ADDIS ABABA UNIVERSITY
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ENERGY CENTER

OPTIMIZATION OF BIOGAS PRODUCTION FROM SLAUGHTERHOUSE WASTE AND DIGESTER SIZING

A Case in Addis Ababa Abattoirs Enterprise

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This is to certify that the thesis prepared by Genet Tseaye, entitled: **Optimization of biogas production from slaughterhouse waste and digester sizing, a case in Addis Ababa Abattoirs Enterprise** and submitted in partial fulfillment of the requirements for the Degree of Masters of Science in Energy Technology complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Abbreviations

AAAE	Addis Ababa Abattoirs Enterprise
AD	Anaerobic digestion
APHA	American Public Health Association
BOD	Biological oxygen demand
COD	Chemical oxygen demand
C/N or C: N	Carbon to Nitrogen Ratio
DM	Dry Matter
EPA	Environmental Protection Authority
HRT	Hydraulic Retention Time
NPV	Net Present Value
KWh	Kilowatt hour
pH	Power of Hydrogen
TS	Total solid
VS	Volatile solid

Abstract

This study focuses on production of biogas from slaughter house waste to generate optimal methane yield. Which has high calorific value under Optimum temperature, pH and substrate proportion (blood, manure and undigested stomach content). And also Digester Design for dumping waste of AAAE. In this study first experiment was carried out to determine pH, total solid, volatile solid and ash content of each type of waste fermented independently at optimal temperature (35^0*c) and at pH 7. Second experiment was by mixing three type of wastes based on crossed D-Optimal design expert software which had 42 run at different proportion of substrate Blood and Manure at range of (10%-20%)' undigested stomach content at range of (60%-80%) , pH range (4-10) and temperature at range of (20*^{o}*c-45*^{o}*c).*

After the experiment the following parameters: methane content, caloric value or energy generation capacity and volume of biogas, pH, temperature, total solid, volatile solids, and Ash content of each type of waste were determined. From individual type of 350ml sample waste (blood, manure and undigested stomach content) Maximum Biogas production and methane composition was 0, 7lit, 4lit and 0%, 66% and 54% respectively. From 42 run experimental result by crossed D-Optimal Design Expert software the best optimal methane composition and biogas production was 79.26% and 0.381lit/gm of VS respectively. Optimal condition was 20% blood, 20% manure and 60% undigested stomach content substrate composition, at pH=7.88 and temperature 32.49^o*c. 79.26%*CH_4 *composition has a potential 7.88kwh per m*^{3} *of Biogas. The amount of biogas produce from AAAE waste is2968m*^{3}*/day which has a potential to generate 23,393.4kwh/day of energy. 3,148.8 kwh/day apply to facilitate anaerobic digestion activity and remaining 17, 207.9kwh/day for steam generation. Which can cover for 70.7% of boiler furnace oil and gas oil consumption and save7, 087,740.ETB birr/year of its budget.*

This study has shown that application of biogas plant for AAAE is financially, environmentally and socially feasible. The cost benefit analysis shows that NPV is positive and benefit cost ratio is 2.03 which is greater than the proposed value for application of given project. As the financial analysis shows after implementation of this project AAAE can annually save Birr 6,006,520. Which can be invested to construct four digester plants having a volume of 753.75m^3 *with daily 120.6m*^{3} *total feedstock fed to the digesters. At optimal mixture of three waste and optimal condition.*

Key words- Digester, Biogas, Methane, slaughterhouse waste, anaerobic digestion

Chapter One

1. Introduction

1.1 Background

Now a day's the demand and the discharge of wastes are increasing from time to time because of fast growing of population, urbanization and industrialization. Extraction of fossil fuels cause global warming due to carbon dioxide (CO_2) released from burning fossil fuels attracts more public attention in development and utilization of alternative, non-petroleum-based renewable sources of energy. In addition, the growing scarcity of petroleum and coal, deforestation of forests for fuel and other purposes and problems related to emission of greenhouse gases such as CO_2, methane, hydrogen sulfide will lead to the global warming of the Earth's surface. To overcome the energy crisis, environmental pollution and global warming, renewable energy sources such as generation of energy from waste (biogas), solar, wind, thermal and hydro powers should be utilized. In Ethiopia 92% of total energy consumption depend on biomass which results deforestation and climate change. (NBPE, 2010)

Industrial waste can easily pollute the environment, misplaced resources and occupy land which could contribute for development purpose and results in severe health problem. The majority of organic waste is generated from Agri-food industry like from slaughterhouses, meat processing companies, dairy companies, refrigeration plants, farms, sugar factories, breweries, distilleries, fruit and vegetable processing companies, and catering facilities. Even though most of the time not considered as contaminant, they emit greenhouse gases and create global warming during the decomposition of waste in open air .Especially slaughter house waste contains phosphorous (P), nitrogen (N_2), high COD and BOD content and when this Waste decomposes in open air H_2S and CH_4 was emitted (EPA,2002).N_2 and P contaminate surface water and distract mineral content of ground water which is required expensive water treatment technology and takes long time for the ground water resource to return to its normal original quality which is much more difficult for developing country.(EPA,2002).

Slaughter house waste is rich in organic content and composed of a complex mixture of fats, proteins and An organic load of COD 1,000 – 6,000 mg/lit, BOD5 1,000 – 4,000 mg/lit, N (250 – 700) mg/lit, NH4-N 200 – 300 mg/lit, P 80 – 120 mg/lit (Tritt W.P, 1992).Which are highly soluble and have high potential to be treated anaerobically for biogas production. The product of biogas can be used as bio fertilizer that improve soil structure ,a complex role in maintaining the natural processes of breaking down and composting of leaves and roots in the ground by micro-organisms by ensuring the proper circulation of air and water (Akwaka et.al.,2014).

In developing country like Ethiopia the largest number of livestock in Africa has much to gain from the growing global market for livestock products. There are currently six export abattoirs under operation without including kera such as Helimex Export Abattoir, Elfora Agro-Processing, Modjo Modern Export Abattoir, Luna Export Abattoir, Abegrelle, Ashraf and Organic Export-Not operational yet. These abattoirs have an annual slaughter capacity of 2.5 million shots for exportation with a possibility of expansion to 4.5 million shoats in the near future. They face major problems related with solid and liquid waste disposal. Except modjo and Luna abattoirs that have little waste treatment plant, all of the rest abattoirs are discharging a total of 825 million liter of waste water annually disposing into a lagoon, river and into the ground(Global Methane Initiative, 2011). Current waste disposal practice of the abattoirs has created smell, negative environmental and health impacts in the community.

In Ethiopia, enough attention has not yet given on biogas production from slaughter house consequently the country is among methane emitter countries and also it is not gaining enough amount of advantage from the resource like bio slurry which can produce organic fertilizer and also the country imports petroleum products from abroad while it being possible to use bio gas produced from high resource of livestock and slaughter wastes to significantly reduce the bulky consumption of fossil fuel. This study focuses on how to utilize abattoir wastes to facilitate the above explained activities, and achieve optimal biogas production from abattoir wastes and optimize and sizing of the biogas digester for slaughter houses.

1.2. Problem Statement

In Ethiopia, the fact that the number of slaughter houses and industries which require high amount of energy to facilitate their activities are increasing such that creating power scarcity and environmental pollution throughout the country. Addis Ababa Abattoirs enterprise uses energy intensive machines as a result 95% of daily total energy cost is for buying diesel oil and furnace oil currently meat demands are increasing hence pushing the abattoirs to use high amount of energy to facilitate their activity and creating power scarcity in the organization. Furthermore, absence of uninterrupted electricity forces the abattoirs to depend on diesel generators using petroleum products which influences their economic profit and increases CO_2 emission gases in to the atmosphere.

On the other hand, a major problem has related to most abattoirs are their production of large capacity of solid and liquid wastes with no waste water treatment plant. AAAE (Kera) annually discharges 27,922,200 kg untreated waste to the environment which is comprise of an estimated 48,240 kg/day of intestinal matter alone and 12,060kg/day of blood; This has an externality negative impact for downstream dwellers and water users from the nearby river (Global Methane Initiative, 2011). In order to reduce these adverse effects, it requires efficient, cost effective and environmental friendly treatment methods such as biogas technology before discharging the waste to the environment.

In Addis Ababa abattoirs enterprises there are initiatives to develop biogas plants to produce renewable energy and compost for bio fertilizer but they have no known amount of good proportion of total solid concentration of the substrate inside the digester and lack optimization. Hence slaughter houses need well optimized bio gas system design to get good yield of methane production and to use the resource efficiently in environmental safe way so as to reduce the cost for energy and solve the shortage of power and reduce environmental pollution.

Thus, the present study was set to create a permanent solution through appropriately designed size of digester and composition of the feedstock to digest the waste and optimal Bio gas production through utilization of the abattoir wastes to generate energy and reduce the direct discharge of waste to downstream dwellers.

1.3. Objective of the project

1.3.1. General objective

To produce bio gas from abundant resource of slaughter house waste by using anaerobic digestion that can be used as source of energy for the abattoir and mitigating greenhouse gases by decreasing methane emit in to the atmosphere from the slaughter houses waste and livestock industry.

1.3.2. Specific objective.

- To examine biogas production potential of each type of waste (blood, manure, undigested stomach content) without mixing each other and characterize the waste.
- To Identify best proportion of three waste mixtures (blood, manure, undigested stomach content) and optimize initial pH and temp to enhance methane yield.
- To recognize the amount and type of available waste of the slaughter house that can use for bio gas production.
- To design potential of biogas that can be produced from Abattoirs and amount of conventional energy source that can substitute.
- To select type and estimate size of the digester at appropriate quantity of feed.

1.4. Scope and Significance of the study

This study is limited to bio gas production from slaughter house wastes in efficient way and sizing bio gas digester for abattoirs. Additionally, all of experimentation will be done on a laboratory scale. However, our goal is to apply the study to an industrial scale. Our laboratory-scale design can be applied to a much larger size with few modifications. This research can serve as a foundation for future research on scaling up similar designs.

The outcome of the study will help for energy and environmental protection policy makers as a reference during preparation of a guideline for increasing number of alternative renewable energy technology means by using different resources, for substitution of fossil fuel throughout the country and for managing slaughter house water wastes. In general it contributes to the economic advancement of the country through production of energy from wastes which reduce the amount of fuel import from abroad and it has great impact on reduction of greenhouse emission from livestock industry.

Chapter Two

2. Literature review

2.1. Waste is misplaced resource

Waste was viewed as an unnecessary element arising from the activities of any industry. In reality, waste is a misplaced resource, existing at a wrong place at a wrong time. Under the sustainable development concept, now a days waste management strategy emphasis on reduction at source and resource recycling. In fact, waste generation is closely linked with the living habit of everyone. If everyone makes his own contribution, jointly cherish and make better use of resources, avoid wasting, and reduce waste at source or further recycle.

Industrial wastes contain solid wastes, semi-solid wastes, and liquid and gaseous wastes that are not permitted to discharged directly in to the environment. this wastes were classified in to organic waste and inorganic wastes based on their components .Industrial waste pollution has become an increasingly serious problem in the world specially in developing countries like Ethiopia. Every year large quantities of industrial solid wastes were generated from the growing industries. However, there are no adequate treatment plant and reusing system of the waste as a source of energy or other. All these challenges have seriously delayed the development of industries in these countries and done harm to human being health and the environment.

