Sudan University of Science & Technology

College of Engineering

Department of Mechanical Engineering (Power)

PERFORMANCE ANALYSIS OF FLEX BAG ANAEROBIC DIGESTER

تحليل أداء هاضم لا هوائي من نوع الكيس المرن

A Project Submitted in Partial Fulfilment for the Requirements of B.Eng. Degree in Mechanical Engineering (Power)

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قال تعالى

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صدق الله العظيم

DEDICATION

Dedicated to the beloved Ummah

To the most precious persons in our life, our fathers, mothers and families.

ACKNOWLEDGEMENT

Thanks to ALLAH, the Most Gracious, the Most Merciful, the Most Bountiful who gave us the courage and patience to accomplish this research work. Without his help and mercy, this would not have come into reality.

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ABSTRACT

This study is aimed to assess the performance of flex bag digester according using different performance parameters; the capacity of the digester was 2000 Liters with working volume of 1500 Liters. The performance parameters assessed were technical performance parameters include temperature fluctuation, pH levels and gas production per kg of feedstock, operational performance parameters include cleanliness of the site and ease of use, economic performance parameters include investment cost, operational cost , and social, environmental parameters include stove and lamp use, and firewood saving. Two kinds of feedstocks were used in the study Cow dung feedstock and food waste feedstock with a dry matter of 20 percent and 50 percent respectively, the average feeding of cow dung feedstock was about 19kg per day, and 10 kg per day for the food waste feedstock. The retention time of the feedstocks was found to be 40 days and 30 days respectively, with potential gas production of 32 Liters per kg of cow dung and 194 Liters per kg of food waste. The absence of an inlet mixing tank at the inlet makes feeding it more cumbersome and also increases the likelihood of spillage of the mixture around the inlet of the biodigester. The produced biogas was used in cooking stove for cooking different types of food. It found that the consumption of biogas is proportionally changes with change of cooking time and the pressure inside the digester.

مستخلص

الهدف من هذه الدراسة هو تقييم أداء هاضم من نوع الكيس المرن بناء على اربعة عوامل اداء, سعة الوحدة هو 2000 لتر والحجم العامل فيها هو 1500 لتر. العوامل الاربعة التي قيم الهاضم بناء عليها هي, عوامل اداء تقنية والتي تتضمن حساسية التأثر بتراوح درجة الحرارة, معدل الحمضية والقاعدية ومعدل انتاجية الغاز لكل كيلوجرام من الخام المغذى. عوامل اداء تشغيلية وتتضمن, نظافة منطقة التشغيل وسهولة استخدام الوحدة, عوامل اداء اقتصادية وتتضمن التكلفة الابتدائة وتكلفة التشغيل, وعوامل اداء بيئية اجتماعية وتتضمن, كفاية الاستخدام في الموقد للطبخ والتقليل من استخدام الحطب. أستخدم نوعان من المواد للتغذية, روث الابقار ومخلفات الاغذية, بنسبة جفاف 20 بالمئة و 50 بالمئة على التوالي. متوسط التغذية اليومي لروث الابقار كان 19كيلوجرام ومتوسط تغذية مخلفات الاغذية 10 كيلوجرام, زمن الاحتفاظ والتكوين لروث الابقار قدر 40 يوم وزمن الاحتفاظ والتكوين لمخلفات الاغذية ب 30 يوم بمعدل انتاجية قدره 32 لتر لكل كيلوجرام من روث الابقار و 134 لتر من مخلفات الاغذية. لوحظ أن عدم وجود مدخل واسع لتغذية الهاضم يؤدي الي تدفق الخليط حول جوانب المدخل مما يتطلب النظافة الفورية منعاً للتلوث. تم إختبار أداء الوحدة لاغراض الطبخ لعدة انواع من الوجبات ووجد أن إستهلاك البايوغاز يتناسب طردياً مع زمن الطبخ وضغط الغاز في الهاضم.

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LIST OF ABBREVIATIONS

AD	Anaerobic Digestion
LPG	Liquefied Petroleum Gas
CH_4	Methane
CO_2	Carbon Dioxide
TS	Total Solids
VS	Volatile Solids
HTR	Hydraulic Retention Time
PUF	Plant Utilization Factor
RMP	Red Mud plastic
PVC	Polyvinyl Chloride
H_2S	Hydrogen Sulphide
H_2	Hydrogen
H_2O	Water Vapour
€	Euro
USD	United States Dollar
pH	Acidity or Alkalinity Number
VFA	Volatile Fatty Acid
FYM	Farm Yard Manure
PV	Photovoltaic
SNV	Netherlands Development Organization
NDBP	National Domestic Biogas Program
GOR	Government of Rwanda
BD	Biodigester
FDBD	Fixed Dome Biodigester
FGBD	Fiber glass Biodigester
FBBD	Flexible Bag Biodigester
URCST	University of Rwanda- College of Science and Technology
NPK	Nitrogen, phosphorus and potassium
REGEDCL	Rwanda Energy Group-Energy Development Corporation Limited
SUST	Sudan University Of Science & Technology

Chapter1

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Production of biogas through anaerobic digestion (AD) of animal manure and slurries as well as of a wide range of digestible organic wastes is seen as one good option, as it converts these substrates into renewable energy, and as a by-product produces a natural fertilizer for agriculture [1]. The technology for small household-scale anaerobic digesters is proven and used around the world. Some countries leading in this are China, India, Nepal, Vietnam and Indonesia. Biogas is also a major source of renewable energy in Europe and the USA. In Africa, the dissemination of biogas digesters has been done in many countries, including Kenya, Uganda, Cameroon, Mali and Ethiopi. For Sudan, It has been estimated that up to a million small and larger anaerobic digesters could be installed and used, but a number of things need to be in place. One of the most important of these is to have a design of small biogas digester that is cheap, simple, tough, efficient, and able to be made within Sudan. For all of these possibilities the first requirement is that the design, manufacture and installation are done to a high standard.

1.2 Project background

Biomass presently provides up to 61% of Sudan's energy requirements, mostly as a source of heat energy but also as a growing production of electricity and of transport biofuels. It is clear that there is great scope to increase the production of all three forms of energy from the various types of biomass (also called 'feed stocks') that are economically and sustainably available in Sudan. However while biomass used to provide energy for cooking and industrial heat (i.e., for brick making and baking) was and still is largely through use of more inefficient methods of conversion of biomass, the technologies increasingly used from now on would be of the more modern and efficient types and utilizing other biomass feed stocks than wood and charcoal.

1.3 Problem Statement

Sudan has a real need for development of new alternatives for cooking fuels for rural households and remote townships. The cost of wood and charcoal continues to rise, woodlands are cut for production of fuel when this means top soil become more likely to blow away or be washed away, and bottled gas has a rising cost and can be unobtainable for many households. But there is a cheap, sustainable and effective fuel that uses wastes like livestock manures, from food preparation and from animal slaughtering. The biogas produced from animal manures can produce enough biogas for a family for cooking all meals of the day, and possibly some also for lighting.

1.4 Project Aim and objectives

This projects aims to assess and analyze the performance of flex bag biodigester currently introduced to the market in Sudan, the specific objectives are summarized in:

- To assess the technical performance parameters, which include: sensitivity to temperature fluctuations, pH levels, and daily biogas production per unit of feedstock.
- To assess the operational performance parameters, which include: ease of use and cleanliness of the site.
- To assess the economic performance, which include: proportion of cooking requirements met, use of biogas on fuel wood savings, and the overall investment cost and operational cost.

1.5 Project Scope

The scope of this project is limited to flex bag plug flow design of biogas digester with size of 2 m3. The feedstock used is cow dung and food waste.

1.6 Project Significance

Household biogas digesters could be of particular importance for some parts of Sudan and details what is required of the householder in order that the system works effectively. In doing this it will rapidly begin to save the family money otherwise spent purchasing cooking fuels, it will mean smoke-free cooking, and it will mean the trees and bushes in the area do not need to be cut down for fuel but can continue to provide shade and shelter from wind. It will also mean that the women and girls, instead of spending time gathering fuel, can do other things. A larger digester can serve more than one house and in some countries it is normal that a small village will use piped biogas coming from one community digester. Lighting for a shop or health care clinic or school could also use biogas, and biogas can run refrigerators in a shop or the clinic. Biogas can be used to run a motor for pumping water or generating electricity.

1.7 Project Layout

This research is divided into five chapters. Chapter 1 addresses the general background, declaration of the problem statement and discussion of the objectives. Chapter 2 presents the literature survey; with focus on biogas and its process, technologies and application. This chapter also reviews the previously published works of researchers related to this study. Chapter 3 explains the methodology by detailing the experimental procedure and equipment used. Chapter 4 is showing the results obtained from the experimental work followed by discussion and analysis of the findings and comparing them with the existing results included in the literature. Chapter 5 is the Conclusion. It contains the theoretical and practical contribution of this study, followed by recommendations for future work.

Chapter2

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Literature review presents the critical past works related to the project work sorted out from international journals publications, conferences publications, reports and books. It provides an insight understanding about related issues on project topic. The review also reveals the limitations encountered in the project area. This chapter presents a detailed literature review with aim to present a general overview of the performance evaluation of biodigesters.

2.2 Definition of Biogas

Biogas is a gas produced through the digestion of organic materials in anaerobic conditions by specific bacteria, called methanogenic bacteria, or methanogens [1]. Biogas at various concentrations is produced naturally in swamps, in animal and human digestive systems (particularly with ruminant animals like sheep, goats and cows) and in wastewater [2]. Biogas is mainly composed of 50 to 70 percent methane (CH_4), 30 to 40 percent carbon dioxide (CO_2) and low amounts of other gases [3, 4].

2.3 Composition of Biogas

Biogas is an odorless and colorless gas that burns with a clear blue flame similar to that of natural gas or LPG but with high methane and low hydrogen sulphide (H_2S) levels [4]. It is about 20 percent lighter than air and has an ignition temperature in the range of 650°C to 750°C [4]. Table 2.1 shows the composition of biogas.

Table 2.1: Composition of biogas [5]

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

2.4 Production of Biogas – The Anaerobic Digestion

The biogas is produced through anaerobic digestion (AD) which is a microbiological process of decomposition of organic matter in absence of oxygen. The main products of this process are biogas and digestate. Biogas is a combustible gas, consisting primarily of methane and carbon dioxide, while the digestate is the decomposed substrate, resulted from the production process [5]. During AD, very little heat is generated, in contrast to aerobic decomposition (in presence of oxygen), as in the case of composting. The resulting energy carrier of methane energy is produced when the chemical bonding the substrate is changed during the complex biochemical processes during anaerobic digestion [5].

The process of biogas formation is a result of series of process steps, in which the initial material is continuously broken down into smaller units. Specific groups of micro-organisms are involved in each individual step. These organisms successively decompose the products of the previous steps. The simplified diagram of the AD process, shown in Figure 2.1, highlights the four main process steps which are hydrolysis, acidogenesis, acetogenesis, and methanogenesis [5, 6]. The first stage is the depolymerisation of organic matter. During hydrolysis complex insoluble substrate such as polysaccharides are hydrolyzed into smaller units by a large number of hydrolytic microorganisms (Clostridia, Micrococcus, Bacteroides, Butyrivibrio, Fusobacterium, Selenomonas, Streptococcus) secreting different hydrolyzing enzymes such as cellulose, cellobiase, xylanase, amylase, protease, lipase [7].

