

First period - 1,193.5 kWh /month

Second period - 738.4 kWh /month

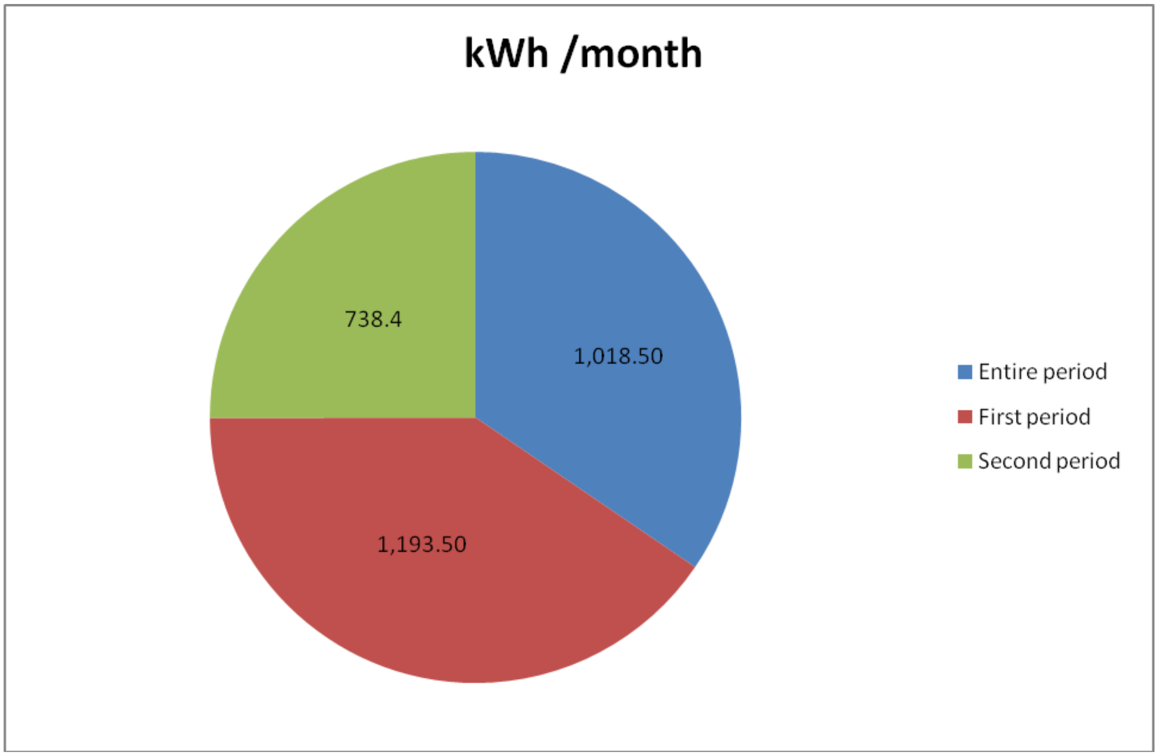


Fig. 4.3. Pie chart of bills for Sinai Hospital between January 2013 and January 2014

The difference between the average consumption for the first period and the second period was:

$$FMAC\text{-}SMAC \qquad (4.4)$$

$$=1{,}193.5-738.4$$

$$=455.1 \text{ kWh/month}$$

This difference of 455.1 kWh/month was concluded to be as a result of the Hospital having stopped usage of electricity for cooking.

To get the cost of electricity saving an average tariff of Ksh19.64/kWh was derived from monthly bills for the 13 month period evaluated.

$$\text{Cost of } 455.1 \text{ kWh/month} = 455.1\text{x Ksh}19.64\text{/kWh} \qquad (4.5)$$

=8,938.16

During the first period, the average consumption of LPG at Sinai Hospital for cooking was 1 cylinder of 15kg for 1.5 months. This was equivalent to 10Kg of LPG a month.

The amount of LPG used in the Hospital during the second period was 2 cylinders of 15kg monthly. Each cylinder cost an average of Ksh3,500, thus the amount of money the Hospital spent on LPG for cooking was:

Ksh3500x2

=Ksh7000/month.

The amount of LPG that was used to replace electricity for cooking was

30-10=20kg/month

Therefore the saving realized by substituting electricity with LPG was

Cost of electricity saving - Cost of 20kg/month

=8,938.16-(20/15x3500)

=8,938.16-4,666.67
=Ksh4,271.49/month

A summary comparing consumption of the two energy sources (electricity and LPG) for cooking during the two periods and their associated cost is shown in table 4.2.