2.2. Biological wastes in Agro -Food industry

Waste from agro-industrial activities is an important source of methane emissions. The organic component of agro-industrial waste is readily biodegradable; thus, greater reduction in biochemical oxygen demand (BOD) and volatile solids (VS) during anaerobic digestion. In addition, higher readily biodegradable fraction of agro-industrial wastes translates directly into high methane production potential. The majority of agro-industrial wastes in developing countries were not treated before discharge and only a minority was treated an aerobically. As a result, agro-industrial wastes represent a significant opportunity for methane emission reductions through the introduction of appropriate anaerobic digestion system.

The majority of organic waste from Agri-food industry is generate in slaughterhouses, meat processing companies, dairy companies, refrigeration plants, farms, sugar factories, breweries, distilleries, fruit and vegetable processing companies, and catering facilities.

2.3. Negative impact of the Abattoirs waste disposes to the environment

One of the most obvious environmental issues common to all abattoirs is the discharge of large quantities of effluent. Abattoir effluent contains blood, fat, manure, undigested stomach contents and cleaning agents. It is typically characterized as having a high level of organic matter, fat, nitrogen, phosphorus and salt (sodium). For plants located near urban areas, effluent discharged into a municipal sewer system or directly into streams, rivers or lakes (Global Methane Initiative, 2011).There by putting these ecosystems at risk. Lack of treatment systems at slaughterhouse facilities was deeply rooted in the shortage of financial and technical resources. Other factors, such as lack of governmental and societal pressures and a lack of knowledge of alternative practices also impede the implementation improved slaughterhouse wastewater management especially in developing country

The most widely disposed wastes are manure, blood and intestinal matters which are highly rich in protein, nitrogen and phosphorus contents (EPA, 2002) So the Wastewater streams in the meat processing industry are high-strength in wastewater effluent streams due to their concentrations of the following biological and chemical contaminants: , (EPA, 2002).

- Biochemical oxygen demand (BOD), commonly referred to as BOD_5, which stands for the amount of oxygen demand over five days at a constant temperature,
- Chemical oxygen demand (COD),
- Nitrogen, and
- Phosphorus

BOD and COD of Blood and Manure

Blood

Blood from beef cattle has an average BOD of 156, 000 mg/L (EPA, 2008) and Raw blood is known to have COD values in excess of 375, 000 mg/L Whereas the recommended limit of COD in treated wastewater before discharge into surface water bodies is put at 125 mg/L (D. O. O mole et.al, 2013) which implies, the relative "strength" of blood as a polluting agent. Maximum amount of blood dispose to Addis Ababa City River from AAAE is 12,300kg/day without any treatment. While blood is one of the most powerful nutrient media for anaerobic bacteria known in nature by mixing with other substrates of a higher carbon content such as paunch Manure.

Manure and undigested stomach content

The generally accepted value for the BOD_5 of manure is approximately 27,000 mg/kg of excreted manure although it does not contribute to the BOD of the wastewater stream as greatly as blood, it pollutes the effluent streams at the same extent (EPA, 2002). COD from the animal dung was put at 15, 000 – 30, 000 mg/L. (D. O. O mole et.al, 2013). The liquid paunch juice has a chemical oxygen demand (COD) of up to 80,000 mg/l. It is a homogeneous, green colored liquid that is highly suitable for digestion in an anaerobic plant, (GTZ, 2001). Maximum amount of Manure and Undigested stomach content disposed to Addis Ababa City River from AAAE is 12060 and 48,240 kg/day respectively without any treatment.

Nitrogen

Nitrogen is also a key component in waste water streams. Blood and manure are the most significant sources of nitrogen in meat processing wastewaters (EPA, 2002) which is essential to the production of plant and animal tissue. It was used primarily by plants and animals to synthesize protein. Nitrate, compound containing nitrogen, can exist in the atmosphere or as a dissolved gas in water, and at elevated levels it can have harmful effects on humans and animals. Nitrates in water can cause severe illness in infants and domestic animals. Common sources of excess nitrate reaching lakes and streams include septic systems, animal feed lots, agricultural fertilizers, manure, industrial waste waters, sanitary landfills, and garbage dumps. (MPCA, 2008)

Phosphorus

Primarily, phosphorus and phosphorus-containing compounds are found in blood and manure, as well as in undigested stomach contents, which were removed during the excretion phase. (EPA, 2002). Phosphorus contributed by human activity has come to be a major cause of excessive algae growth and degrades lake water quality. (MPCA, 2008).Because of the content of above biological and chemical contaminants Addis Ababa abattoirs waste have great potential to pollute the environment due to high content of BOD,COD ,Nitrogen and Phosphorous and affects downstream dwellers which has negative impact on drinking water , river and streams and atmosphere.(EPA, 2002)

Impacts on Drinking Water

When the Abattoirs waste disposed to lagoon which seeps in to underground sources of drinking water that increase the amount of nitrate in the ground water supply can reach unhealthy levels. The microorganism (cryptosporidium) found in animal waste can pose public health threats. If the presence of this microorganism set beyond the standard, the community will not only face health risks but also they have to find new sources for their drinking water supplies.

River and Stream Impact

Blood, manure and undigested stomach content can severely harm river and stream ecosystem. These wastes contain ammonia which is highly toxic to fish at low level. Increased amounts of nutrients such as nitrogen and phosphorus can cause algal blooms which block water ways and deplete oxygen as they decompose. This can kill fish and other aquatic organisms (EPA, 2002).

Impacts on atmosphere

Atmospheric pollution can be caused by gases emitted from decomposition of wastes. This air pollution can cause lung inflammation and increase respiratory diseases. Emission of reactive organic and ammonia can play a role in the formation of ozone (smog) and particulates. In addition to negative health impacts, ozone can reduce agricultural yields and make plants more vulnerable to disease. Odorous and toxic gases such as sulfur dioxide produced by decomposition of animal waste may also cause headaches, throat and eye irritation after prolonged exposure. Methane emission from waste decomposition also contributes climate change (EPA, 2002)

2.4. Potential of slaughterhouse wastes for biogas production

Substrates must meet nutritional requirements of microorganisms for energy, new cells formation and as well as trace elements and vitamins for microbial enzymes. The C: N ratio should not be too high to avoid nitrogen deficiency (Yen and Brune, 2007). Not too high levels of C: N ratios can stimulate methanogenesis. The C: N ratios for various substrates are shown in Table 5. Materials have different energy content; hence produce gas with varying methane content (WCECS 2014), Table 1 shows approximate biogas volumes and methane content from carbohydrates, protein and fats. These values can be used for theoretical calculation of the amount of gas that can be produced.

Proteins are a rich energy sources and produce a lot of methane during decomposition. Proteins are first converted into amino acids during hydrolysis and these were later converted to ammonia and ammonium. An increase in ammonium production due to increase in temperature and pH leads to foaming. Materials with high sugar content should be mixed with less digestible material to achieve a balanced process although fats are very energy rich materials which can produce a lot of biogas. They also cause process instability due to foaming at high temperatures. (WCECS, 2014).

Table 1: Biogas production from carbohydrate, fats and protein (WCECS, 2014),

Items	Biogas formed (m3/kg VS)	Biogas composition: CH_4: CO_2 (%)
Carbohydrates	0.38	50:50
Fats	1	70:30
Protein	0.53	60:40

Slaughterhouse waste is very energy-rich waste stream of meat industry (Edström, 2003*)*.It is an attractive material to treat through anaerobic digestion for the production of biogas due to its content of a complex mixture of fats, proteins, complex organic compounds and water.

A study done by (Thibault Caille , 2011) showed that there is strong potential for biogas and bio fertilizer production from residues of slaughter houses at high altitude and cold climate in Bolivia. Blood is the major component responsible for the contamination of water. Biogas production led to avoid water contamination and also limit the greenhouse effect by limiting the methane release into the atmosphere. Due to uncontrolled waste management and to improve the agriculture yields through the use of organic fertilizer.

Biogas production using a mixture of pig manure and slaughterhouse waste showed that pig manure and slaughterhouse waste mixed at the ratio of 9:1 which is the most efficient for use in energy production (Vytautas, 2011). A study done on the potency and characteristics of biogas production using slaughterhouse wastes showed that slaughterhouse wastes either liquid or solid. It is highly suitable and has high potential to be treated an aerobically for biogas production (Budiyono, *et al*., 2011).

2.4.1. General process of Slaughter house waste

Small to medium meat processing facilities can be categorized according to the activities performed at the facility: A) slaughter and Boning, B) Processing and C) Rendering. Available waste that generate from each process describe as follows:-

Reception of livestock -Animals are delivered to the abattoir in trucks, and held for one day in holding yards and manure or cattle dung dispose in this area.

Stunning and bleeding- Effluent with high organic load, especially blood is discharged

Hide removing -Generation of putrescible by-products and Effluent with a high content of organic matter.

By-product processing

Edible offal components and casings (intestinal tract) are separated from the viscera and sent on for cleaning and further processing. From this generate large amount of intestinal and stomach content waste.

Rendering

At various stages in the process, inedible by-products such as bone, fat, heads, hair and condemned offal are generated. These materials are sent to a rendering plant either on site or off site for rendering into feed materials and tallow.

2.4.2. Energy sources used and Energy consumption in Addis Ababa slaughterhouse

The primary energy sources consumed are 19 % electricity, 80% furnace oil and 1% gasoline (Figure 1). Electricity was used for both slaughter and rendering section. Furnace oil and gas oil was used for hot water & steam generation and diesel generator. There are significant differences in the energy breakdown for rendering and non-rendering sites. Non-rendering sites use both gas oil and electricity. Rendering sites use more furnace oil and gas oil 80% of overall energy consumption due to the additional steam required for the rendering process and wash down activities (Figure 1).

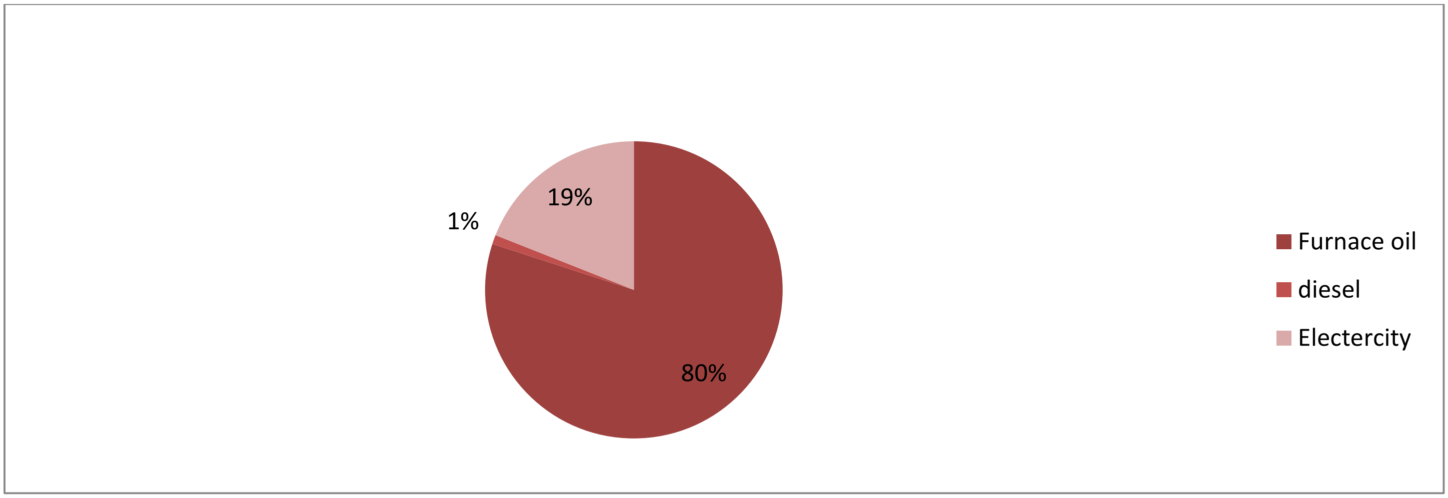


Figure 1-Breakdown of energy sources at AAAE.