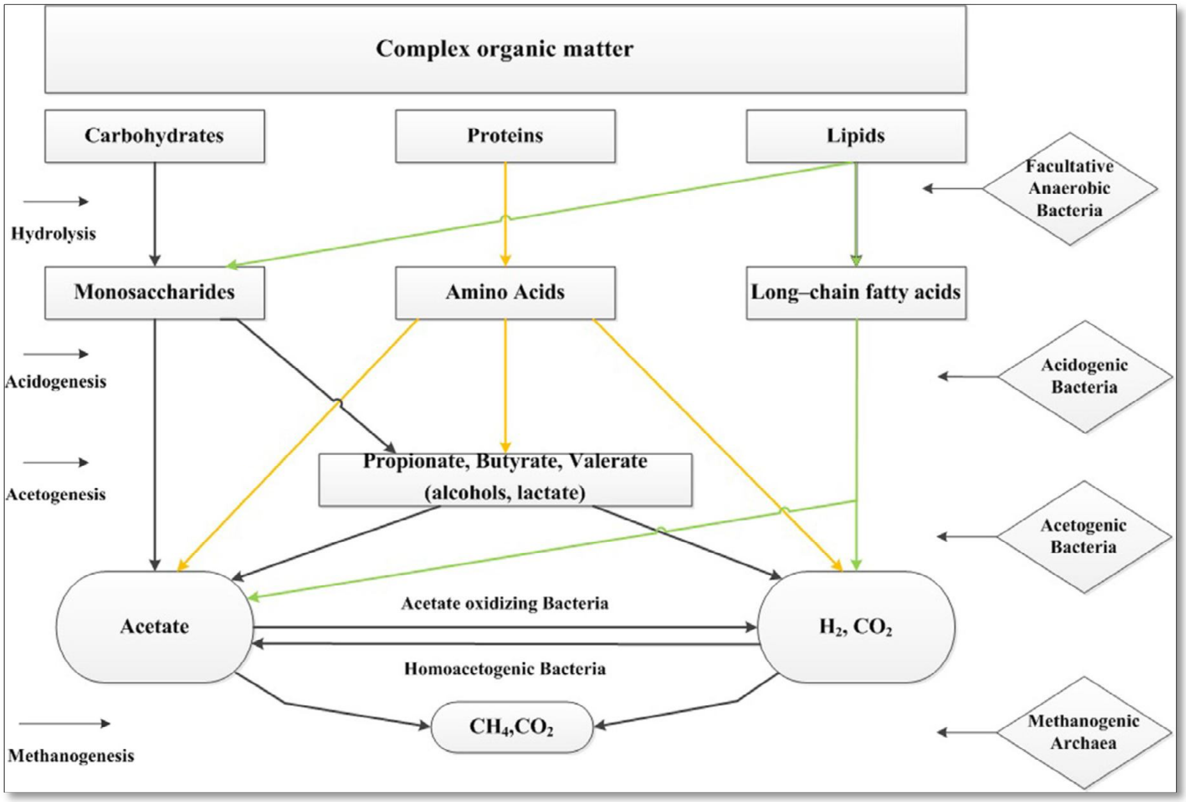

Figure 2.1: Schematic representation of anaerobic decomposition. [8]

Hydrolytic reactions comprise two phases, force by extracellular enzymes secreted by bacteria which are obligate or facultative anaerobes. In the first phase a bacterial colonization takes place where the hydrolytic bacteria cover the surface of solids .Bacteria on the particle surface release enzymes and produce monomers which can be utilized by the hydrolytic bacteria themselves, as well as by the other bacteria. In the second phase the particle surface will be degraded by the bacteria at a constant depth per unit of time [9].

The second step is acidogenesis; Hydrolytic and acidogenic microorganisms are growing about ten times faster than methanogens .Acidogenesis is usually the fastest reaction in the anaerobic conversion of complex organic matter in liquid phase digestion [10]. During acidification of sugars, long chain fatty acids and amino acids resulting from hydrolysis are used as substrate for fermentative microorganisms (Streptococcus, Lactobacillus, Bacillus, Escherichia coli, Salmonella) to produce organic acids ,such as acetic ,prop ionic ,butyric and other short-chain fatty acids, alcohols, H2 and CO2 or by anaerobic oxidizers [11,12].

The third step is acetogenesis; Acetogenic bacteria are strict anaerobes, have optimum pH around 6 and isolated mostly from anoxic habitats and utilize a pathway (the acetyl coenzyme path way) that contain enzymes extremely sensitive to O2 [13]. They are slow growing, sensitive to fluctuations in organic loadings and environmental changes, they require long lag periods for adjust to new environmental conditions [14]. Increasing hydrogen concentration in the liquid will lead to accumulation of electron sinks (lactate ethanol, propionate, butyrate and higher volatile acids) which cannot be consumed directly by the methanogens and should be degraded further by the obligate hydrogen producing acetogenic bacteria and the process is referred to as acetogenesis [15]. The obligate hydrogen producing acetogenic bacteria (Syntrophomonas wolfeii, Syntrophobacter wolinii) degrade the electron sinks to acetate, carbon dioxide and hydrogen. This transition is important for the successful production of biogas [16]. Acetogenesis make syntrophic associations with hydrogen-consuming methanogens because they depend on low hydrogen partial pressure for their degradation.

The last step is Methanogenesis; the production of methane and carbon dioxide from intermediate products is carried out by methanogenic bacteria. 70% of the formed methane originates from acetate, while the Remaining 30% is produced from conversion of hydrogen (H) and carbon dioxide (CO2), Methanogenesis is a critical step in the entire anaerobic digestion process, as it is the slowest biochemical reaction of the process. Methanogenesis is severely influenced by operation conditions. Composition of feedstock, feeding rate, temperature, and pH are examples of factors influencing the methanogenesis process. Digester overloading, temperature changes or large entry of oxygen can result in termination of methane production [6].

2.4.1 Substrates for Anaerobic Digestion

A wide range of biomass types can be used as substrates (feedstock) for the production of biogas by AD. These include:

- Animal manure and slurry.
- Agricultural residues and by-products (usually of high moisture content).
- Digestible organic wastes from food and agri-industries (vegetable and animal origin).
- Organic fraction of municipal waste and from catering (vegetable and animal origin).
- Sewage sludge.
- Dedicated energy crops (e.g. maize, miscanthus, sorghum, clover).

Table 2.2 shows Technical parameters of the most important feed stocks, while Table 2.3 shows approximate figures for the amount of biogas that can be produced from different substrates.

Table 2.2: Technical parameters of the most important feedstock for anaerobic digestion [17]

Feedstock	Total Solids TS (%)	Volatile Solids (% if TS)	Biogas Yield (m3/kg VS)
Pig Slurry	3 – 8 d	70 – 80	0.25–0.50
Cow Slurry	5 – 12 d	75 – 85	0.20–0.30
Chicken Slurry	10 – 30 d	70 – 80	0.35–0.60
Whey	1 – 5	80 – 95	0.80–0.95
Leaves	80	90	0.10–0.30 b
Straw	70	90	0.35–0.45 e
Wood Wastes	60–70	99.6	n.a.
Garden Wastes	60 – 70	90	0.20–0.50
Grass	20 – 25	90	0.55
Grass Silage	15 – 25	90	0.56
Fruit Wastes	15 – 20	75	0.25–0.50
Food Remains	10	80	0.50–0.60

b depending on drying rate ;d depending on dilution; e depending on particle size; n.a.= not available

Table 2.3: Amount of gas yields from different substrates [18]

Raw material		Methane production (m^3/ton Dry weight)	Methane production (m^3/ton fresh weight)
Liquid manure (cows)		156	14
Liquid manure (pigs)		225	18
Slaughterhouse waste	(Stomach Contents)	300	45
	Sludge from slaughterhouse waste treatment plants	338	54
	Soft parts (fat, intestine, etc.)	633	190
Source-sorted food waste	Households	433	130
	Restaurants	440	110
	Wholesale/retail	427	64

2.4.2 Loading Rate

Loading rate is the amount of raw materials fed per unit volume of digester capacity per day. If the plant is overfed, acids will accumulate and methane production will be inhibited. Similarly but for different reasons, if the plant is underfed, the gas production will also be low [19].

2.4.3 The Inlet (Collection Tank)

The inlet serves as the collection tank of the manure. It can either be circular or Rectangular in shape. It is divided into two compartments, namely: the collection compartment and the inlet compartment. The collection compartment is directly connected to the canal system of the animal pen. It collects the manure and serves as a Sedimentation tank where foreign matters which are non-biodegradable like sand, hair, etc. could be collected to avoid its entry to the digester. The inlet compartment is connected to the digester through an inlet pipe which then conveys the slurry to the digester. The inlet should be provided with cover to avoid the entrance of rainwater and for safety purposes [20].

2.4.4 Biodigester

The Biodigester is a physical structure, commonly known as the biogas plant. Since various Chemical and microbiological reactions take place in the Biodigester, it is also known as bioreactor or anaerobic reactor. The main function of this structure is to provide an anaerobic condition within it. As a chamber, it should be air and water tight. Construction of this structure forms a major part of the investment costs for a biogas plant [19].

2.4.5 Retention Time

Retention time (also known as Hydraulic retention Time, HRT) is the average period that a given quantity of input remains in the digester to be acted upon by the methanogens. The theoretical retention time is calculated by dividing the average slurry holding volume of the digester by the volume of daily added substrate added daily. Depending on the vessel geometry, the means of mixing, etc., the effective retention time may vary widely for the individual substrate constituents. Selection of a suitable retention time thus depends not only on the process temperature, but also on the type of substrate used. In general the optimum retention time can vary between 30 and 100 days. For a night soil biogas digesters the retention time is extended with another 10 days so that the pathogens present in human faeces are largely destroyed [19].

2.4.6 The Outlet Chamber

The outlet chamber serves as the hydraulic tank which maintains the pressure of the biogas inside the gas storage. It can either be circular or rectangular in shape. The Chamber is provided with discharge outlet where sludge or effluent can be collected [20].

2.4.7 Bio slurry

After extraction of biogas (energy), the slurry (also known as effluent) comes out of digester as by-product of the anaerobic digestion system. It is almost pathogen-free stabilized manure that can be used to maintain soil fertility and enhance crop production. Slurry is found in different forms inside the digester as mentioned below:

– A light rather solid fraction, mainly fibrous material, which floats on the top forming the Scum.

– A very liquid and watery fraction remaining in the middle layer of the digester.

– A viscous fraction below which is the real slurry or sludge; and

– Heavy solids mainly sand and soil that deposit at the bottom.

There is less separation in the slurry if the feed materials are homogenous. Appropriate ratio of urine, water and excrement and intensive mixing before feeding the digester leads to homogeneous slurry [19].

2.5 Biodigester designs

Biodigester provide an energy alternative to burning wood, charcoal and dried animal dung for fuel and can be used for the treatment of human waste. Suitable feedstocks include non-fibrous plant materials, food waste, and most types of animal dung. Millions of biogas systems have been constructed in the developing world for treating organic waste and providing a clean alternative energy supply for cooking instead of traditional biomass burning, leading to an overall improvement to human health and the environment. A number of factors need to be considered prior to installing a biogas system, especially regarding the digester size and the location. Quality installations require sound design and adherence to the correct construction methods, strongly influencing the level of success of the biogas system [21].

There are many different types, sizes and designs for AD that are used to produce biogas and fertilizer depend on the way of construction and the abundance of biodegradable materials. Design of the digesters is varied based on the geographical location, availability of substrate, requirement for daily gas volume and climatic conditions. For tropical countries, it is preferred to have digesters underground due to the higher air temperature [22]. Some of the commonly used designs are discussed below.