Table 4.2. Consumption of LPG and Electricity for period 1 and 2

	period 1(Jan. -Aug. 2013)		**Period 2(Sept.- Jan.2014)**	
	Monthly consumption	Monthly cost(Ksh)	Monthly consumption	Monthly cost(Ksh)
LPG(kg)	10	2,333.30	30	7000
Electricity(kWh)	455.1	8,938.16	0	0
Total cost		11,271.46		7000
Monthly saving	**4,271.46**			
Annual saving	**51,257.52**			

4.2. Ongata Rongai slaughter house data

Ongata Rongai slaughterhouse operates between Mondays to Saturdays. Normally no slaughtering is done on Sundays.

The slaughterhouse is fairly busy because it serves the local market within Ongata Rongai.

The average number of animals slaughtered daily at the slaughterhouse was 10, 8.25 and 3.5 heads of cattle, goats and sheep respectively. The information obtained for the number of animals slaughtered daily for the month of February 2014 is presented in table 4.3.

Table 4.3. Number of animals slaughtered at Ongata Rongai slaughter house in February 2014

Day	**Date**	**Cattle (No.)**	**Goats (No.)**	**Sheep (No.)**	**Expected waste (kg)**	**Excess/ surplus of 439kg**	**Amount in the holding tank**
Saturday	01.02.2014	18	10	5	943.11	504.11	504.11
Monday	03.02.2014	9	12	4	512.61	73.61	577.72
Tuesday	04.02.2014	11	6	4	580.37	141.37	719.09
Wednesday	05.02.2014	5	8	4	299.81	-139.19	579.9
Thursday	06.02.2014	4	3	3	222.46	-216.54	363.36
Friday	07.02.2014	8	14	5	478.73	39.73	403.09
Saturday	08.02.2014	19	6	2	957.67	518.67	921.76
Sunday	09.02.2014	0	0	0	0	-439	482.76
Monday	10.02.2014	6	6	5	343.35	-95.65	387.11
Tuesday	11.02.2014	10	3	2	507.85	68.85	455.96
Wednesday	12.02.2014	14	3	5	715.82	276.82	732.78
Thursday	13.02.2014	3	11	1	203.07	-235.93	496.85
Friday	14.02.2014	10	10	6	560.98	121.98	618.83
Saturday	15.02.2014	19	0	1	923.86	484.86	1103.69
Sunday	16.02.2014	0	0	0	0	-439	664.69
Monday	17.02.2014	9	1	4	459.48	20.48	685.17
Tuesday	18.02.2014	4	13	0	256.27	-182.73	502.44
Wednesday	19.02.2014	3	10	5	217.56	-221.44	281
Thursday	20.02.2014	4	7	0	227.29	-211.71	69.29
Friday	21.02.2014	12	2	5	614.25	175.25	244.54
Saturday	22.02.2014	14	14	5	768.95	329.95	574.49
Sunday	23.02.2014	0	0	0	0	-439	135.49
Monday	24.02.2030	5	8	6	309.47	-129.53	5.96
Tuesday	25.02.2031	17	15	0	894.74	455.74	461.7
Wednesday	26.02.2032	7	6	6	396.55	-42.45	419.25
Thursday	27.02.2033	11	15	5	628.67	189.67	608.92
Friday	28.02.2034	18	15	1	947.94	508.94	1117.86
Total		**240**	**198**	**84**	**12,848.64**		
Average		**10**	**8.25**	**3.5**	**458.88**		

The total number of animals slaughtered for the month was 240, 198 and 84 for cattle, goats and sheep respectively.

Cattle slaughtered per day varied greatly depending on the day with Saturdays having more slaughters and Wednesdays and Thursdays having the least numbers. This is illustrated in the bar chart fig.4.3.