Rendering unit use more energy than slaughtering only, as is depicted in Figure 2 energy consumption increase from slaughtering to rendering process unit .Within these categories, the amount of product cooling and species mix also has impacts on the energy use.

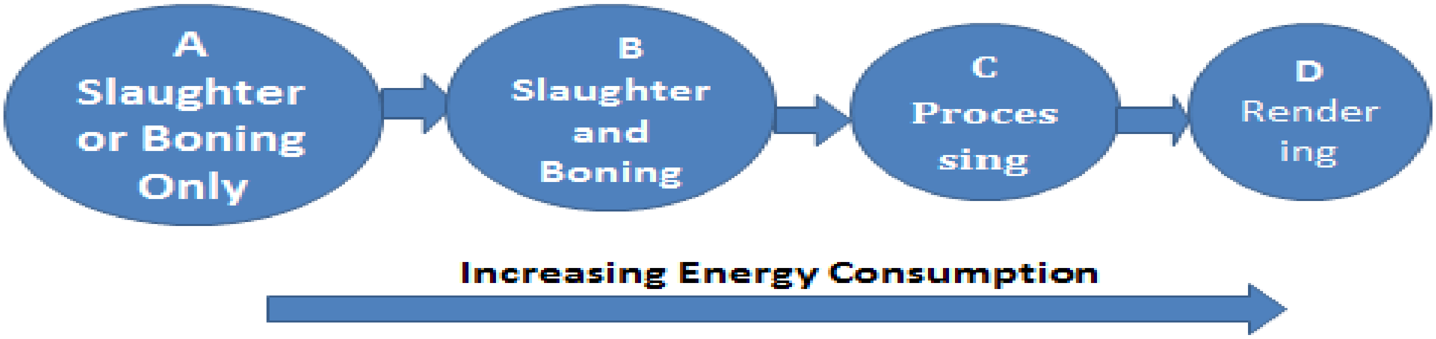


Figure 2-Relationship Energy consumption between activities

2.4.3. Energy consuming Equipment of Slaughter House

The main energy consuming equipment's are refrigeration plant, steam and hot water generating equipment (Boiler), cooker and Bone Crusher. The actual percentage breakdown for the energy consuming equipment will differ depending on whether the site does rendering or not

Steam and hot water generators-Boilers which produce steam and hot water is powered by furnace oil, naphtha, and electricity, almost 60-80% of the overall energy is use for cleaning, sterilizing and rendering purpose. For rendering sites up to 80% of total energy consumption was used in the process of generating steam and hot water (Figure 3).

Refrigeration equipment-Energy demand for refrigeration is dependent on the amount of meat stored and the location of the plant; it is powered by electricity and diesel generator (figure 3). Plants in colder areas have lower cooling requirements than plants in warmer locations in which case refrigeration shares15-31% of over the overall energy used.

Pumps- use for a number of purposes including circulation of fluids in refrigeration and hot water systems, water supply for stock, waste water treatment, recycled water and irrigation. 3% of the overall energy use.

Processing Equipment -Processing equipment includes items such as conveyer screw press, hammer mill, band saws, skin tumbler and loin washers that is 2% of overall energy use(figure 3) and other high energy intensive equipment like Bone Crusher, pre heater of furnace oil and cooker which were powered by electricity and working for long time.

Air compressors -Compressed air use to run air knives, animal handling apparatus, and pneumatic controls for automated machinery and shares1% of the overall energy use(figure 3).

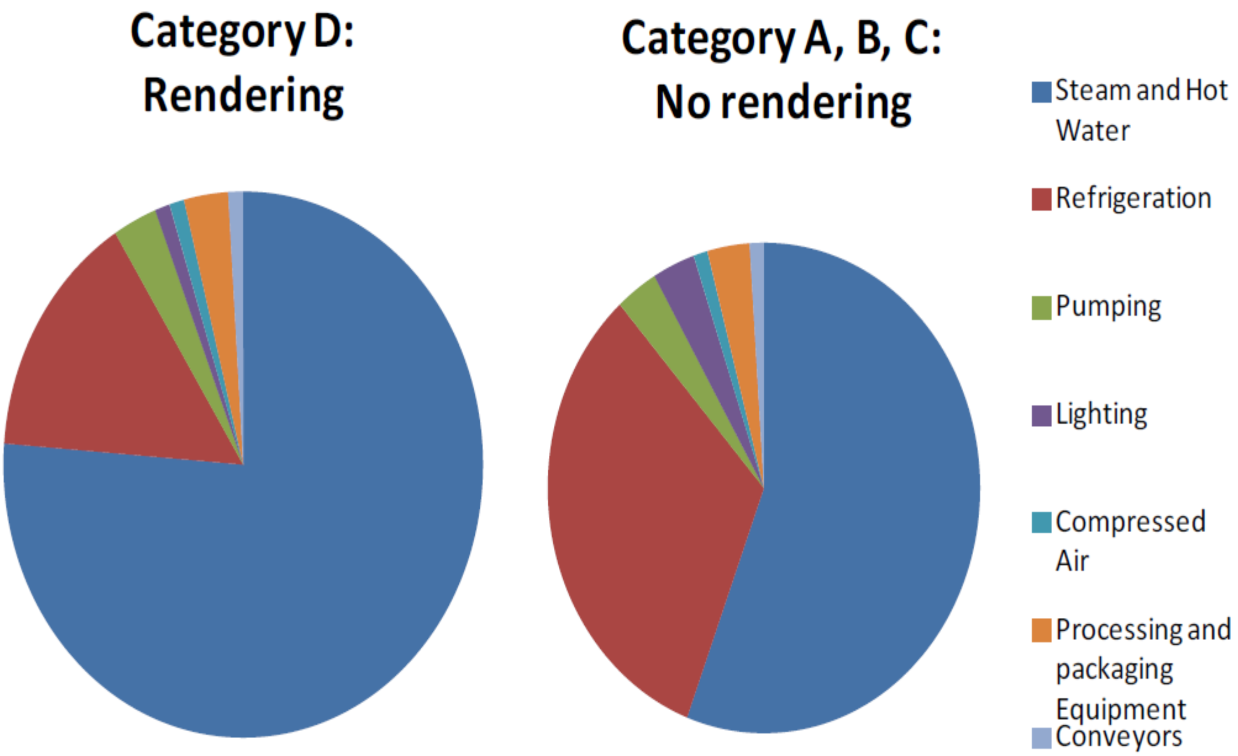


Figure 3- Energy consumption by equipment. (Phuong and Mike , 2013)

2.5. Anaerobic Digestion and Biogas technology

Anaerobic digestion is a process by which microorganism’s breakdown biodegradable material in the absence oxygen which can generate biogas. It uses to manage waste and energy production of industrial or domestic purpose. The biomass was converted by the action of bacteria in an anaerobic environment, producing a gas with an energy content of about 20–40% of the lower heating value of the feedstock. AD is a commercially proven technology and was widely used for treating high moisture content organic wastes having high moisture content, i.e. 80– 90% moisture.

Biogas can be used directly in gas turbines and can be upgraded to higher quality i.e. Natural gas quality, by the removal of CO_2. When use as a fuel to produce electricity only, the overall conversion efficiency from biomass to electricity is about 10–16%. As with any power generation system using an internal combustion engine as the prime mover. Waste heat from the engine oil and water-cooling systems and the exhaust could be recovered using a combined heat and power system. ((P.McKendry, 2002).

Biogas is a combination of methane and carbon dioxide with small amounts of other gases such as nitrogen and hydrogen sulfide. Methane which is a combustible gas, with no color and odor, is the gas responsible of the combustion of the biogas. A typical biogas composition is shown in the following Table2.

Table 2: Typical composition of biogas (**(Thibault cailee, 2010)**.

Biogas components	**Symbol**	**Content**
Methane,	CH_4	60– 80 %
Carbon dioxide,	CO_2	15 – 35 %
Water vapor,	H_2O	Saturation
Nitrogen,	N_2	2– 3%
HydrogenSulfide,	H_2S	1-2%
Oxygen,	O_2	0 – 2 %
Ammoniac,	NH_3	0-1%
Hydrogen.	H_2	0-2%
Organic compounds		Traces
Oxygen	02	0-2%

Methane is virtually odorless and is invisible in bright daylight. It burns with a clear blue flame without smoke and is non-toxic. It produces more heat than kerosene, wood, charcoal, cow-dung chips etc. The specific gravity of methane (relative to air) is 0.55, critical temperature = 82.5°C and pressure for liquefaction 5000 psi. Air requirement for combustion (m^3/m^3) is 9.33 and the ignition temperature 650°C.

2.5.1. Energy potential of Bio gas

Biogas is a combustible gas with a high calorific value 26 MJ/m^3 of biogas which depends on the substrate and digestion process (Wilson, 2004). Biogas has a capacity to apply in technological processes and for power engineering purposes. Production of thermal energy in gas boilers and production of thermal and electrical energy in associated units from 1 m^3 of biogas has a calorific value of 22 MJ has a methane content of 50-60% in associated production of energy 2.1 kWh of electrical energy and 2.9 kWh of heat is obtained; (Krzysztof and Magdalena, 2012).

The average efficiency of methane digestion reaches approximately 0.24 m^3 of methane from 1 kg of dry organic matter. 1m^3 calorific value may replace 0.77 m^3 of natural gas of 33.5 MJ calorific value, 1.1 kg of hard coal of 23.4 MJ calorific value or 2 kg of firewood of 13.3 MJ Calorific Value (Arbon, 2002). And Table 3 shows that biogas has a high calorific value compared to the other energy sources.

Table 3: Comparison between biogas and other thermal energy sources **(Noxolo and Muzenda, 2014)**

Fuel Type	U.M	Caloric Power(Kcal/U.M)	Equivalent in U.M. for1m^3 of bio gas
Biogas 60% Methane	m^3	5137	1
Dry Wood	Kg	1800-2200	2.85-2.34
Lignite	Kg	1800-3800	2.85-1.35
Coal dust briquettes	Kg	4000-6800	1.28-0.76
Tar	Kg	9,400-9,500	0.55-0.54
Fuel Radiator	Kg	9,500-9,700	0.54-0.53
Diesel Fuel	Kg	10,000-11,000	0.51-0.47
Natural Gas	Kg	8,500	0.60
Liquefied petroleum gases	Kg	22,000	0.23

U.M= Unit Volume, Kg= Kilograms, m3= Meter Cube, ^{o}C = Degree Celsius, Kcal/U.M= Kilocalories per Unit Volume.

2.5.2. Biological Process

The decomposition of organic waste to produce biogas depends on a complex interaction of several species of microorganisms (bacteria).This bacteria species require a harmonious environment for efficient utilization of biomass waste to biogas. The digester operation should be in dynamic equilibrium which is progressive change without disrupting the harmonious environment of the system. Any sudden change in the environment will result in production of unwanted product which ultimately inhibits the overall production. Therefore, it is essential to understand the major microbiological pathways, for sufficient and effective production of biogas.