2.5.1 Fixed Dome Digester ''Chinese Design''

The fixed dome or Chinese type is an underground reactor of typically 6 to 8 m^3 (Figure 2.2). It may be supplied with household sewage, animal manure and organic household waste. The reactor is operated in a semi-continuous mode, where new substrate is added once a day and a similar amount of digestate liquid is removed once a day. The reactor is not stirred, so, for substrates with higher cellulose or dirt content, the sediment solids may need to be removed 2-3 times per year. On this occasion a large portion of the sediment and any undigested material is removed and a small part (about one fifth of the reactor content) is left as an in oculum for the refilled digester [6].

The size of a fixed dome digester depends on the location, number of households (so amount of biogas production needed), and the amount of substrate available every day. For instance, the size of these digesters can typically vary between 4 and 20 m^3 in Nepal, between 6 and 10 m^3 in China, between 1 and 150 m^3 in India and in Nigeria it is around 6m^3 for a family of 9. Instead of having a digester for each individual home, a large volume digester can be used to produce biogas for 10 – 20 homes, and is then called a community biogas digester. In countries where houses are clustered together, as in Nigeria, these types of biogas digesters are more feasible [22, 23, 24].

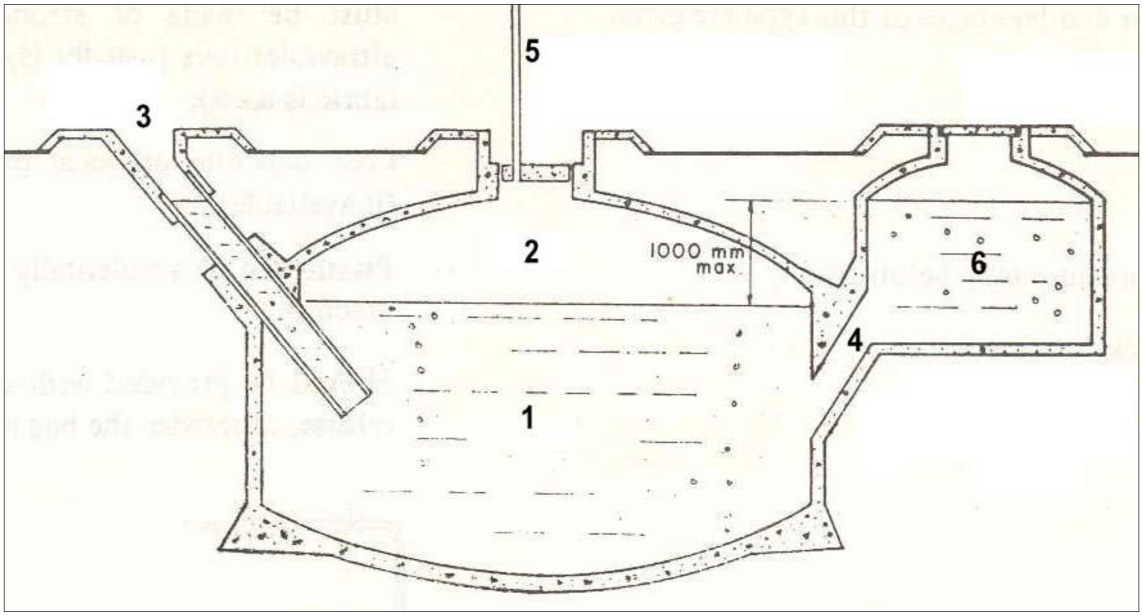

Figure 2.2: Fixed dome plant design [19]

1. Digester part. 2. Gas holding part 3.Inlet. 4. Manhole. 5. Gas pipe. 6. Outlet chamber also called compensation chamber.

2.5.2 Floating Drum Digesters ''Indian Design''

The Indian type illustrated in Figure 2.3 is similar to the Chinese type in that it is a simple underground reactor for domestic and small-scale farming waste. The difference is that the effluent is collected at the bottom of the reactor and a floating gas bell functions as a biogas reservoir [6]. The average size of these kinds of digesters is around 12 m^3. For small-medium size farms the size varies from around 5–15 m^3. Singh and Gupta compared 14 different biogas plants with a floating drum model. The size of each digester was about 85m^3. The ratio of the waste fed to the plant in one day to the capacity of the plant is called plant utilization factor (PUF), and it was found to be 0.36. This result suggests that the full capacity of the plant was not utilized [22].

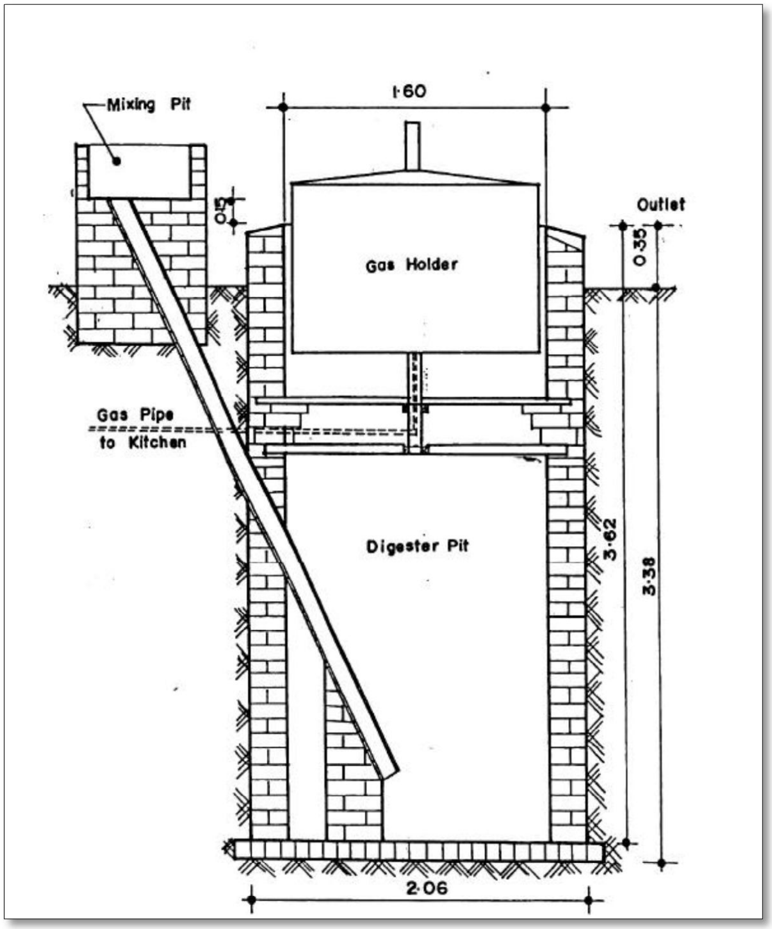

Figure 2.3: Schematic sketch of a floating drum digester [22]

2.5.3 Plastic tank digester

This technology is mainly composed of two pre-built rigid plastic tanks as shown in Figure 2.4. The first tank is for the digestion of organic materials, while the second tank is for the storage of the biogas that is produced. This technology is thus rather easy to install. The tanks are usually not underground, hence potentially damageable. This digester is derived from water tank technologies. Typical volumes are 1.8 m3 for the digester tank and 1.5 m3 for the gas storage tank. A lifespan of 20 years can consequently be expected by analogy with water tanks. However, it must be noted that the number of plastic tanks digesters currently installed is very low [1].

Figure 2.4: Plastic tank digester [1]

2.5.4 Plug Flow Digesters

The disadvantage with the fixed dome and floating drum models is, once installed they are impossible to move. Hence, portable models built mainly above the ground including the so-called tubular or plug flow digesters were developed as shown in Figure 2.5 [22]. Plug flow digesters have a constant volume, but produce biogas at a variable pressure. The size of such digesters usually varies from 2.4 to 7.5 m^3. Plug-flow digesters consist of a narrow and long tank with, an average length to width ratio of 5:1. The inlet and outlet of the digester are located at opposite ends, kept above ground, while the remaining parts of the digester is buried in the ground in an inclined position. As the fresh substrate is added from the inlet, the digestate flows towards the outlet at the other end of the tank. The inclined position makes it possible to separate acidogenesis and methanogenesis longitudinally, thus producing a two-phase system. In order to avoid temperature fluctuations during the night and maintain the process temperature, a gable or shed roof can be erected above the digester to cover it, which acts as an insulation both during day and night [22].

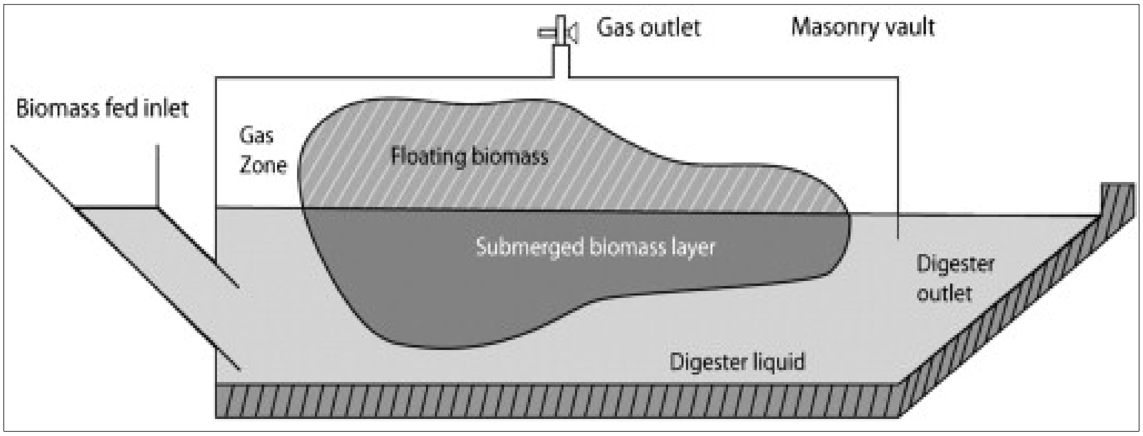

Figure 2.5: Schematic sketch of a plug flow digester [22].

2.5.5 Flexible Bag Digester (Taiwanese)

The Taiwanese bag digester shown in Figure 2.6 was developed in the 1960s and is a cheaper form of plug flow digester. It is a flexible bag made of plastic, for instance Red Mud plastic (RMP), or flexible PVC. It is a popular design in especially Central and South America [22].

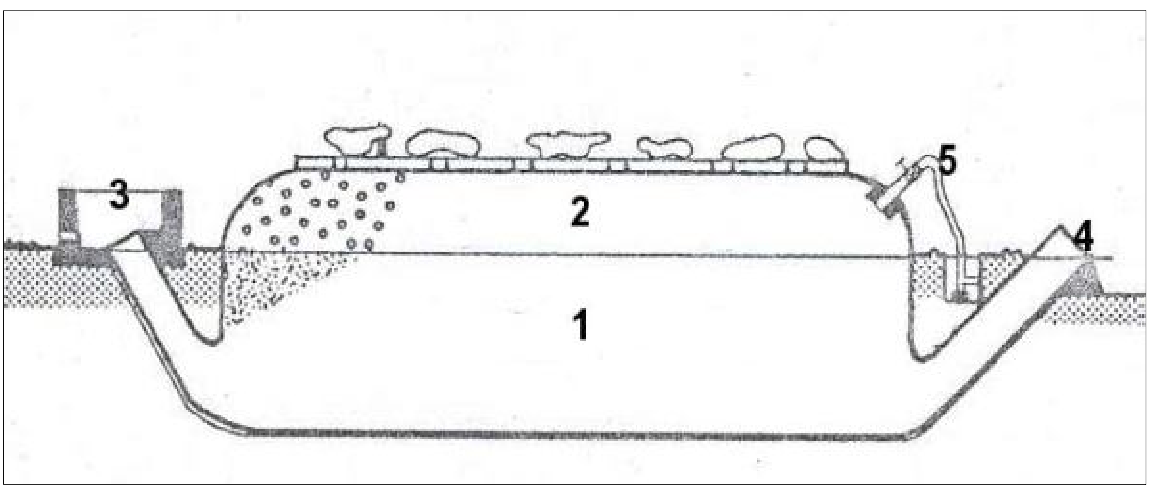

Figure 2.6: Taiwanese bag digester [22]

1. Digester part 2. Gas holding part 3. Dung inlet 4. Slurry outlet 5. Gas outlet pipe

Advantages and disadvantages of different types of biogas digesters are shown in Table 2.4.