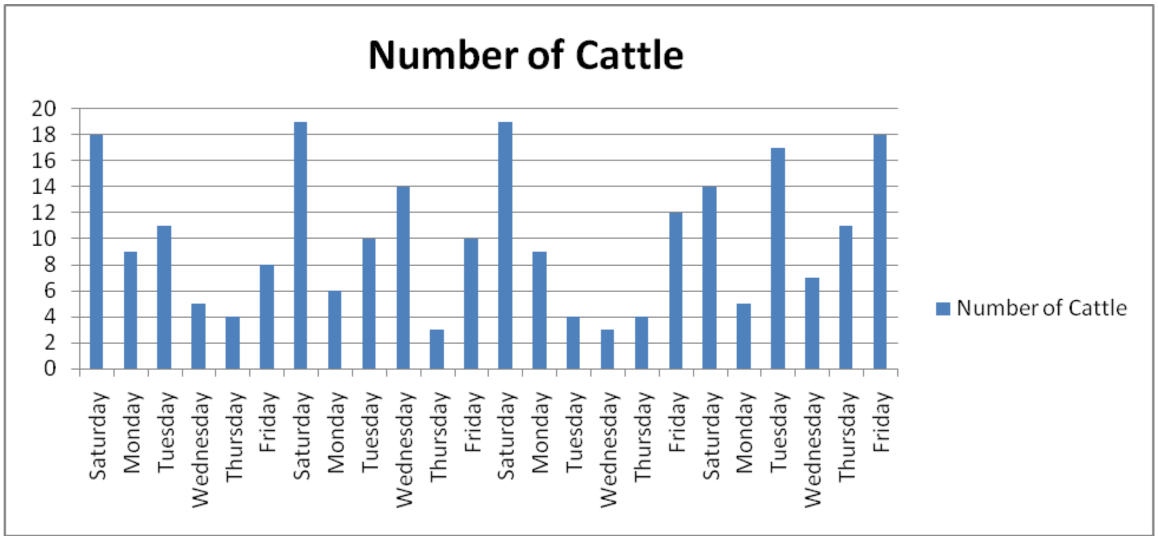


Fig. 4.4. Rate of slaughter at Ongata Rongai slaughter house in the Month of February 2014

4.3. Fuel substitution and tariff derivation

Fuel substitution

From table 2.14 the biogas expected per day from the 44m^3 digester is between 12m^3 and 18m^3. This comes to 16.5m$^{3/}$day by interpolation. The total amount of gas expected per month would be 495m^3. According to the literature reviewed (subtopic 2.9), for every kilogram of LPG, 2.1m^3 of biogas would be required for substitution. Sinai Hospital used 30kg of LPG a month (1kg of LPG per day) for cooking equivalent to 2.1m^3 of biogas per day. After supplying the hospital, there would remain a balance of 14.4m^3/day. Assuming that an ordinary family consumes one cylinder of 13kg LPG a month (0.433kg a day) on average, then the remaining biogas would be enough to supply to 33households in the neighbouring flats assuming no losses due to leakages and pressure drops.

Tariff derivation

If the slaughter house were to generate the biogas and not sell, the payback period for the digester based on the savings would be (Total investment)/(total savings in a year).

Total cost of the digester is Ksh393,813.20.

Savings per month for not using hired disposal services is Ksh5,600.00.

Payback period is 393,813.20/(5600x12)=5.86yrs.

Tariff for 5 years payback period

Payback period = (Total investment)/(total savings in a year + total income in a year)

5yrs = 393,813.20/(5600+monthly income)/12 (4.12)

5x12x(5600+monthly income) = 393,813.20

Monthly income = 393,813.20/(5x12) - 5600

=6,563.55-5600

= 963.55

The amount of biogas to generate this income in a month is 495m^3(from subtopic 4.6).

Therefore the tariff would be

963.55/495

= Ksh1.95/m^3.

Tariff for 2 years payback period

Payback period = (Total investment)/(total savings in a year + total income in a year)

2yrs = 393,813.20/(5600+monthly income)/12

2x12x(5600+monthly income) = 393,813.20

Monthly income = 393,813.20/(2x12) - 5600

=16,408.88-5600

= ksh10,808.88

The amount of biogas to generate this income in a month are 495m^3.

Therefore the tariff would be 10,808.88/495

= ksh21.84/m^3.

5.0. CONCLUSION

The results of the study showed that Ongata Rongai has an energy potential, of 495m^3/month of biogas. Since the cooking energy requirements of Sinai hospital is equivalent of 63m^3/month of biogas, the remainder would be enough meet cooking needs of 33households(assuming each household uses a 13kg LPG cylinder per month for cooking).

If the slaughter house, therefore, was to establish a biogas digester to handle the waste, It would require about ksh393,813.20 to construct the digester. This amount is recoverable within 2 years of providing the biogas to customers at a tariff of ksh21.84/m^3.

Biogas would be preferred as cooking energy for targeted users due to fair tariffs in comparison to LPG, and also due to being cleaner in comparison to charcoal.

With this venture, the slaughter house would minimize the cost of its waste disposal, generate some extra income. It would also maintain good environmental conditions within the slaughter house and its environs by curbing pollution. The land under soak pits together with the resulting fertilizer, in form of slurry, could also be utilized to grow vegetables or feedstock for animals awaiting slaughter.

To reap benefits from waste, it is recommended that the slaughter house adopts the proposal to generate biogas and sell to the hospital and the neighbourhood.

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