Here the detailed microbiological path ways will be discussed. Bio Gas production by anaerobic digestion was accomplished in three stages as explained below (Liuguo, 2010*)*

Solubilisation or Hydrolysis-Initially, feedstock is solubilize by water and enzymes. The feedstock was dissolved in water to make slurry. The complex polymers were hydrolyzed into organic acids and alcohols by hydrolytic fermentative bacteria, which are mostly anaerobes.

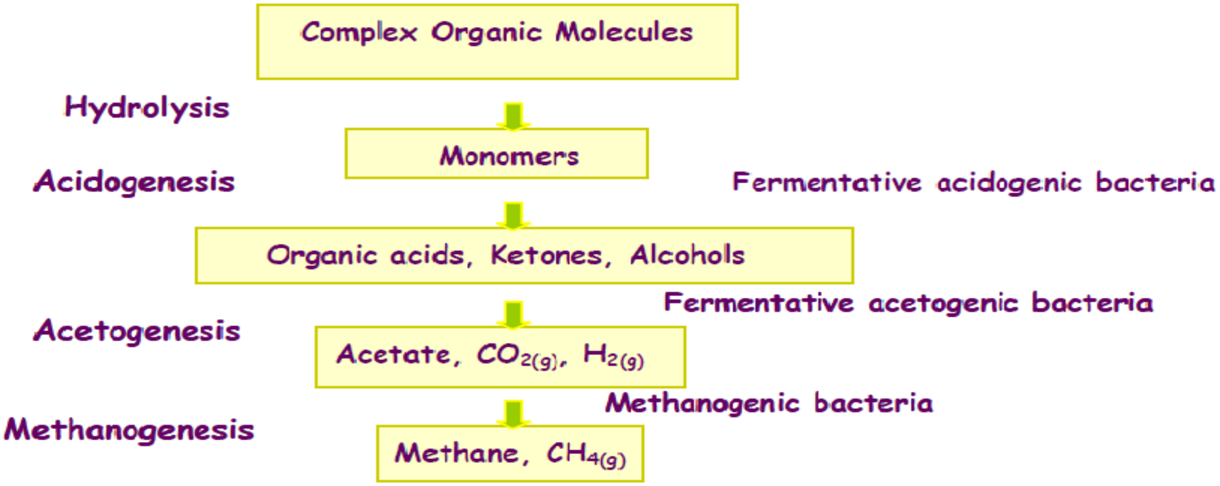


Figure 4-Schematicdiagram of anaerobic digestion process for Biogas production (Awosolu, 2007*)*

The microbial cell is impermeable to the cellulose molecule so the organism must excrete extracellular enzymes in order to make the carbon source available. This stage converting carbohydrate, fat and protein to simple sugar, fatty acid and amino acid. The extra cellular catalysts act hydrolytically, converting the insoluble materials to soluble sugars that penetrate the cell membrane. The large molecular complex substances are soluble into simpler ones (especially volatile acids, which are low molecular weight organic acids) with the help of extracellular enzyme excreted by the acid forming bacteria. The phase was also known as polymer breakdown stage. (Fabient, 2003)

Acidogenesis:-In this stage the products of hydrolysis were subsequently metabolized by obligatory anaerobic bacteria collectively called Acidogenic bacteria. The intermediate products formed are short chain fatty acids Alcohol, hydrogen and carbon dioxide. The interesting products as initial intermediate product for the formation of methane gas are acetic acid, hydrogen and carbon dioxide. The overall performance of the anaerobic digestion was affected by the concentration of individual fatty acids (short chain fatty acids) formed in the Acidogenic stage because acetic acid and butyric acid are the preferred precursor for methane production.(Hwang, 2001).

As pH drop occurs owing to acetate accumulation, microbes would limit acidification from metabolism by producing lactate or butyrate of acetate or by re-up taking acetate to acetyl-coenzymes. Bacteria responsible for acid production are facultative, obligatory or both. But in general the microorganisms which produce short fatty chain acids exhibit obligate proton-reducing metabolism. *(*Cheong, 2005*)*

Acetongenic phase-The term 'Acetogen' refers to the collection of bacteria that generates acetate (CH_3COOH) as a product. The end product of acetogenic phase is acetic acid, carbon dioxide and hydrogen in well monitored production. This intermediate conversion is important for proper anaerobic digestion and methane production because methagones bacteria performing the next last phase called methanogenic phase don't utilize these volatile fatty acids directly (Parawira2004*)*. In other terms, what it means is the bacteria in the next phase can process only acetate, hydrogen and carbon dioxide.

The acetogens are very slow-growing, sensitive to fluctuations in organic loads and also sensitive to environmental changes. Which long lag periods are likely to be required for these bacteria to adjust to new environmental conditions (Xing, *et al.*, 1997).
They also depend on low partial pressure of hydrogen in order for the acetogenic degradation to proceed. Therefore, syntrophic associations with hydrogen-consuming methanogens are required. Syntrophy means literally eating together' and refers to the inter dependence of the hydrogen-producing and hydrogen consuming methanogenic microorganisms. Such associations between acetogenic/acidogenic bacteria and methanogens are necessary when such reactions are thermodynamically unfavorable, as indicated by the conversion of simple substrate intermediates to acetate and hydrogen and their use to produce methane
(Table 4).

Table 4: **Acetogenic and methanogenic reactions (**Wilson, 2004)

Acetogenic reactions		
Propionate Acetate		
$CH_3CH_2CH_2COOH+2H_2O$	$\rightarrow$	$2CH_3COOH+2H_2$
Ethanol		Acetate
$CH_3CH_2OH+H_2O$	$\rightarrow$	$CH_3COOH+2H_2$
Lactate		Acetate
$CH_3CHOHCOOH+H_2O$	$\rightarrow$	$CH_3COOH+CO_2+2H_2+H_2O$

Methanogenic reactions

Acetate Methane

$CH_3COOH+2H_2O \longrightarrow CH_4+CO_2+H_2O$

Carbon dioxide + Hydrogen Methane

$CO_2+H_2 \longrightarrow CH_4+H_2O$

.Methanogenesis-The final step in anaerobic digestion is termed as methanogenic phase. The methanogens utilize mainly H_2/CO_2 and acetic acid to form methane and carbon dioxide. Methane-producing microorganisms are obligate anaerobes and very sensitive to environmental changes (Rozzi and DiPinto, 1994). The hydrogen-utilizing methanogens have been found to be more resistant to environmental changes than aceticlastic methanogens and, therefore, methanogenesis from acetate has been shown to be rate limiting in several cases of anaerobic treatment of easily hydrolysable waste (Archer, 1983.)

2.5.3. Factors influencing Anaerobic Digestion

The rate of biogas production depends on: the nature of the substrate, temperature, pH, loading rate, toxicity, stirring, nutrients, slurry concentration, digester construction and size, carbon to nitrogen ratio, retention time, alkalinity, initial feeding, total volatile acids, chemical oxygen demand (COD), total solid (Ts), volatile liquids etc.

2.5.3.1 Temperature

The temperature affects directly the velocity of the biological reactions by influencing the metabolic activity of the microorganisms involved in the process. The efficiency of anaerobic processes is thus highly dependent of the reactor temperature. In anaerobic digestion three different temperature ranges were identified depending on the suitable range for microorganisms to grow and metabolize the substrate available. Psychrophilic temperature (0-20^{o}C). Mesophilic temperature (20^{o}C-42^{o}C) and Thermophilic temperature (42^{o}C -75^{o}C*)* *(*Rajeshwari, 1999*)*

At Psychrophilic temperature there is very low biogas production rate because of low mixing intensity and poor substrate biomass contact. Which results scum formation inside the digester because of very low rate limiting degradability of the long-chain fatty-acids which follows accumulation of fatty acid inside the reactor and foaming may occur and so inhibit process continuity.

Anaerobic digestion reactors were normally operated within the mesophilic and thermophilic ranges (Van Lier, *et al*., 1996). Mesophilic processes are optimal temperature range for stable digestion process and good gas production.

Thermophilic conditions have been adopted for anaerobic digestion of some industrial organic wastes, manure and domestic sewerage (Archer, 1983; Song, *et al*., 2004). Thermophilic anaerobic digestion may become an attractive alternative to mesophilic digestion because of the higher growth rates of the bacteria involved in short retention time. Therefore, the high activities per unit biomass, and higher loading rate of organic materials that can be active (Dugba and Zhang, 1999). However, thermophilic temperature range the digestion process becomes increasingly unstable with rising temperature and needs higher rate of heat input. Which is usually not economically acceptable. The bio slurry discharge from the digester containing larger amount of dissolved solid because of the short retention time the bacteria cannot decompose all dissolve solid inside the digester. In addition to this the disadvantage of thermophilic digestion has not been successful in practice because thermophilic bacteria are very sensitive to small temperature changes. (Viessman and Hammer, 1993). Results of comprehensive studies suggest that thermophilic anaerobic digestion may be attractive for treating high-temperature industrial effluents and specific types of slurries. Food industries, such as vegetable processing and canning factories, and alcohol distilleries, employ high-temperature unit operations, which generate hot effluents. (Lepisto and Rintala, 1997).

2.5.3.2. C: N ratio

The relationship between the amount of carbon and nitrogen present in organic materials is expressed in terms of the carbon/nitrogen ratio (C/N). Ranging from 20:1 to 30:1 is optimal for anaerobic digestion (Akwaka, 2014).If the C/N ratio is very high, the nitrogen will be consumed rapidly by methanogens for meeting their protein requirements and will no longer react on left over carbon content of the material. As a result, gas production will be low. On the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of ammonia. Ammonia will increase the pH value of the content in the digester. The C: N ratio of different feed stock is shown Table 5

Table 5:- C/N ratio of materials used as substrates for biogas production (WCECS, 2014)

Material	C/N ratio
Cattle manure-liquid	6 to 20
Chicken manure	3 to 10
Swine manure-liquid	5
Straw	50 to 150
Grass	12 to 26
Potatoes	35 to 60
Sugar beet/beet foliage	35 to 46
Cereals	16 to 40
Fruits and vegetable	7 to 35
Mixed food waste	15 to 32
Food waste	3 to 17
Slaughterhouse waste –guts	22 to 37

2.5.3.3. pH

Each group of microorganisms involved in the anaerobic fermentation has its own optimal pH for growing. The optimum of pH for acetogens is around 6.6 while it is around 6.8-7.2 for the methanogens. Acidogens have an optimal pH around 5-6 and hydrolytic bacteria around 7.2-7.4 (Zoetemeyer*et al*., 1982).The growth rate of methanogenic microbes decreases sharply below pH 6.6 (Mosey and Fernandes, 1989). The sensitivity of methanogens to low pH values may be the result of deterioration of the energy-generating process of the organisms. Variations in pH levels from 6.0 to 8.0 have been reported to affect the dominant microbial populations in the acidic phase (Demirel and Yenigun, 2002). Acidogenesis can occur at pH values approaching neutrality.

Efficient methanogenesis from a digester operating in a steady state should not require pH control but during start-up or with unusually high feed loads, pH control may be necessary. pH can only be used as a process indicator when treating waste with low buffering capacity, such as carbohydrate-rich waste (Wilson, 2004***).***

This parameter affects considerably the enzymatic activity of microorganisms. The pH of the system also influences other parameters such as the toxicity of certain compounds (ammonia). Thus it is important to control the pH of the system between 6.5 and 8 because of methanogenesis to occur and to monitor and control the anaerobic reactions.