Table 2.4: Pros and Cons of Four different types of domestic biogas plants [25]

Technology	Pros	Cons
Fixed dome technology (Analysis based on the Rwanda design)	• Long lifespan: more than 20 years. • Not damageable (underground). • Many references (e.g. 2,700 units in Rwanda, 250,000 units in Nepal for other fixed dome technologies). • Easy to operate. • Job creation.	• Expensive technology • Between € 670 and €1150 (USD 870-1500). • Potentially long interval before the start-up of the biogas production (depending on filling rate).
Floating drum digester	• Provides constant gas pressure at outlet. • Visual indication (floating gasholder level above the pit) of the amount of available gas.	• Very expensive compared to fixed dome digesters. • Steel drum (gasholder) is subject to corrosion. • Lower lifespan than fixed dome technology
Plastic tube digester	Inexpensive technology: Between € 100 and € 150 (USD 130-200).	• Very easy to damage. • Short lifespan: 4 years max. • Relatively few successful installations. • Not very easy to operate. • Dismantling and recycling of the unit
Plastic tank digester	• Easy installation. • Quick biogas production start-up after installation (3-4 days). • Small digester tank volume, therefore appropriate for limited livestock manure volume/day.	• Expensive technology approximately € 740 (USD 960) for the 1.8 m3 model. • Potentially damageable (not underground). • Small digester volume available, hence low biogas production. • No employment creation. • Few existing installations, hence little feedback • Dismantling and recycling of the unit.

The produced gas depends on daily feeding and type of feedstock used. This point is illustrated in Table 2.5.

Table 2.5: Daily feeding, gas production and fuel wood equivalent per plant volume [26]

Digester size (m^3)	**Daily dung feeding (Kg)**	**Daily gas production (m^3)**	**Biogas stove (hrs/day)**	**Fuel wood replacement value (kg)***
4	20 to 40	0.8 to 1.6	3.5 to 4	4 to 8
6	40 to 60	1.6 to 2.4	5.5 to 6	8 to 12
8	60 to 80	2.4 to 3.2	7.5 to 8	12 to 16
10	80 to 100	3.2 to 4	9.5 to 10	16 to 20

** Based on a commonly used, low tech wood stove with 10% efficiency rate. 1 m^3 biogas will replace about 5 kg of fuel wood.*

2.6 Biogas Stoves

A biogas stove is a relatively simple appliance for direct combustion of biogas. Its burner is premix and multi-holed burning ports type, operating at atmospheric low pressure. A typical biogas stove consists of gas supply tube, gas tap/valve, gas injector, primary air hole(s) or regulator, nozzle or throat, gas mixing tube/manifold, burner head, burner ports, pot supports and body frame Assembly of a typical biogas burner is shown in the figure below.

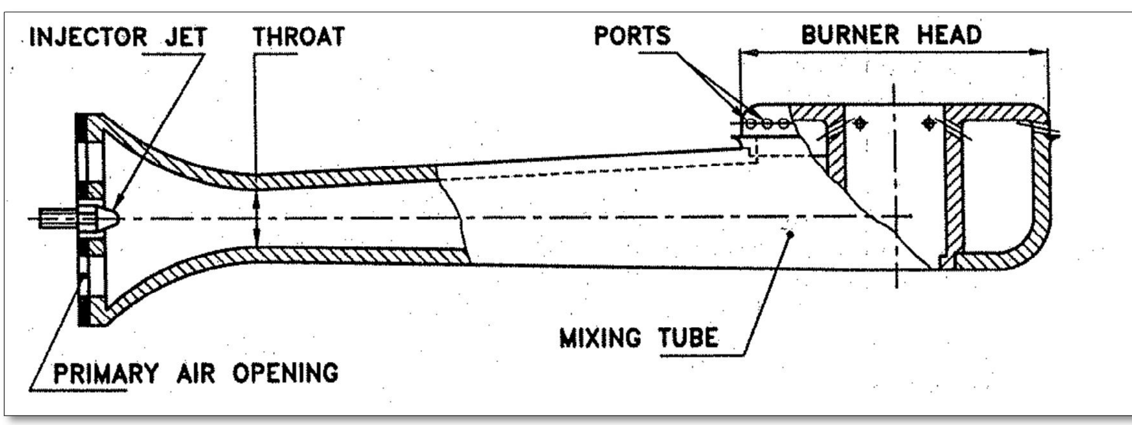

Figure 2.7: Assembly of a typical biogas burner [19]

Biogas reaches with certain speed at the stove, depending upon the gas pressure in the pipeline of a certain diameter from the biogas plant. With the help of an injector jet at the inlet f the stove, the speed is increased to produce a draft to suck primary air. The gas and air get mixed in the mixing tube and the diffused gas mixture goes into the burner head. The cone of the diffuse and the shape of the burner head are formed in such a way as to allow the gas pressure to equal everywhere before the mixture of gas and air leaves the burner through the orts (orifices) with a speed only slightly above the specific flame speed of biogas. For the complete combustion of biogas, more oxygen is drawn from the surrounding air, called secondary air [19].

2.7 Biogas a Lamps

In villages without electricity, lighting is a basic need as well as a status symbol. Therefore provision of biogas lamps will often be an imported part of a biogas programme and a strong motivation for a farming family to install a plant. However, biogas lamps are not very Energy efficient. This means that they, besides light, also generate a lot of heat [19].

The bright light of a biogas lamp is the result of incandescence, i.e. the intense heat-induced luminosity of special metals, so-called "rare earth" like thorium, cerium, lanthanum, etc. at temperatures of 1000-2000°C. If they hang directly below the roof, they can cause a fire hazard. It is important that the gas and air in a biogas lamp are thoroughly mixed before they reach the gas mantle and that the air space around the mantle is adequately warm [19].

The mantle of a biogas lamp resembles a small net bag. A binding thread made of ceramic fiber Thread is provided for tying it onto the ceramic head. When heated at a temperature of more than1000oC, the mantle glows brightly in the visible spectrum while emitting little infrared radiation. Fabric of the mantle, when flamed for the first time, burns away, leaving a residue of metal oxide. Therefore the mantle shrinks and becomes very fragile after its first use. In general the mantles do not last long because of insect damage and high gas pressure, regular maintenance and mantle change is needed [19].

Since thorium is radioactive material it should be handled with utmost care. The particles from thorium gas mantles could fall out over time and get into the air where they could be inhaled. Also of concern is the release of thorium bearing dust if the mantle shatters due to mechanical impact. Alternative materials which could be used are yttrium or zirconium, although they are either more expensive or less efficient [19]. The key factor which determines the luminous efficiency is the type and size of mantle, besides the inlet gas pressure, the fuel-air mixture, etc. The hottest inner core of the flame, should match exactly with the form of the mantle [19].

Another critical parameter that determines the luminance is the intake gas pressure. At a gas pressure of less than 75 mm of water column, the shining efficiency was found poor and at 150 mm water column, the shining efficiency was excellent. This means that biogas lamps cannot be used for plastic bag digesters or for plants where the gas is stored in plastic bags [19]. Figure 2.8 illustrates the feature of biogas lamp

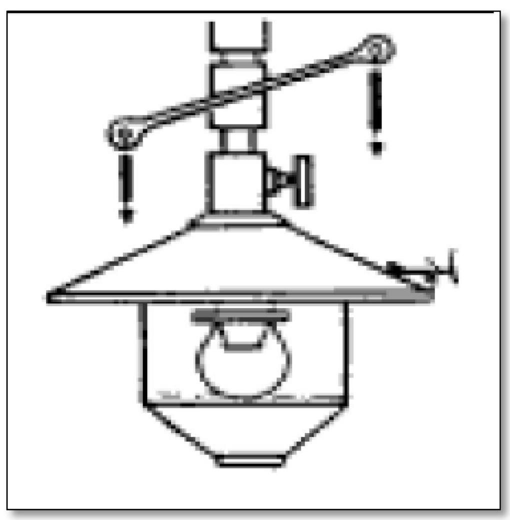

Figure 2.8: biogas lamp [19]

2.8 The Biodigester Performance parameters

The performance efficiency of the biodigester is influenced by some critical parameters includes technical performance parameters, operational performance parameters, economical performance, social and environmental impact parameters.

2.8.1 Technical performance parameters

The parameters used in the evaluation of the Technical performance efficiency of the biodigester loaded with different combination of substrates are usually the sensitivity to temperature fluctuations, pH level, and Gas production per unit of feedstock.

1) Sensitivity to temperature fluctuations

The methanogens are inactive in extreme high and low temperatures. The optimum temperature is 35° C. When the ambient temperature goes down to 10° C, gas production virtually stops. Satisfactory gas production takes place in the so called mesophilic range; between 25º to 30° C. Proper insulation on top of the digester, i.e. by the placement of a haystack, helps to increase gas production in the cold season. When the ambient temperature is 30° C or less, the average temperature within the dome will than remain about 4º C above the ambient temperature. The process of bio-methanation is very sensitive to changes in temperature. The degree of sensitivity, in turn, is dependent on the temperature range. Brief fluctuations not exceeding 1°C per hour may be regarded as still un-inhibitory with respect to the process of fermentation. The temperature fluctuations between day and night are no great problem for plants built underground, since the temperature of the earth below a depth of one meter is practically constant [19].

Temperature fluctuations are most often due to technical problems, but the underlying cause may also be biological. The breakdown of certain materials (crops) may result in heat production in the biogas process and, hence in problems caused by temperature fluctuations. Many microorganisms are inhibited if temperature fluctuations in the process are too large. For example, a reduction in temperature results in slow growth of the methane producers and a risk that they are gradually washed out of the system and are thus not able to effectively degrade fatty acids. This can result in an accumulation of decomposition products, followed by problems with instability. This problem will be especially severe if the temperature fluctuates back and forth because the organisms will not have time to adjust [20].

2) pH levels

The pH-value is the measure of acidity/alkalinity of a solution (and so of the substrate mixture, in the case of AD). The pH value of the AD substrate influences the growth of methanogenic microorganisms and affects the formation of some compounds of importance for the AD process (ammonia, sulphides, and organic acids). Experience shows that methane formation takes place within a relatively narrow pH interval, from about 5.5 to 8.5, with an optimum range between 7.0-8.0 for most methanogens; Acidogenic microorganisms usually have lower value of optimum pH [6].

The optimum pH interval for mesophilic digestion is between 6.5 and 8.0 [6]. The pH value can be increased by ammonia, produced during degradation of proteins, or by the presence of ammonia in the feed stream, while the accumulation of VFA decreases the pH-value. The value of pH in anaerobic reactors is mainly controlled by the bicarbonate buffer system [6].Therefore; the pH value inside digesters depends on the partial pressure of CO_2 and on the concentration of alkaline and acid components in the liquid phase. If the digester content swings to being more base or acid, the buffer capacity counteracts these changes in pH, up to a certain level. When the buffer capacity of the system is exceeded, drastic changes in pH-values occur, completely inhibiting the AD process. For this reason, the pH-value is not recommended as a stand-alone process-monitoring parameter [6].

A decrease in pH is usually caused by increasing contents of fatty acids formed during substrate decomposition. An increase in fatty acids may occur either because of an overload or because the activity of methane producers is inhibited. An increase in pH is often associated with an increase in ammonia content during the degradation of protein rich material. Ammonia is released, which is a strong base. Changes in pH may also occur if the substrate is highly acidic or alkaline. The rate at which a change in pH occurs is strongly related to the buffering capacity (alkalinity) of the process. A process with good buffering capacity can cope with relatively high levels of fatty acids before any change occurs [20].

3) Gas production per unit of feedstock

When the biogas plant is properly sized, it is possible to calculate the daily biogas production quite accurately. It mainly depends on the composition of the organic materials that feed the digester. For domestic biogas, organic materials are mainly composed of animal dung [1].

Table 2.6 summarizes the biogas production as a function of dung quantity for different livestock.

Table 2.6: Dung production and related biogas potential for different animals [1]

Livestock	Dung production [kg/100kg of animal/day]	Biogas potential [liter of biogas/kg of fresh dung]
Cattle (cows and buffaloes)	8	35
Pig	4	51
Goat	4	35

Low/uneven gas production could be due to several factors such as:

- Poor gas production potential in the substrate (low energy content, high content of hard-to-digest components, lack of trace elements, too coarse material, etc.)
- Uneven load
- Presence of inhibitory substances
- Low degree of digestion
- Fluctuations in temperature

A well-functioning biogas process always has some fluctuation in gas production and this variation is not in itself a sign that the process has problems. There may be Several reasons for production rates that are smaller than expected from theory, but probably the degree of digestion of the material is low, which may be because the Retention time is too short, the material contains a high proportion of poorly digestible Material or the substrate consists of large aggregates with insufficient surface area for the Microorganisms to exploit. If gas production suddenly drops even though the same Substrate is being used, this may be a sign that the load is uneven or that some toxic Substance has accumulated to levels that inhibit the microorganisms.

A change in gas production may also occur in the event of a change in the input Material if the gas production potential of the new substrate is different. If the new Material contains inhibitory substances, gas production may decline. In this context, it should be pointed out that the measured gas production may sometimes change due to Temporary changes in pH, since pH affects the amount of carbon dioxide which is dissolved in the process fluid. If pH increases, more carbon dioxide can be dissolved in the liquid and this may affect the methane content in the gas [20].

A change in gas production may also occur if the process experiences changes in Temperature. This is because temperature affects the microbial growth rate and hence gas Production [20].

2.8.2 Operational performance parameters

The parameters used in the evaluation of the Operational performance efficiency of the biodigester are: Ease of use (mixing / slurry discharge operations), Cleanliness of the site.

1) Ease of use (mixing / slurry discharge operations)

The absence of an inlet mixing tank makes feeding the Biodigester more cumbersome and also increases the likelihood of spillage of the cattle dung and water mix around the inlet of the Biodigester [21].

2) Cleanliness of the site

The site should be as clean as possible to the point of gas utilization, but at the same time, close from the source of raw materials such as piggery or poultry [20]. The site should be closed to where the effluent is to be used or stored like vegetable garden or drying bed [20].

2.8.3 Economical performance parameters

The parameters used in the evaluation of the Economical performance efficiency of the biodigester are: Investment cost, operational cost (maintenance) and savings from replacing chemical fertilizers

1) Investment cost and operational cost (maintenance)

Exact estimations for the construction and operation of biogas plants serve the following purposes:

- To compare the costs of alternative models (optimal project selection).
- For the information of the users as far as future financial burdens are concerned.
- The calculation of financing needs including public subsidies (budget planning).

Capital costs consist of redemption and interest for the capital taken up to finance the construction costs. For dynamic cost comparison the capital fixed in the plant is converted into equal annual amounts. The operation and maintenance costs consist of wage and material cost for:

- Acquisition (purchase, collection and transportation) of the substrate.
- Water supply for cleaning the stable and mixing the substrate.
- Feeding and operating of the plant.
- Supervision, maintenance and repair of the plant.
- Storage and disposal of the slurry.
- Gas distribution and utilization.
- Administration.

The running costs of a biogas plant with a professional management are just as important as the construction costs, for example for operation, maintenance, expenses for plastering or painting, service and repair.

2) Savings from replacing chemical fertilizers

The chemical fertilizer use only replenishes only a small part of the soil nutrients removed every year. With the poor management (loss of manure due to insufficient gathering and nutrients during the composting process) and application of Farm Yard Manure (FYM), soils are not replenished fully with the nutrients mined every year in terms of agricultural production. Thus, the productivity of soils is declining due to this continuous over mining [11].

Organic matter plays an important role because of its beneficial effects in supplying plant Nutrients, improving soil aggregation, increasing water holding capacity of soils, stabilizing its humid content and increasing its water holding capacity. Organic soil amendments support biological activities and also control root pathogens. Biodigester slurry has proved to be a high quality organic manure Compared to FYM, digested slurry will have (slightly) more nutrients, because in FYM, the nutrients are lost to some extent by volatilization (nitrogen) due to exposure to sun (heat) as well as by leaching [11].

The farmer needs to use chemical fertilizer to increase his crop production. However, if only Mineral fertilizers are continuously applied to the soil without adding organic manure, productivity of land will decline. On the other hand, if only organic manure is added to the soil, desired increase in crop yield cannot be achieved. Fertility trials carried out in Nepal and elsewhere have revealed that optimum results can be achieved through the combined application of both chemical and organic fertilizers [19].

In countries where biogas technology is well developed, for instance in China, there are evidences which support the fact that productivity of agricultural land can be increased to a remarkable extent with the use of slurry produced from biogas plant. In Nepal too, when properly managed, the biogas slurry plays a major role in supplementing the use of imported and expensive chemical fertilizers [19].

2.8.4 Social and Environmental performance parameters

There are many social impacts out from the technology of biogas. Biogases plants help improve beneficiaries' quality of life. First, they reduce the workload usually required for typical tasks such as firewood collection and fire tending which allow women to spend more time on other activities and on education. Also, cooking with biogas stoves is more convenient and faster than with firewood or charcoal stoves. Moreover, biogas is much cleaner than firewood or charcoal. By contrast, cooking with firewood or even with charcoal usually results in the production of soot which usually soils the kitchen and cooking utensils [1]. It consequently contributes to food security for beneficiaries and the community in general. On other hand, the lighting quality of biogas lamps is generally better than traditional lighting methods (e.g. kerosene lamps, which can also generate cancer-causing smoke) [1].

Cooking on biogas has also a significant health advantage over traditional cooking with an open fire. The major point is the fact that cooking is smokeless and that will diminish the number of eye infections and respiratory problems among in particular women usually in charge of cooking and small children being near their mothers. Also the danger that children burn themselves while cooking is less when using a biogas stove [19]. Biogas technology showed potential uses for small scale at the household level, same as wind and solar technologies. However while solar PV cells and small or large wind turbines produce only electricity, biogas that is produced from the anaerobic digestion of animal waste can be used for cooking, lighting, chicken brooders, water heating, electricity generation, pumping and chaff cutting, by use of the correct appliances. Because biogas is a clean cooking fuel, it also helps to address the health issues associated with indoor air pollution from smoky wood or dung-fuelled fires while decreasing dependence on biomass fuels such as wood or charcoal, where this use may be contributing to increasing loss of remaining woodlands [27]. The parameters used in the evaluation of the social and environmental performance of the biodigester are: Proportion of cooking and lighting requirements met, Impact on crop yields, and Fuel wood saving.

1) Proportion of cooking and lighting requirements met

Biogas produced from the household digesters is mainly used for cooking [28, 29]. The amount of biogas used for cooking purposes usually varies between 30 and 45 m3 per month. Assuming that the biogas plant is properly sized, 40 kg of cattle dung would lead to the production of 1400 liters of biogas, which represents approximately a cooking duration of 6h30 (with one stove)[1]. The minimum livestock required for a domestic biogas plant can be estimated according to the related cooking duration. As a result, a minimum of approximately two cows is required for a household to be able to cook properly with a biogas stove on a daily basis. Table 2.7 presents the equivalents in terms of dung production for adult livestock [1].

Table 2.7 Minimum number of animals for different types of livestock [1]

Livestock	**Cow**	**Pig**	**Goat**
Minimum number	2	4	20

A combination of different livestock is also acceptable (e.g. one cow and two pigs instead of two cows) [1]. It must be noted that these results assume that the biogas plant is properly sized to process 40 kg of dung every day. A smaller digester could fit lower cooking needs. Cooking on biogas is the most commonly used application and the sturdiest one. It has number of advantages over traditional cooking on the ground on an open fire, or wood stove, there are:

1. Higher net efficiency: 5 times higher stove efficiency than traditional firewood stove.
2. When firewood collection for traditional cooking is taken into account and the plant is laid out well, cooking on biogas is time-saving.
3. Does not produce smoke, less chance of eye irritations and respiration-problems (CARA)
4. Does not soothe the pans, less work to clean and faster.
5. Flame can be regulated.
6. Cooking can be done in up-right position.

7. Cooking can easily be done inside the house.
8. Use of pressure cooker, which again saves energy and time, becomes possible.
9. More safe, less chance for children to get burned as is the case with open fire, or stoves etc.

2) Impact on crop yields

The bio-slurry has valuable fertilizing properties and is particularly interesting in a predominantly agricultural context. Several studies have been performed regarding the benefits of bio-slurry compared to traditional fertilizers such as manure and inorganic fertilizers. In Ethiopia, yield increases of 64% (wheat) to 72% (barley) after applying bio-slurry compost were reported [30]. In Rwanda, best performances were observed with bio-slurry combined to inorganic fertilizers, enabling yields to increase by 314.5% (Irish potato in KARONGI District) [31]. In Asia, SNV has observed yield increases between 11% and 48% on vegetable crops such as cabbage, cauliflower and tomato [32].

3) Fuel wood savings

The energy saving aspect and thus saving on cost for firewood is from the point of view of the farmer household an important aspect. Moreover it is one of the major considerations of government to promote this technology because it reduces the burden on the environment. It saves trees and helps thereby to combat erosion and to store carbon (reduction of green house gasses) [19].

2.9 Experience of comparing the performance of different biogas digesters in Rwanda

In Rwanda the introduction of biogas plants started in 2005, when a joint effort was undertaken by SNV and other partners together with the Government of Rwanda through the National Domestic Biogas Program (NDBP). The initiative introduced the fixed “brick” dome type (FDBD) which was widely promoted in the country. However, in 2008 the GoR and NDBP imported the so called pre-fabricated Fiberglass biodigester (FGBD) from

China, as stakeholders sought to find an alternative that took less time to install and was more affordable. Subsequently, 100 units were installed in the country under a subsidy scheme. Later on in 2014 private companies previously supported by NDBP for implementation and development activities of, introduced a plastic Biodigester dubbed the Flex bag biodigester (FBBD) [21].

These simultaneous evolutions of biogas technologies introduced in Rwanda led to the assumption that the FGBDs and FBBDs were marketed by suppliers at lower cost, requiring less time for installation, and with higher efficiency compared to FDBDs. To test these assumptions, SNV Rwanda proposed to carry out a study to compare the performance of the three different types of household Biodigester installed in the country [21].