2.5.3.4. Hydraulic retention time (HRT) and Organic Loading rate (OLR)

HRT (Hydraulic Retention Time):-the total time required by a given amount of dung to produce 80 to 85 % of total gas. HRT is expressed in days and the time that the biomass spends in the bio digester, from its charge into the bio digester until its discharge. There is no way to calculate theoretically the optimal HRT since its value depends on the ambient temperature and of the organic material loaded in the bio digester. : (Mohammad et al., 2013)

The higher is the degradability of the organic material, the shorter is the retention time, with an optimal value. If the HRT is too short, bacteria do not have time enough to degrade the organic material. While if it is too long, the bacteria will starve and the production of methane decreases once the optimum was exceeded. This explains also why the temperature is very important because it influences the velocity of degradability of the organic material. HRT define as follows: (Mohammad et al., 2013)

$$\text{HRT [day]} = \frac{\text{Volume of the digester } [\text{m}^3]}{\text{Volume of organic material daily loaded } \left[\frac{\text{m}^3}{\text{day}}\right]}$$

2.5.3.5. Inhibitory Factor

Mineral ions, heavy metals and the detergents are some of the toxic materials that inhibit the normal growth of pathogens in the digester. Generally many nutrients stimulate the growth of microorganisms at low concentration. At intermediate concentration have no effect but present in high concentration inhibit it. The synergism and antagonism concepts are important to consider when dealing with toxicity and inhibition. Antagonism is the decrease in toxicity of a substrate in presence of other ones while synergism is the increase in toxicity of a substrate in presence of other ones .All microorganisms has the ability to adapt themselves to inhibitors but the time of adaptation varies depending on the microorganism. We can note that methanogens are considerably more sensible to toxicity and inhibition than the other microorganisms involved in the anaerobic digestion. Indeed the growing rates are lower which means that the risk of inhibition is higher.

Table 6: Limiting concentrations for various inhibitors of Bio Methanation

Substance	mg/l
Copper	10-250
Calcium	8000
Sodium	8000
Magnesium	3000
Nickel	100-1000
Zinc	350-1000
Chromium	200-2000
Sulfide	200
Cyanide	2

2.5.3. 6. Effect of total and volatile solid on gas production

This parameter leads to calculate the efficiency of the bacterial activity in the transformation of organic material into biogas. The velocity of degradability of the organic material depends on the Characteristics of the raw material. For example, manure produces biogas more rapidly than any Cellulosic material. The content of organic material of any waste can be expressed in different units since all organic materials were composed of water and a fraction of solids. The fraction of solids is called 'total solids' and corresponds to the total solid content of a mixture. It is an important factor to consider with the kind of mixture used in order to ensure a satisfactory process. The best biogas production occur when total solid range from 7% to 10% because of avoiding solids settling down or impeding the flow of gas formed at the lower part of digester (FAO/CMS, 1996). Therefore; dilution of organic substrate or wastes with water to achieve the desirable total solids percentage is required.

2.6. Biogas production in Ethiopia trend and challenges

The biogas technology was introduced in Ethiopia as early as 1979, when the first batch type digester was constructed at Ambo Agricultural College. During the last two and half decades around 1000 biogas plants were constructed in various parts of the country. Size ranges were from 2.5 m^3 to 200 m^3 in households, community, and governmental institutions. Many of the biogas plants were built by the government mainly for demonstration purposes without follow-up structure in place, variations in design, and the absence of a standardized biogas technology (Boers ,*et al*., 2007). Although the raw materials for the technology availables in large amount, such problems have created difficulty in the expansion and use of biogas technology.

Recently, The Ethiopian government under NBPE in collaboration with the Netherland Development Organization (SNV Ethiopia), an international NGO, has embarked on an ambitious biogas program to construct 14,000 plants by 2013 so as to address the rural energy crisis and indoor pollution caused by the burning of traditional biomass. The first phase program is being implemented in Amhara, SNNPRS, Oromia and Tigray regions Anonymous. These biogases are mainly used in small and very small installations for providing household energy and for supplying social institutions with gas as fuel for cooking, heating and lighting. However, potentials for industrial biogas and electricity generation in the country remain largely untapped. This is despite the need to scale up electricity generation in Ethiopia to bridge the huge production demand gap.

The main challenges for dissemination of biogas technology in Ethiopia is such as:-

High Initial Investment Cost-the main bottleneck to the implementation of biogas technology in Ethiopia where an important number of population lives under the poverty line. Hence, they cannot afford Biogas construction cost.

Lack of Information Sharing and Recent Research Information on Biogas Technology

Research engagements are not yet fully adopted by academicians and government institutions sometimes due to lack of funds or roadmap. These actually have negative impact on biogas dissemination and also obstruct joint research programs between developed countries and developing countries.

Biogas Technology Pilot Phase Failure – few digesters constructed face fallerity that disrupted biogas dissemination campaign (NBPE, 2012).

2.7. Types of Bio Gas Digester

There are different an aerobic digester type available in the market that vary in process configuration and operating condition. Design considerations and operating conditions is these treatment trains may be suitable for a particular type of feedstock or feedstock mix but may not be applicable or economical for others. That is why digester type and technology should be selected based on the intended feedstock characteristics and availability of resource. the first three models which were classified based on the Gas holder type of biogas plant and the second type is waste water treatment systems which are High Rate, low rate Anaerobic and passive Treatment systems are briefly discussed below.

2.7.1. Floating Drum Digester.

The digester chamber is made of brick. When methane gas was produced the gas pressure pushes the mild steel drum upwards and as the gas was being used the drum gradually lowers down. By observing the level of drum, one can assess the gas volume available. Since the mild steel drum practically 'floats" above the digestion chamber as shown in Figure 5.

Floating drum digesters produce biogas at a constant pressure with variable volume. From the position of the drum, the amount of biogas accumulated under the drum is easily detectable. However, the floating drum needs to be coated with paint in a constant interval to avoid rust. Additionally, fibrous materials will block the movement of digester. (Karthik et al., 2012)

Advantages

The gas pressure is constant, determined by the weight of the gas holder. The construction is relatively easy, construction mistakes do not lead to major problems in operation and gas yield and Suitable for larger plants.(GTZ.1989)

Disadvantages

The floating drum plants became obsolete due to comparatively high investment and maintenance cost along with other design weaknesses. For example, the mild steel drum corrodes and needs to be replaced within 5-10 years ,Cannot be built in remote areas, nearby workshops are necessary, Regular (annual) maintenance required ,Fairly sensitive for temperature changes and less suitable in mountainous regions .(GTZ.1989)

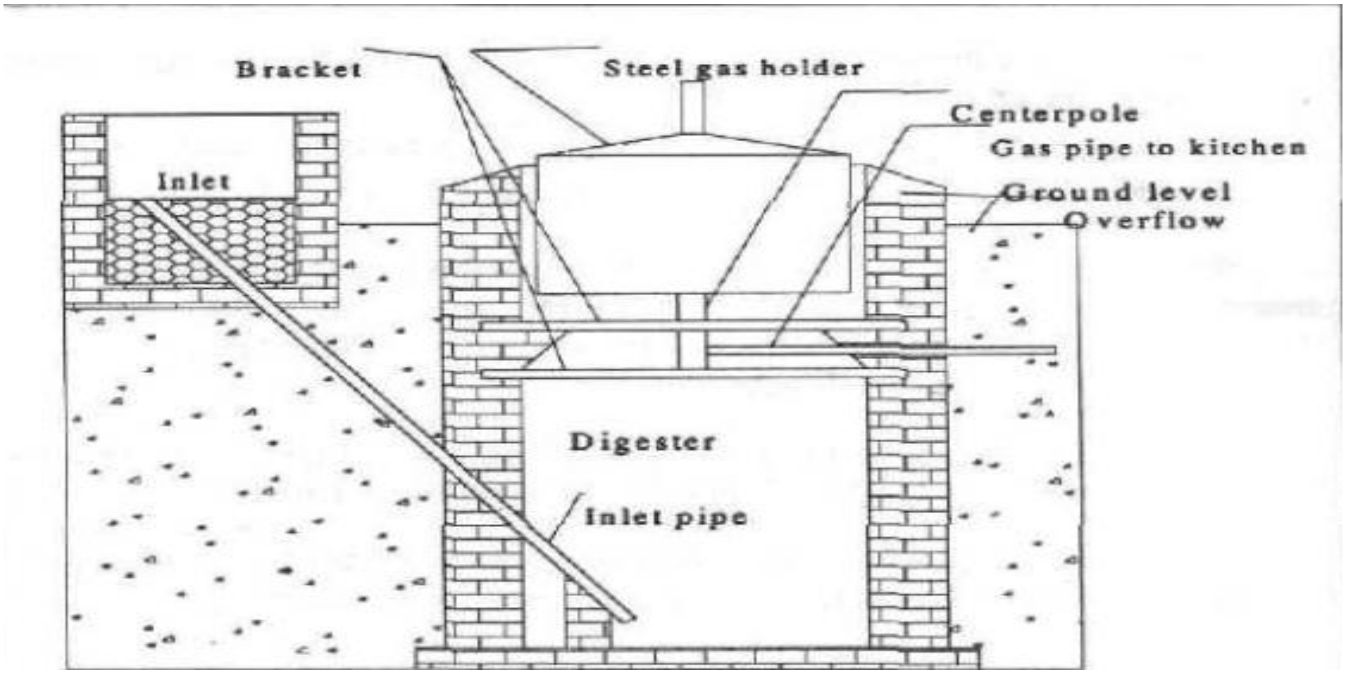


Figure 5-Floating gas holder system.(karthik et al.,2012)

2.7.2. Fixed Dome Digester

The fixed dome digesters are the most common model developed and used mainly in China for biogas production (Santerre et al, 1982). The digester was filled through the inlet pipe until the level reaches the bottom level of the expansion chamber as shown in figure 6. The produced biogas was accumulated at the upper part of the digester called storage part. The difference in the level between slurry inside of the digester and the expansion chamber creates a gas pressure. The collected gas requires space and presses a part of the substrate into an expansion chamber. The slurry flows back into the digester immediately after gas is released (Sasse. ,*et al*, 1991).

Fixed dome digesters are usually built underground (Santerre ,*et al*., 1982) .The size of the digester depends on the location, amount of energy consumption, 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 6 m^3 for a family of 9. (Adeoti, et *al.*, 2000)

Instead of having a digester for each individual home, a large volume digester is used to produce biogas for 10–20 homes, and is called community type biogas digesters. In countries where houses are clustered as in Nigeria, these types of biogas digesters are more feasible (Akinbami,*et al*, 2001)

Advantage

Fixed Dome Digesters have relatively low construction costs, due to the absence of moving parts and rusting steel parts. If well-constructed, fixed dome plants have a long life span. The underground construction saves space and protects the digester from temperature changes. The construction provides opportunities for skilled local employment**.**(GTZ, 1989).

Disadvantages

The frequent problem is due to the gas-tightness of the brick work gas holder (a small crack in the upper brick work can cause heavy losses of biogas). Fixed-dome plants are recommended only where construction can be supervised by experienced biogas technicians. The gas pressure fluctuates substantially depending on the volume of the stored gas. (GTZ, 1989).