In December 2014, SNV Rwanda commissioned the University of Rwanda- College of Science and Technology (UR-CST), with the support of the University of Murdoch (Australia) and SNV's technical teams, to develop this research study which aims to assess the performance of the three types of Biodigester of the same size (6m3) on their technical, financial, and socioeconomic performance. The sample size for the study was a total of 19 Biodigester; 11 FDBDs, 4 FGBDs, and 4 FBBDs, located in the districts of Gasabo and Kicukiro in the Central Province of Kigali, and Rwamagana, Kayonza, Kirehe and Ngoma in the Eastern Province. In the case of FDBDs and FGBDs, plants that had been in use for at least 5 years were selected. Of the 100 installed FGBDs, only few were found to be in a working order and this limited the sample size. According to the statistics from REG-EDCL (former EWSA-NDBP), 78.3% of FDBDs and 47% FGBDs were in use/operation countrywide. The FDBD Biodigester were chosen from a total of 40 visited households as they met the selection criteria of being fully functional, well maintained, and in operation for a minimum of 5 years. In the case of FBBDs the condition was restricted to at least six months in use because it was considered as a recently introduced technology. The number and period of time in operation of FBBDs was limited as they were only introduced in Rwanda in 2014 [21].

Important parameters such as daily feeding, pH, ambient and internal digester temperature, gas pressure, and biogas consumption were measured and recorded using "computerized data loggers" at six of the sites. For the remaining Biodigester, information was measured and recorded manually. Samples of the bio slurry and feedstock were collected at each site and tested in the UR-CST laboratory to determine its nutrient values (NPK), presence of pathogens, total solids (TS), and volatile solids (VS). No significant difference in the rate of pathogen reduction was observed between the different types of Biodigester. The NPK content calculated based on the laboratory results was consistent with those found in similar studies. FBBDs were found to have the highest nitrogen (N) and phosphorus (P) content while FDBDs had the highest potassium (K) content. All three Biodigester types in each district were estimated to achieve a reduction of 97.5 % to 100.0% for E.coli [21].

All surveyed households used a 1:1 mix of cow dung and water with an average of daily digester feeding of 37.3 kg/L and 34.4 L/d for cattle dung and water, respectively. The average gas flow of 1,417 L/d for FDBDs, 655 L/d for FGBDs, and 898 L/d for FBBDs, was used along with the daily average cow dung fed for each Biodigester type to estimate the gas production potential [21].

FDBDs were found to have the greatest gas production potential of 36.47 L per kg of cow dung fed compared to 31.64 and 19.16 L per kg of cow dung fed for FBBDs and FGBDs, respectively. Overall, the results of the study indicated that FDBDs offer many advantages over FGBD and FBBDs, specifically in gas production, gas stove use hours, robustness, and firewood savings. FGBDs were found to be the least sensitive to ambient temperature fluctuations, but had the highest repair costs out of all three Biodigester types. FBBDs were found to be the most economically viable due to low investment and repair costs, although the overall technical and operational performance is lower compared to FDBDs and FGBDs [21].

Chapter3

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter explains the methodology used in this project. The equipment and tools used during the project work are also illustrated and discussed in this chapter. Temperature inside and outside the digester and pH level data for the units were daily collected, biogas production per kg of feedstock from the digester was measured by using biogas flow meter then, different performance parameters were analyzed. The methodology flow-chart of this project is shown in Figure 3.1.

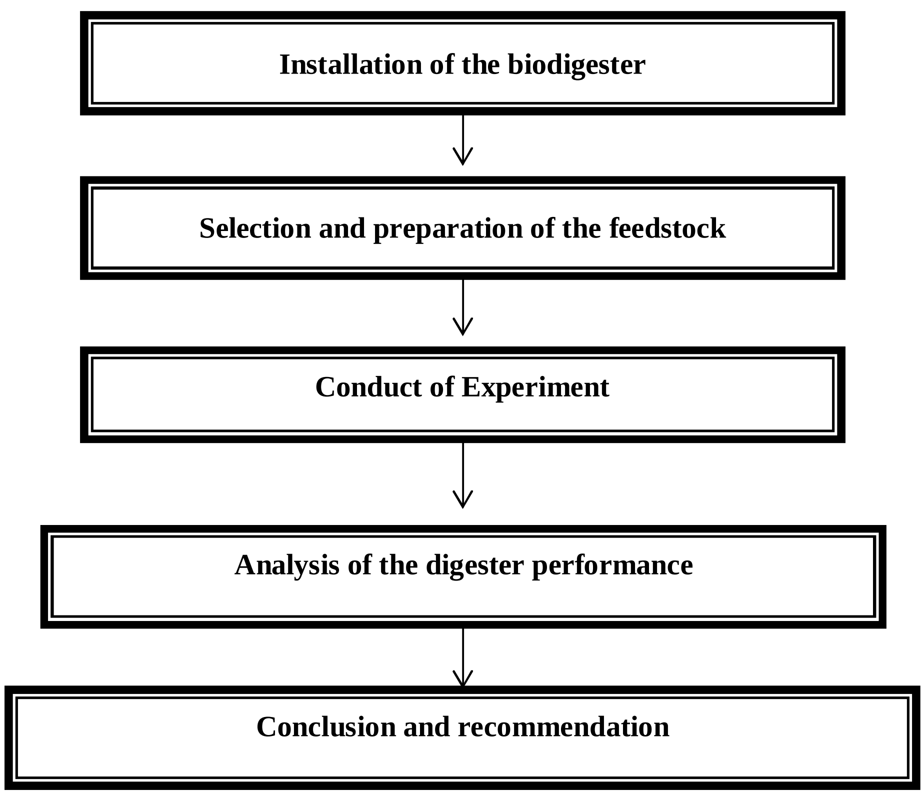

Figure 3.1: Methodology Flow Chart

3.2 Installation of biodigester

A flex bag biodigester (FBBD) was assembled and installed at professor Saber laboratory at Faculty of Engineering, Sudan University of Science and Technology. The digester was exposed to a tensioning mechanism to increase the pressure inside the digester, also it was covered with sheet for protection from outside conditions, and the main material which this digester made of is polyethylene. The System has to main ports and both of them located at the bottom of the biodigester and connected with a tube an upper location to prevent form the leak and to ensure the flowing process, the figure below is illustrate the feature of this digester. The specification of the biodiesegester is as shown in Table 3.1.

Table 3.1: Specifications of Flex Bag Biodigester

Parameters / Type	Material	Total Volume	Working volume	Gas storage
Flex bag (FBBD)	Polyethylene	2000 L	1500 L	Inside the bag

3.2 Material and Method

Two types of feedstock were selected for the experiment. They were wet (fresh) cow dung collected from Al-Sahafa slaughter house and food waste collected from restaurants at Faculty of Engineering, Sudan University of Science and Technology. Based on the dry matter of the feedstock, mixing ratio with water was determined, then the specific amount of water added to the feedstock and homogeneously mixed using hand mixer. The mixture was placed inside the digester at to the working volume (75% of the total volume). Readings of temperature inside and outside the digester, pH were taken and recorded on a daily basis, the specifications of the feed stocks are illustrated in the table below.

Table 3.2: Types of feed Stocks and the specification of each one

Feed stock	Dry matter	Mixing ratio (Feedstock to water)	Source of feedstock
Cow dung	20%	1:1	Khartoum Slaughter House, Khartoum
Dry Food waste	50%	1:4	Restaurant of Faculty of Engineering at SUST,

3.2.1 Hydraulic Retention Time (HRT)

Hydraulic retention time (HRT) is an important parameter for dimensioning the biogas digester. The HRT is the average time interval for which any particular unit of the substrate is inside the digester tank. HRT is correlated to the digester volume and the volume of substrate fed per time unit, according to the following equation:

$$HRT = V_R / V \qquad (3.1)$$

Where:

HRT = hydraulic retention time [days]

V_R = digester volume [m³]

V = volume of substrate fed per time unit [m³/d]

By knowing the hydraulic retention time, and the digester volume, the necessary daily feedstock required was calculated and then the daily biogas produced from the digester per kg of feedstock was measured.

3.3 Analysis of Performance Parameters

Performance Parameters are the general properties or factors that enlighten us to assess biogas digesters, there are many types and subtypes of performance parameters, the assessed parameters on this study are: Technical performance parameters, Operational performance parameters, Economic performance parameters, and Social and environmental parameters.

3.3.1 Technical performance parameters

The technical parameters assessed in this study were sensitivity to temperature fluctuations, pH levels, and gas flow (production) per kg of feedstock. Sensitivity to temperature fluctuations is a critical factor that may affect the efficiency of the digester, and it's an important and difficult parameters to preserve within optimized limits in domestic biogas digesters is the temperature. Different researchers revealed that breakdown of organic matter in slurry stores increases with temperature.

The pH-value is the measure of acidity/alkalinity of a solution and so of the substrate mixture, in the case of Anaerobic Digestion. The pH value of the Anaerobic Digestion substrate influences the growth of methanogenic microorganisms and affects the formation of some compounds of importance for the Anaerobic Digestion process (ammonia, sulphides, and organic acids).

Gas flow is the volume of gas that passes a particular point in a particular period of time. Gases are compressible and change volume when placed under pressure, heated or cooled; a volume of gas under one set of pressure and temperature conditions is not equivalent to the same gas under different conditions. This parameter was daily indicated with the gas flow meter which mounted on the gas connecting lines. The importance of obtaining gas flow is to estimate the amount of gas that will be produced per day for each type of feedstock, and so it will help to decide whether the amount of gas produced from the size of digester is enough for fulfilling household's needs for gas per day.

3.3.2 Operational performance parameters:

Cleanliness of the site and the ease of use (mixing / slurry discharge operations), were the two operational parameters assessed in this study. The mixing process of the feedstock prior to be uploaded in the digester was done manually by the hand mixture, and the slurry was directed to a seeding vat without any need for expert. The cleanliness of site gives an accepted feature for the place and with no cleaning there will be an accumulation of unfed waste which could attract the flies and other kind of bugs.

3.3.3 Economic performance parameters

The most economic performance assessed were investment and operational costs. The assessment here was mainly based on the capital and the maintenance costs of the digester and the period (gabs) between maintenances, also the labor cost could be considered.

3.3.4 Social and environmental parameters

The social and environmental parameters assessed in this study were the proportion of cooking and lighting requirements, and fuel wood saving. This parameter is related to the capability to satisfy the stove using (cooking) and the lighting needs, and it's directly related to gas pressure inside the digester or the gas holder.

Chapter4

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the experimental results obtained from the biodigester assessed in this project with a different feedstocks and analysis of different performance parameters using the method and equipment described in chapter 3. More over the combustion of dual diesel engine with biogas produced from the biodigester is also evaluated.

4.2 Flex Bag Biodigester (FBBD)

The flex bag biodigester was installed and its performance was assessed base on different parameters when using cow dung and food waste as feedstocks. The base was built firstly blocks of bricks and cement with dimensions of 200cm length, 130cm width and 60cm height. A tube of 4” was installed in the front side of the basin at a height of 10cm from the bottom. This tube is then connected with other vertical tube of 135cm. the combination of these tubes system is called the outlet tube or the outlet system. Following that installing the outlet tube, the inlet was installed at the back side of the unit with its height been 115cm and 50cm as a vacuum from the bottom, making a total height of 165cm from the ground to prevent the occurrence of gas leakage. The flexible bag unit is then added and installed to the basin, then tightened with a flexible rope to increase the pressure inside the system; a containing frame is then installed to the unit to carry the protection thick bag which protects the unit from the outside conditions.

Figure 4.1 shows the installed flex biodigester mounted on cement base with inlet for feeding process and outlet for the Bioslurry removal.

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Figure 4.1: Flex bag biodigester

4.3 Analysis of Performance Parameters

The assessment of the performance parameters were carried out for the biodigester installed when filled with fresh cow dung and food waste. Total volume of 1500 liter of mixture poured into the biodigester for fermentation and different parameters measured. The following section discusses the results obtained.

4.3.1 Technical Parameters

4.3.1.1 Sensitivity to temperature fluctuations

The daily ambient temperature for the flex bag biodigester ranged from 33°**C** to 40°**C** at an Average of 37.5°**C**, while the temperature inside the digester was measured to be between 32°**C** to 39°**C** at an average of 36.9°**C** when using both feedstocks of fresh cow dung and food waste. The data on the ambient and digester temperatures for flex bag digester in the study are given in Appendix A. FBBD was found to be high sensitive to temperature fluctuations based on observations from daily temperature readings as shown in Figure 4.2 and 4.3.

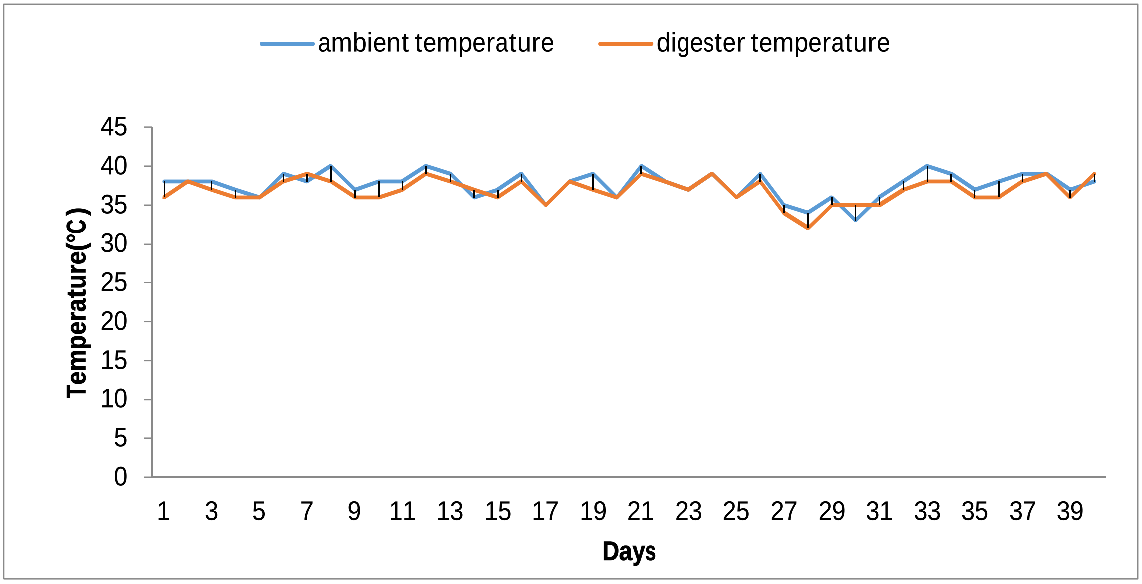

Figure 4.2: daily Ambient and digester temperatures for FBBD using fresh cow dung

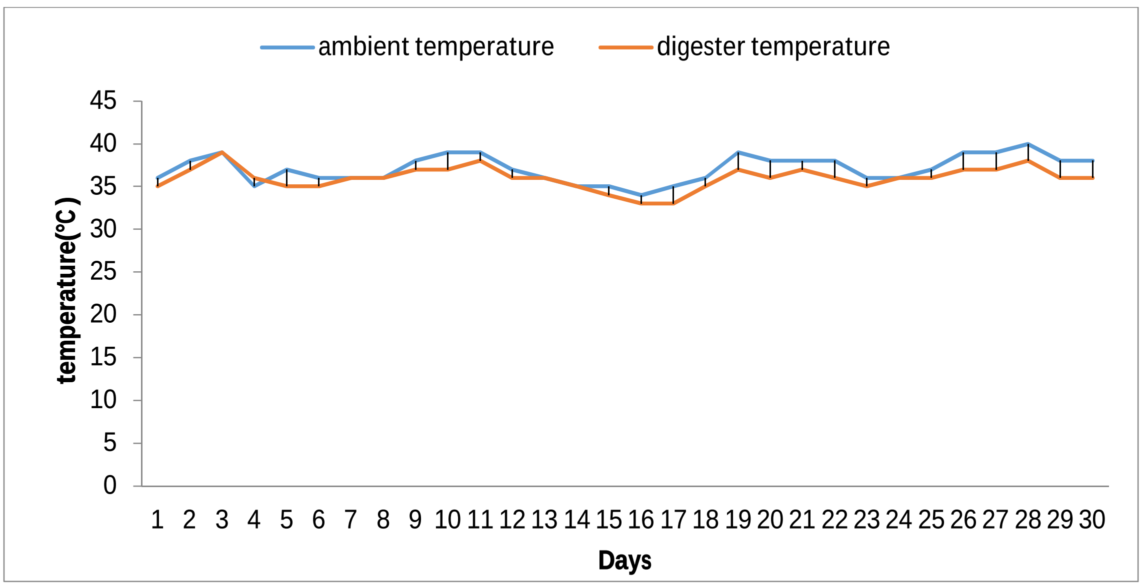

Figure 4.3: daily ambient and digester temperatures for FBBD using food waste

4.3.1.2 pH level

The pH values for the mixture were stable inside the biodigester for the first days at 7 and 5 when using fresh cow dung and food waste respectively. Then for both feedstocks the pH values started to rise until it reached 8 at the end of retention time. The explanation of this is that the mixture became more alkaline. This due to the batch feeding as usually the pH stay stable inside the digester with daily feeding. The illustration of the change of pH for both feedstocks is shown in Figure 4.4 and Figure 4.5.

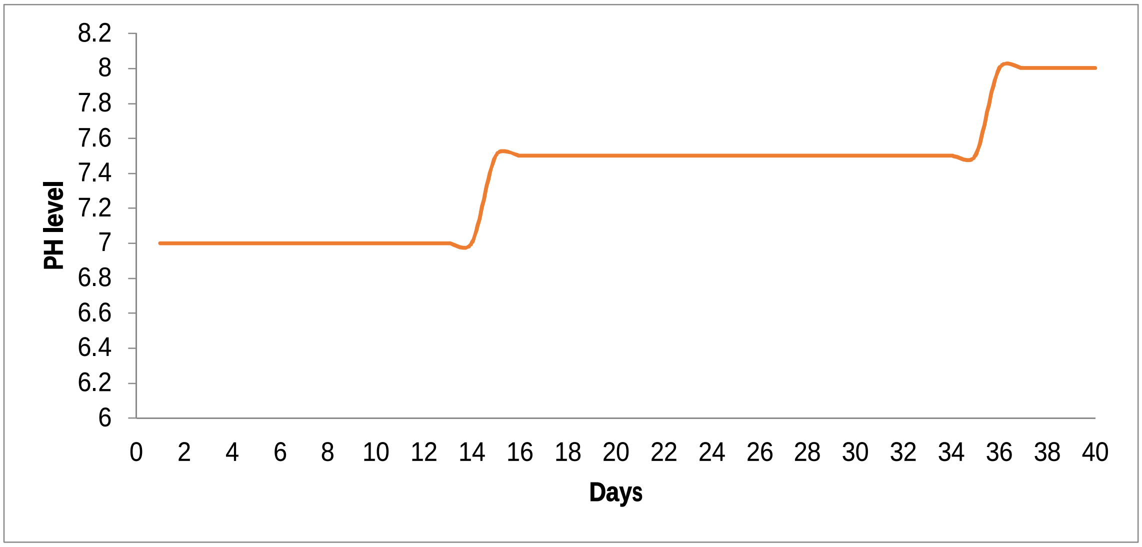

Figure 4.4: Measured pH level for fresh cow dung feedstock

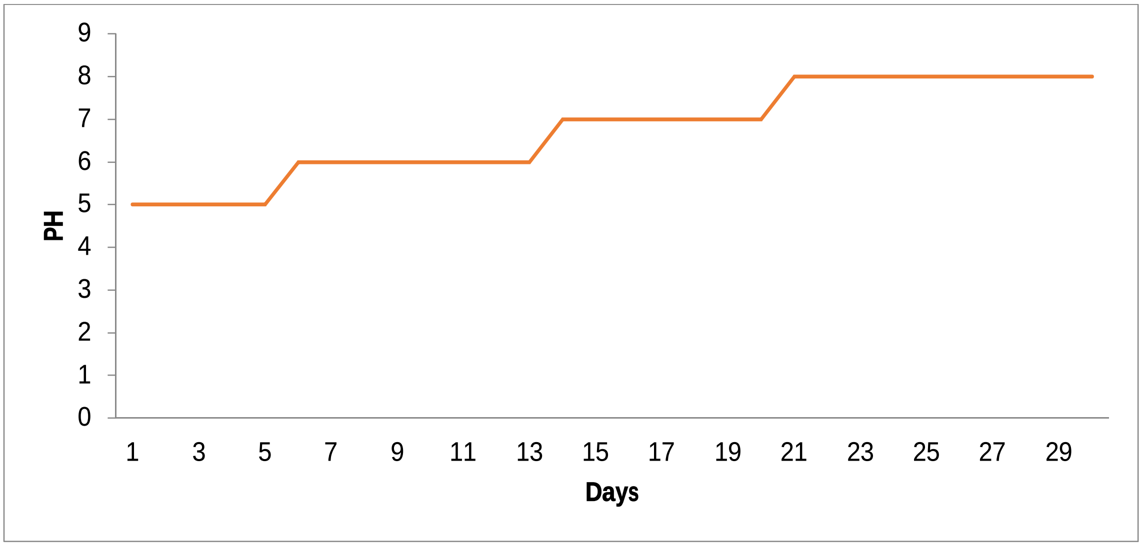

Figure 4.5: Measured pH level for food waste feedstock

4.3.1.3 Gas flow and production per kg of feedstock

When using the fresh cow dung feedstock, the Hydraulic Retention Time was found to be 40 days, with an average daily feeding of 37.5Kg of mixture with mixing ratio of 1:1feedstock to water (19 kg of feedstock). By using of gas flow meter, the gases flow was found to be of 608 Liter per day, in average of 32 L per kg of fresh cow dung as shown in Figure 4.6. The gas flow could be accurately measured over 24hours.

On other hand, the Hydraulic Retention Time was found to be 30 days when using food waste feedstock, with an average daily feeding of 50Kg of mixture with mixing ratio of 1:4 feedstock to water (10 kg of feedstock). The total gas produced was 1940 L/d, in average of 194 L per kg of food waste. This is clearly shown in Figure 4.7.