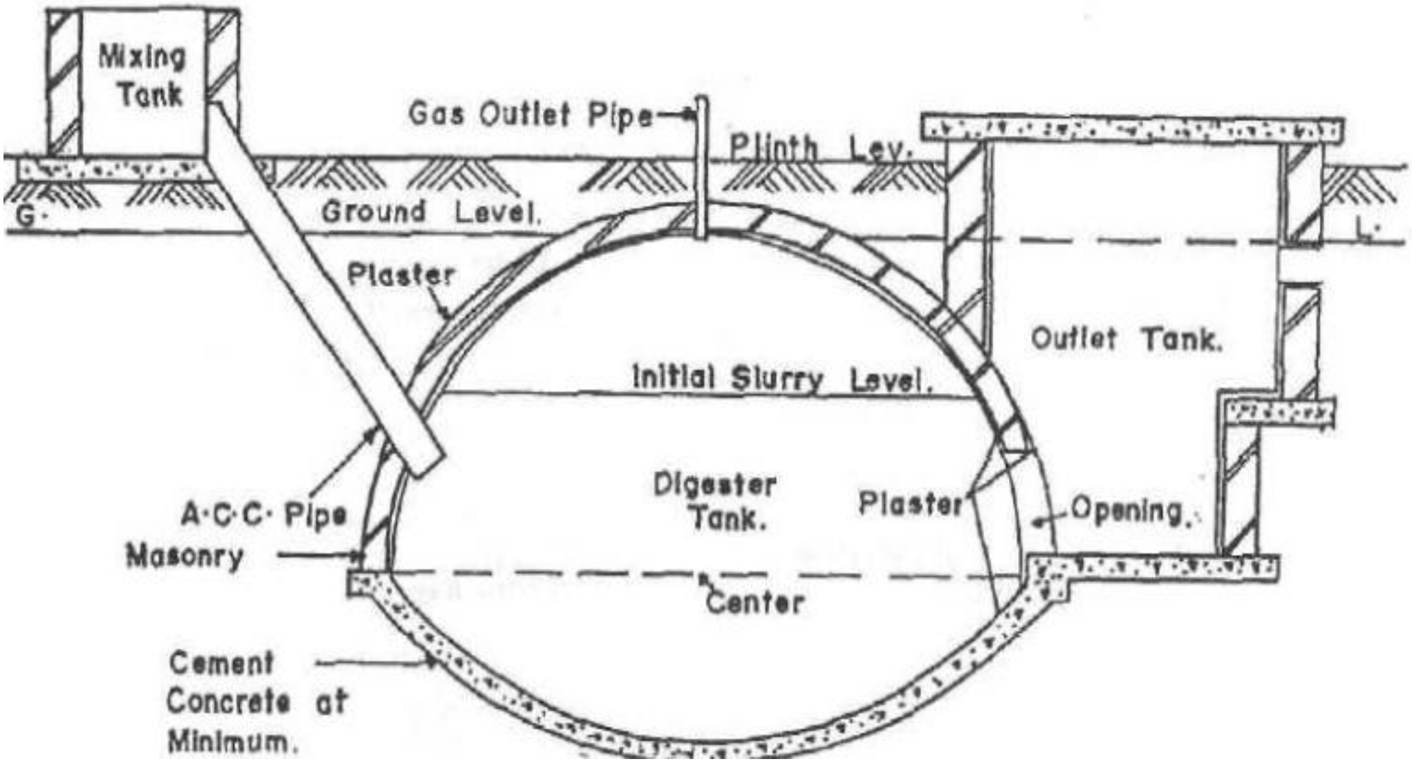


Figure 6: **Fixed dome bio gas digester. (Karthik et al., 2012)**

2.7.3. Plastic Bag digester

The digester is a long cylindrical bag (tube) supported by a hardened layer of masonry, concrete, compacted sand or mud trench is shown figure 7. The digester is fed semi-continuously, 1-2 times per day.

Advantage

A great advantage of the bag digester is the simple design and low material costs, ease of transportation, low construction sophistication, high digester temperatures, uncomplicated cleaning, emptying and maintenance

Dis advantage

Furthermore, the effective life span of a bag digester is less than other digesters (short life span 4year max), Very damageable, relatively few successful installation and not very easy to operate

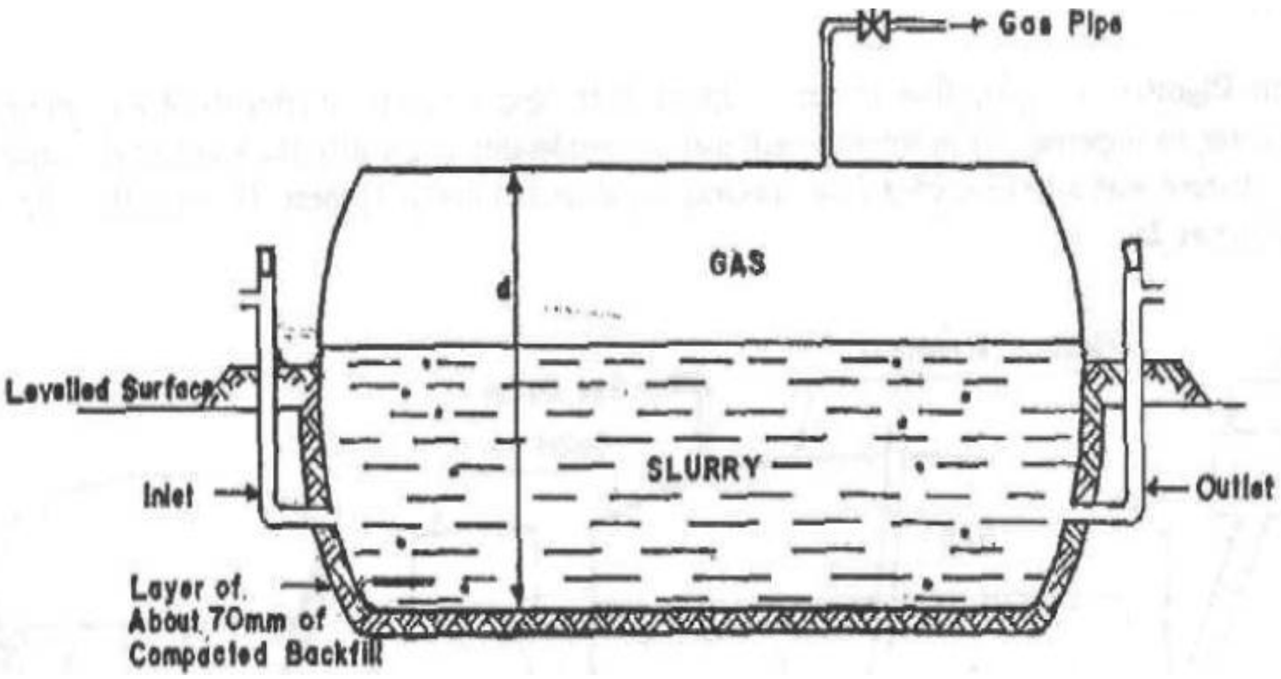


Figure 7: Bag Digester. (Karthik et al., 2012)

Other type of Biogas digesters are - High rate system, Low rate system and Passive system (Ann C.Wilkie, 2005).

2.7.4. High Rate Anaerobic reactor technology

High Rate Anaerobic Treatment are unfit for the digestion of concentrated slurries but suitable for diluted and concentrated waste water. The sludge retention time is longer than the hydraulic retention time, as the sludge is retained in the reactor by using internal settler systems or external settlers with sludge recycling or fixation of biomass on support material. High rate systems are most suitable for waste streams with low suspended solids content. Different types, used world-wide for the treatment of waste water are:-

- **Anaerobic** Contact process.
- Up flow Anaerobic Sludge Bed (UASB).
- Anaerobic fluidized bed reactors.
- Anaerobic Filter (AF).
- Anaerobic sequencing batch reactor (ASBR).

2.7.4.1. Anaerobic contact process

In Anaerobic contact process (figure 8) due to sludge recycling, the SRT is no longer coupled to the HRT. As a result, considerable improvements in treatment efficiency can be achieved. Major drawback is poor sludge settlement arose from gas formation by anaerobic bacteria in settling tank. ACP more complex than other high rate Ads and Absence of any internal fittings offers some advantages for the treatment of wastes having high solids content. (Ann C.Wilkie, 2005).

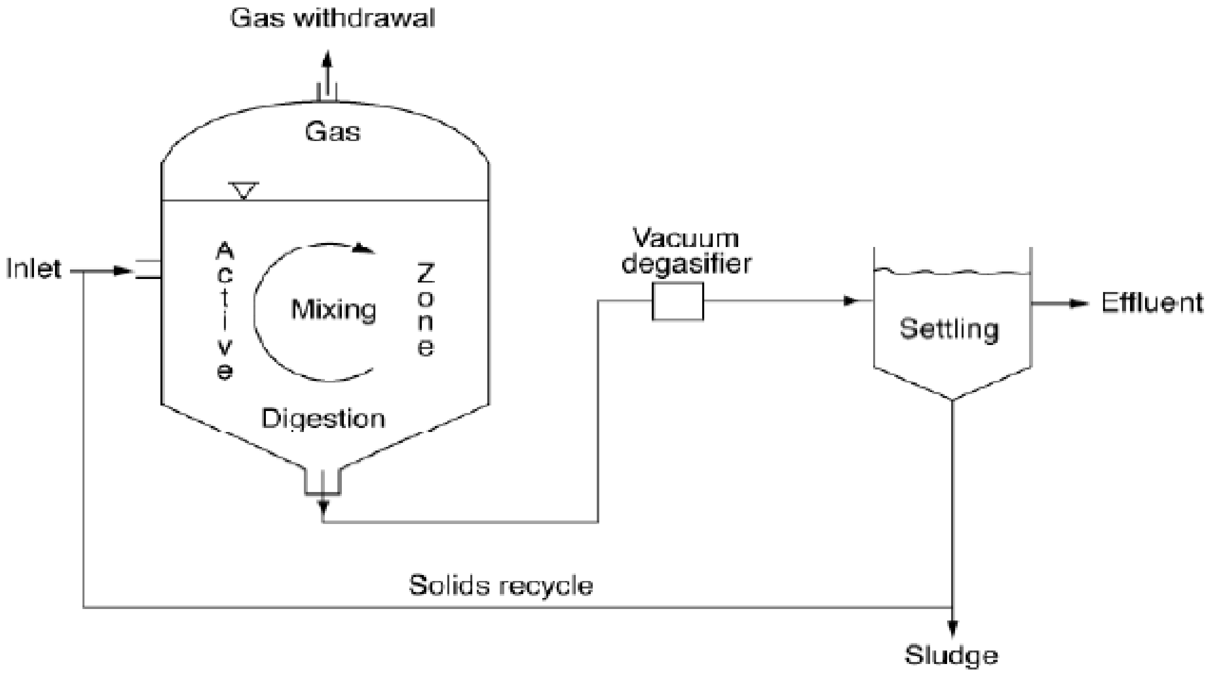


Figure 8-**Schematic drawing of Contact Stabilization Digester.**

2.7.4.2. Anaerobic sequencing batch reactor (ASBR)

An Anaerobic Sequencing Batch Reactor is a variation on an intermittently mixed digester. Methanogens are kept in the digester by settling solids and decanting liquid. An ASBR operates in a cycle of four phases (Figure 9). The digester is fed during the fill phase, manure and microbes are mixed. During the react phase, solids are settled during the settle phase, and effluent is drawn off during the decant phase. The cycle is repeated up to four times a day for nearly constant gas production. Hydraulic retention times can be as short as five days. These digesters work well with very dilute manures and if filled with active microbes during start-up, can even produce (Ann C.Wilkie, 2005)