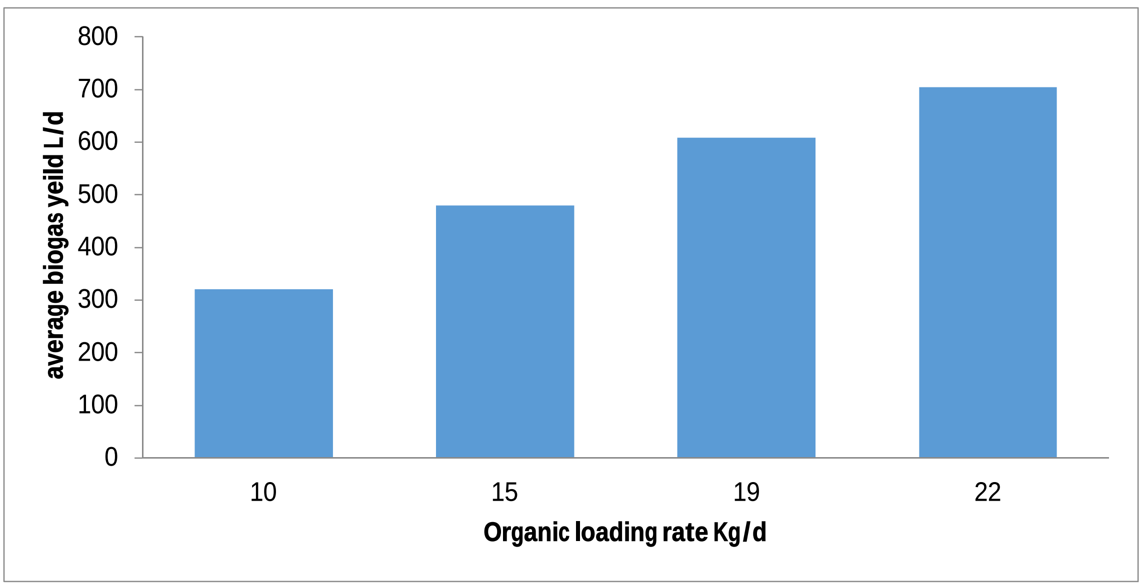

Figure 4.6: Biogas production from fresh cow dung

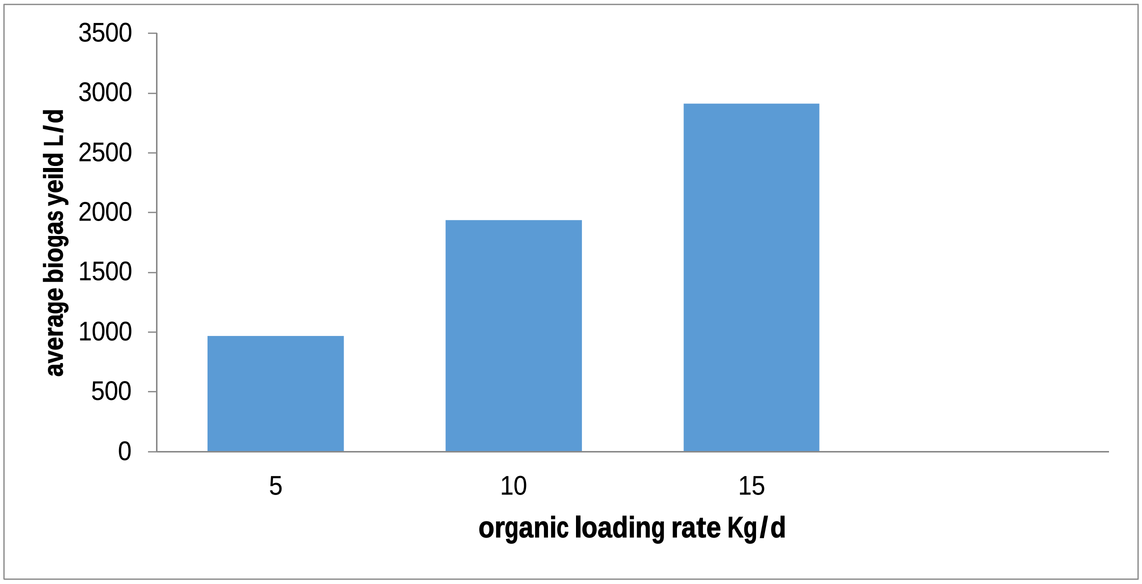

Figure 4.7: Biogas production from food waste

4.3.2 Social parameters

The biogas produced in this study was enough to run the cooking stove for 1hr 38min and 4hr 47min daily when using fresh cow dung and food waste respectively. Moreover, the amount of firewood saved per day was calculated assuming that 1m3 of biogas being equivalent to 5.5kg of firewood [21]. In this case using of FBBD was found to yield saving of 3.34kg of and 9.8kg of firewood per day when using fresh cow dung and food waste respectively.

4.3.3 Operational parameters of FBBD

The absence of an inlet mixing tank at FBBD makes feeding it more cumbersome and also increases the likelihood of spillage of the feedstock and water mix around the inlet of the biodigester, in the other hand slurry discharge operation from the digester was very convenient. During the study the area around the inlet of the biodigester was cleaned regularly, and the site was provided with a barrel as slurry pit to collecting the slurry.

4.4 Analysis of cooking parameters

The biogas produced from the digester fed with mix of food waste and fresh cow dung was used to run a cooking stove. The analysis of cooking parameters such as cooking time and the biogas consumed for different kind of foods is shown in Table 4.1. It also shows the biogas pressure inside the biodigester at start and end of cooking.

Table 4.1: Cooking by Biogas Experimental Results

Kind of meal	Cooking Time (minutes)	Initial Pressure (kPa)	Flow meter Initial reading (m3)	Final Pressure (kPa)	Flow meter final reading (m3)	Gas consumed (m3)
Tea	6	7	223.540	7	223.556	0.016
Tea	11	8	220.583	7	220.621	0.038
Omelette	13	7	227.152	5	227.220	0.068
Coffee	21	7	221.360	6	221.420	0.06
Faba Bean (Heating)	30	7	223.561	4	223.645	0.084
Faba Bean (Heating)	35	9	226.833	7	226.926	0.093
Aubergine	39	8.5	223.717	5.5	223.826	0.109
Faba Bean	45	8	220.648	7	220.729	0.081
Mutton	47	7	226.926	5	227.101	0.175
Rice	60	1	221.676	0	221.771	0.095
Bean	155	8	227.3	0	227.823	0.523

As seen in Table 4.1, it noticed that the Bean had the longest cooking time duration, where the tea had the lowest, it is clear from the experiment that the biogas Consumption was influenced by cooking time and the biogas pressure inside the biodigester as shown in Figure 4.8.

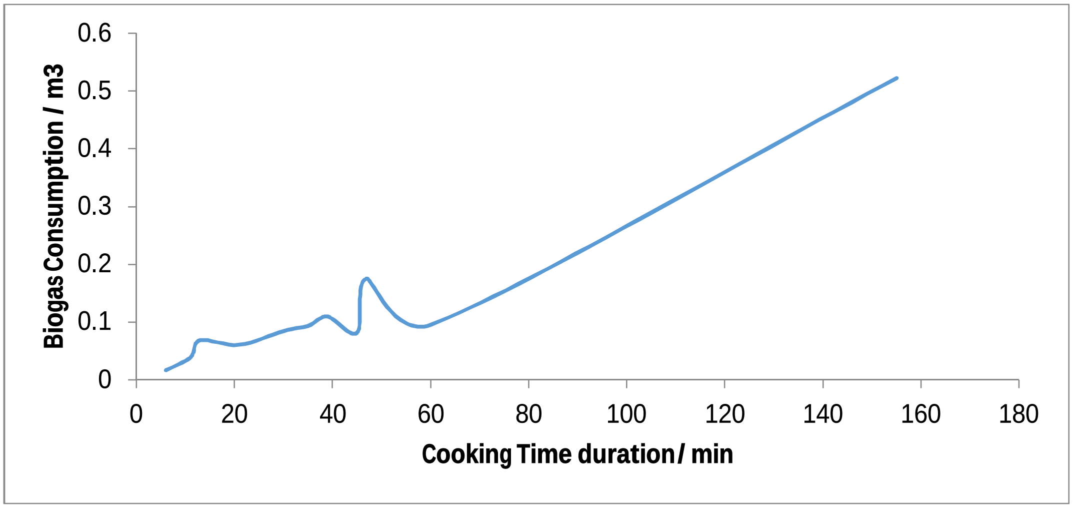

Figure 4.8: Variation of the biogas consumption with the cooking time duration

It also found that the biogas pressure inside the biodigester at ending of the cooking, less than at starting due to consumption of biogas, and then the pressure returns to a peak value due to fermentation of substrate.

4.5 The Construction Cost of Digester

The calculation of the construction cost of the digester used in this project was mainly based on the materials and components cost, and construction cost. The summary of the total cost is shown in Table 4.2.

Table 4.2: Cost Structure of flex biogas digester

Item	Total Cost (SDG)
Components and Materials include the biogas stove and lamp.	8520
Construction	3000
Total	**11520**

Chapter5

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

This chapter summarizes the work done in this project with the sets of the results achieved and which are within the objectives of the project. Finally, leading from this project, several recommendations are made for areas of possible future research**.**

5.1 Conclusion

1. Flex bag digester was found to be high sensitive to ambient temperature fluctuations with cow dung and food waste as feedstocks.
2. The HRT using cow dung was 40 days, and 30 days for food waste.
3. The measured pH values for cow dung and food waste were change with time at no daily feeding, slightly alkaline, indicating no risk of inhibition.
4. Flex bag digester was found to have a gas production potential of 32 L per kg of fresh cow dung fed, and 194 L per kg of food waste fed.
5. The estimated average daily savings on firewood as a result of using biogas was 3.34 kg per day for cow dung as feedstock, and 9.8 kg per day for food waste.
6. Food waste was found to be suitable for powering biogas stoves and lamps, because there gave the high gas production and pressure.
7. Flex bag digester was more difficult to use due to an absence of an inlet mixing tank.
8. The area around the inlet of the biodigester was cleaned regularly to achieving cleanliness of the site.
9. Biogas consumption for cooking was influenced by the cooking time and the biogas pressure inside the digester.
10. The total construction cost of the 2000 litre digester was found to be 11520 SDG.

5.2 Recommendations

On the basis of information gained in completing this project, these recommendations are suggested for incorporating into future studies:

1. Experiments can be done by mixing different types of feedstock.
3. Future studies are recommended where the ambient and digester temperatures fluctuations are observed over a 24 hour period for the biodigester.
4. Future studies can be done to assess other parameters such as gas pressure in the biodigester , volatile Solids (VS) degradation , pathogen reduction ,and nutrient content in bio slurry
5. The impact of applying the bio slurry on crop yields and the economic savings from replacing chemical fertilisers also requires future research.

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Appendix A

Table A.1: Cow dung (wet) experiment results

Days	To °C	Ti °C	pH
1	38	36	7
2	38	38	7
3	38	37	7
4	37	36	7
5	36	36	7
6	39	38	7
7	38	39	7
8	40	38	7
9	37	36	7
10	38	36	7
11	38	37	7
12	40	39	7
13	39	38	7
14	36	37	7
15	37	36	7.5
16	39	38	7.5
17	35	35	7.5
18	38	38	7.5
19	39	37	7.5
20	36	36	7.5
21	40	39	7.5
22	38	38	7.5
23	37	37	7.5
24	39	39	7.5
25	36	35	7.5
26	39	38	7.5
27	35	34	7.5
28	34	32	7.5
29	36	35	7.5
30	33	35	7.5
31	36	35	7.5
32	38	37	7.5
33	40	38	7.5
34	39	38	7.5
35	37	36	7.5
36	38	36	8

Days	To °C	Ti (°C)	pH
37	39	38	8
38	39	39	8
39	37	36	8
40	38	39	8
Average	37.5	36.9	7.4

Table A.2: Food waste experiment results

Days	To °C	Ti °C	pH
1	36	35	5
2	38	37	5
3	39	39	5
4	35	36	5
5	37	35	5
6	36	35	6
7	36	36	6
8	36	36	6
9	38	37	6
10	39	37	6
11	39	38	6
12	37	36	6
13	36	36	6
14	35	35	7
15	35	34	7
16	34	33	7
17	35	33	7
18	36	35	7
19	39	37	7
20	38	36	7
21	38	37	8
22	38	36	8
23	36	35	8
24	36	36	8
25	37	36	8

Days	**To °C**	**Ti °C**	**pH**
26	39	37	8
27	39	37	8
28	40	38	8
29	38	36	8
30	38	36	8
Average	37.1	36	6.8