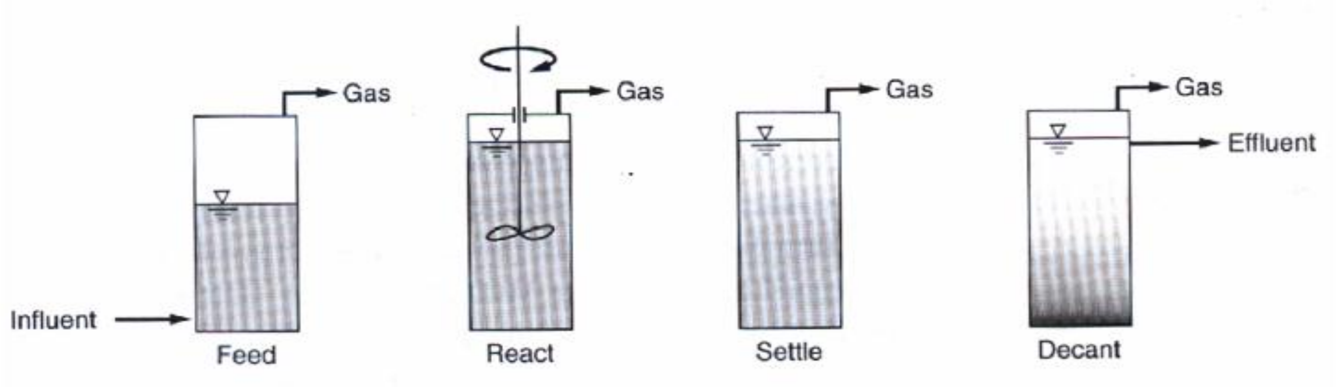


Figure 9-**Four phases of an ASBR Cycle.**

2.7.4.3. Anaerobic filter

Fixed Film Digester: In this digester, methane forming microorganisms grow on supporting media such as wood chips or small plastic rings filling a digestion column (Figure 10). These digesters are also called Attached Growth Digesters or Anaerobic Filters. The slimy growth coating the media is called a biofilm. Hydraulic retention times of fixed film reactors can be shorter than five days, making for relatively small digesters. Effluent is recycled to maintain a constant upward flow. One drawback to fixed film digesters is that manure solids can plug the voids between the supporting media. A solid separator is needed to remove particles from the manure before feeding it to the digester. Some potential biogas is lost due to removing manure solids. Anaerobic filters are therefore unsuitable for wastewaters with high solids contents. Additionally, there is a relatively high cost associated with the packing materials (Ann C.Wilkie, 2005)

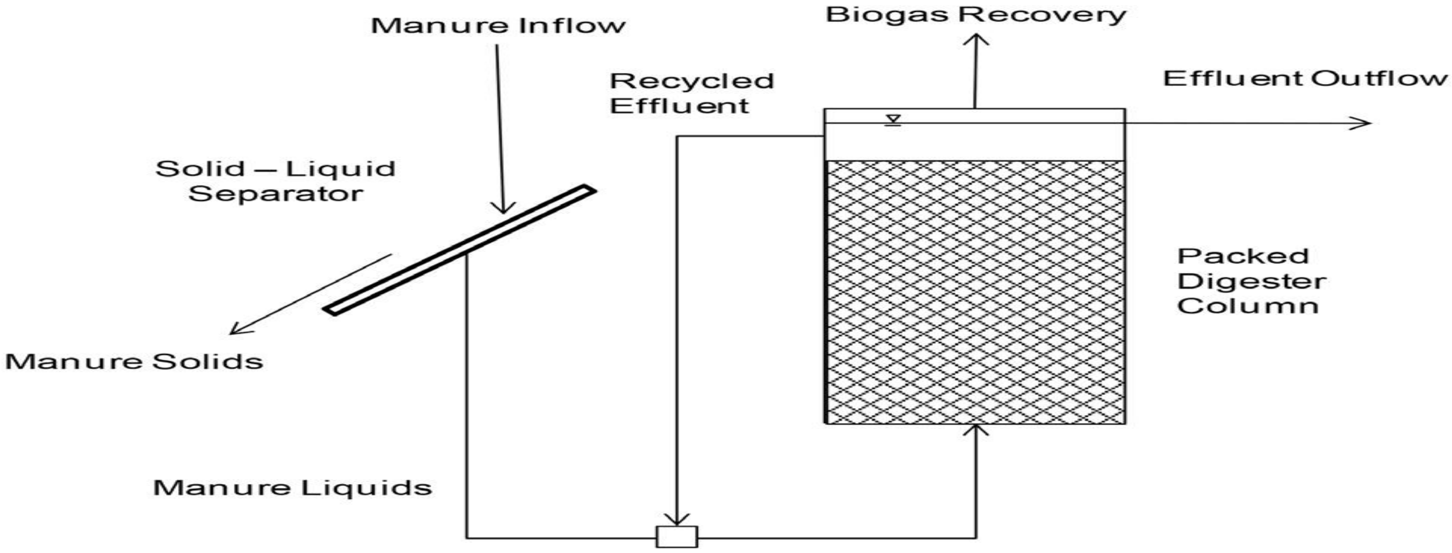


Figure 10- **Schematic drawing of a Fixed Film Digestion System**

2.7.4.4. Anaerobic fluidized bed reactors

In these digesters, microbes are suspended in a constant upward flow of liquid. Flow is adjusted to allow smaller particles to wash out. While allowing larger ones to remain in the digester. Microorganisms form bio films around the larger particles and methanogens stay in the digester. Effluent is sometimes recycled to provide steady upward flow. Some designs incorporate artificial supporting media such as sand for microbes to form a bio film these are called Fluidized Bed Digesters. Suspended media digesters that rely on manure particles to provide attachment surfaces come in many variations. Two common types of suspended media digesters are the Up flow Anaerobic Sludge Blanket Digester or UASB Digester (Figure 11) and the Induced Blanket Reactor or IBR Digester (Figure 12). UASB digesters work best with low solids influent. IBR digesters require high solids manure to function properly.(Ann C.Wilkie,2005)

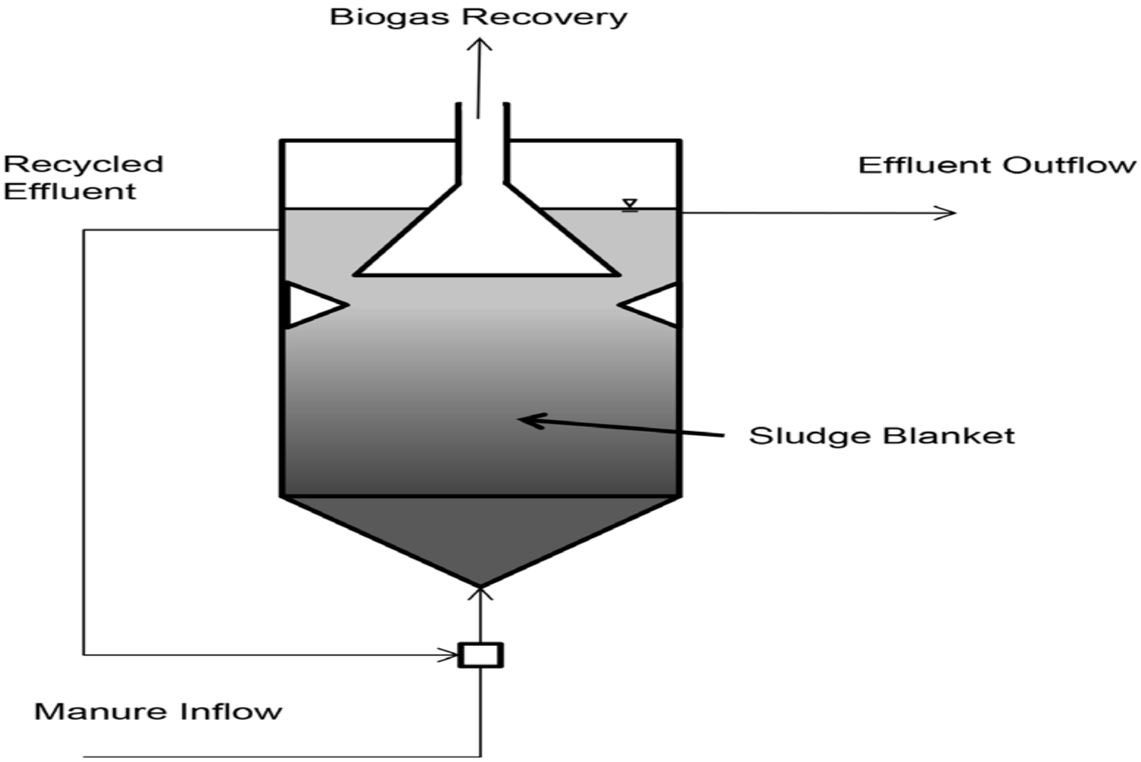


Figure 11-**Schematic drawing of an Up flow Anaerobic Sludge Blanket (UASB) digester**

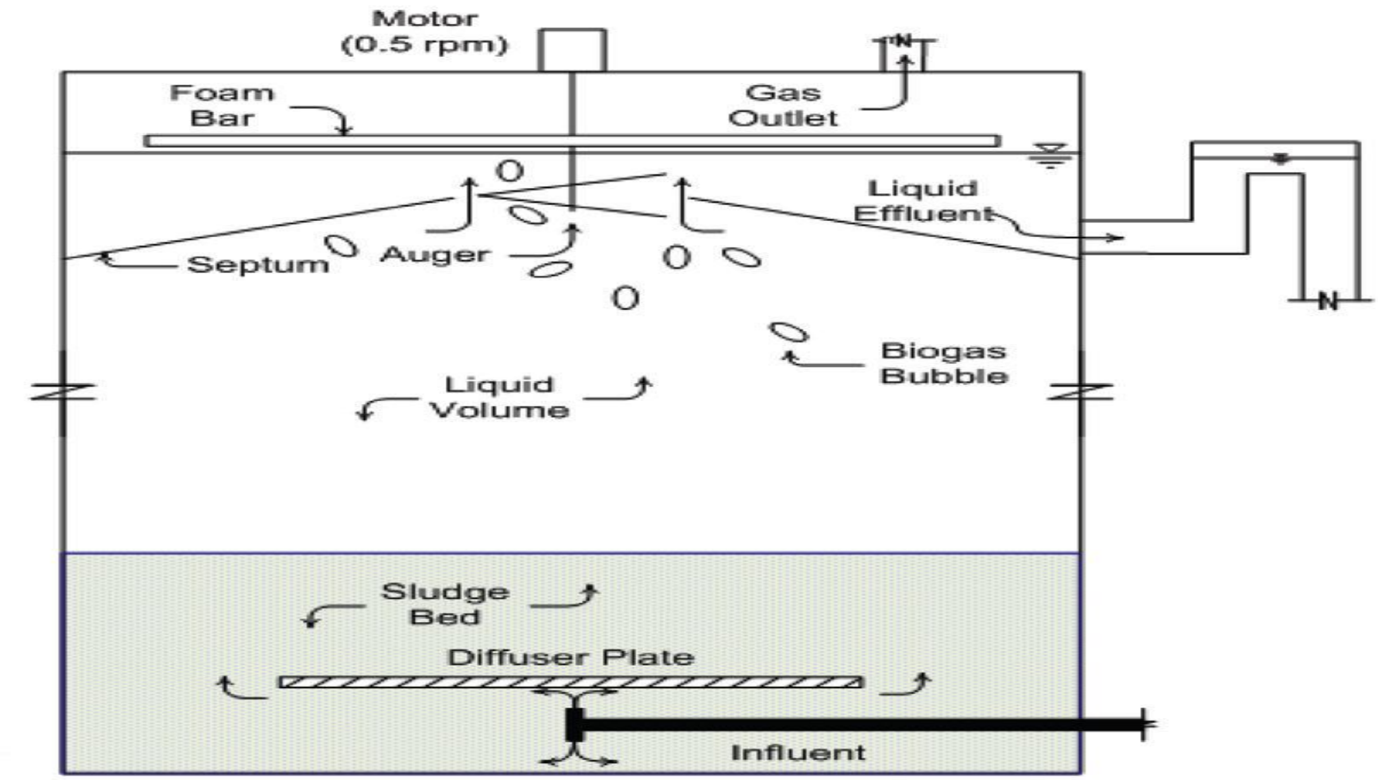


Figure 12- **Schematic drawing of an Induced Bed Reactor (IBR) Digester**

2.7.5. Low Rate Systems

Low Rate Systems: feedstock added to a digester is the main source of methanogens. Solids retention time (SRT) of the digester or the length of time solid particles are held in the digester equals hydraulic retention time (HRT) the length of time liquid is held in the digester.

2.7.5.1. Complete Mix Digester

A complete mix digester is basically a tank in which substrate is heated and mixed with an active mass of microorganisms (Figure 13). Incoming liquid displaces volume in the digester and an equal amount of liquid flows out. Methanogens flow out of the digester with the displaced liquid. Biogas production is maintained by adjusting volume so that liquids remain in the digester for 20 days to 30 days. Retention times can be shorter for thermophilic systems. The digester can be continuously mixed or intermittently mixed. Intermittent mixing means the tank is stirred during feeding and only occasionally between feedings. Sometimes digestion takes place in more than one tank. For instance, acid formers break down feed stock in one tank, and methanogens convert organic acids to biogas in a second tank. Complete mix digesters work best when organic waste contains 3 percent to 10% percent solids. Digester size can be an issue at lower solids concentrations. Lower solids mean greater volume which means you need a larger digester to retain the microbes in the digester for 20 days to 30 days.

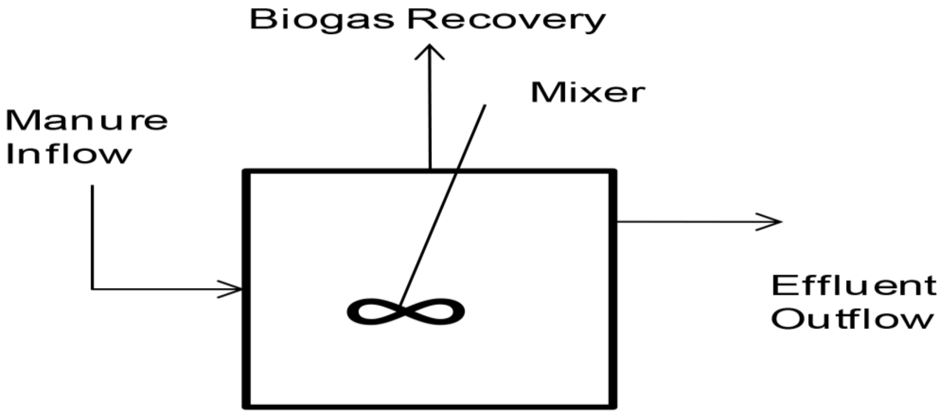


Figure 13-Schematic drawing of a Complete Mix Digester.

2.7.5.2. Plug Flow Digester:

The idea behind a plug flow digester (Figure 14) is the same as a complete mix digester substrate flowing into the digester displaces digester volume and an equal amount of material flows out. However, the contents of a plug flow digester are thick enough to keep particles from settling. Manure moves through the digester as a plug, hence the name "plug flow." Plug flow digesters do not require mechanical mixing. Total solids content of manure should be at least 15 percent and some operators recommend feeding manure with solids as high as 20 percent. This means you may need to add extra material to manure to use a plug flow digester. This is not always a bad thing if you consider the added material may also be biodegradable. More degradable material means more biogas. Plug flow digesters are usually five times longer than they are wide. Recommended retention time is 15 days to 20 days. (Ann C.Wilkie, 2005)

Figure 14- Plug Flow Digester on a Dairy Farm

2.7.5.3. Mixed Plug Flow Digester:

This is a patented variation on a plug flow digester in which manure flows down a hairpin raceway (Figure 15). The contents are heated along the central divider so that the manure mixes in a corkscrew pattern. (Ann C.Wilkie, 2005)

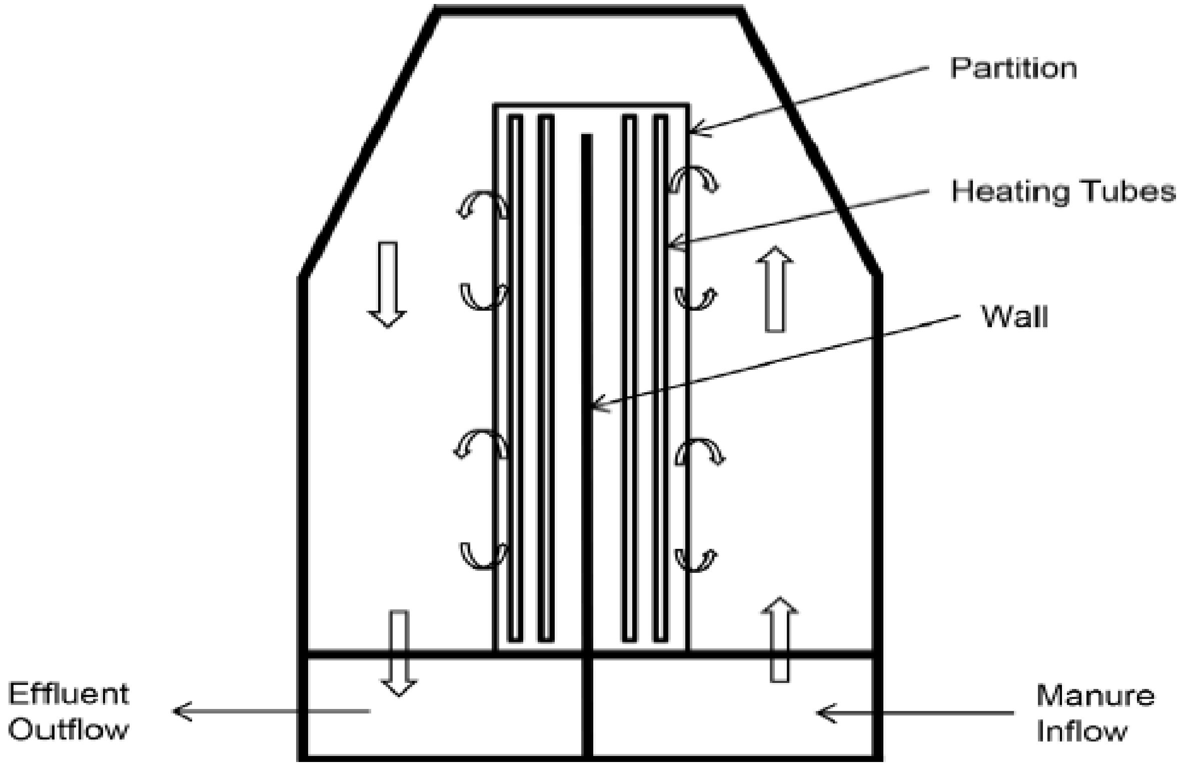


Figure 15- Birds eye schematic of a Mixed Plug Flow Digester.

Bio Gas digester construction technique

Component of Biogas Plant

In principle a biogas plant should have four essential components as follows:

Digestion Chamber: Anaerobic reaction or digestion of organic matter by methanogenic bacteria takes place in the digestion chamber. Since such reaction can occur only in the absence of air, this chamber needs to be airtight.

Mixing Pit (tank) In this tank the feedstock is well mixed and agitated before injected to the digester which helps to prevent the substrate form scum layer inside the digester and feed the organic matter into the digestion chamber via the inlet.

Inlet and Outlet: An inlet structure is required to feed the organic matter into the digestion chamber via the inlet. An outlet structure is required to remove the digested organic matter, i.e., the effluent from the digestion chamber. The outlet level is always lower than the inlet level to ensure one-way flow of the digested slurry (effluent).

Gas-holder is usually of flexible material, therefore to be protected against weather It can be placed either directly above the substrate, then it acts like a balloon plant, or in a separate 'gas-bag'.

2.8. Bio gas digester Design

2.8.1. Design constraint

Selection of Bio Gas plant Design- the Criteria for the selection of bio gas plant design should be based on the following considerations:

a. Economic:

An ideal plant should be as low-cost as possible in terms of the production cost per unit volume of biogas both to the user as well as to the society. At present, with subsidy, the cost of a plant to the society is higher than to an individual user.

b. Utilization of local materials:

Use of easily available local materials should be emphasized in the construction of a biogas plant. This is an important point to be considered.

c. Durability:

Construction of a biogas plant requires certain degree of specialized skill which may not be easily available. A plant of short life could also be cost effective. Especially in situation where people are yet to be motivated for the adoption of this technology and the necessary skill and materials are not readily available, it is necessary to construct plants that are more durable although this may require a higher initial investment.

d. Suitable design for the type of inputs:

The design should be compatible with the type of inputs that would be used. If plant materials such as rice straw, maize straw or similar agricultural wastes are to be used then the batch feeding design or non-continuous system should be used instead of a design for continuous or semi continuous feeding. Frequency of using inputs and outputs: selection of a particular design and size of its various components also depend on how frequently the user can feed the system and utilize the gas.

2.8.2. Sizing of Biogas plant

Biogas plants come in different sizes depending on the needs of the user and also the availability of the feed materials. Sizing of a biogas plant entails determining the size of plant to be constructed. The main determining factors being type and amount of feedstock, energy needs of the biogas owner and material cost relating to affordability by the biogas owner.

If a plant is over sized, it will be underfed, the gas production will be low; in this case, the pressure of the gas might not be sufficient to displace the slurry in the outlet chamber. This means that the amount of slurry fed into the digester is more than the amount of slurry thrown out from the outlet. This will cause the slurry level to rise in the digester and into the gasholder and it may eventually enter into the gas pipe. Therefore, the slurry should always be fed according to the prescribed amount.

Some slaughter house construct the digester without considering the amount of substrate feed to digester as a result methane directly emit to the environment with discharge of bio slurry because of over feeding to the digester and under size volume of digester.

Chapter three

3. Materials and Methods

3.1. Study location

The slaughterhouse considered in this study is Addis Ababa Abattoirs Enterprise in Addis Ababa city and location map is as shown in Figure 16. Addis Ababa Abattoir Enterprise(AAAE) was the biggest Abattoir in the city responsible to Provide 85% of the city's meat demand (both in slaughtering and distributing meat) and 400 Goat, 600 Sheep, 700 Cattle are slaughtered daily (excluding Tuesday and Thursday). In this slaughterhouse much organic wastes were produced including manure, blood and undigested stomach content and waste water from slaughterhouse. Data gathered from the slaughterhouses indicates that more than 120.6 m^3 solid wastes and waste water were generated daily. All of waste directly dispose to the environment without any treatment which were often washed into the adjoining stream by runoff water.

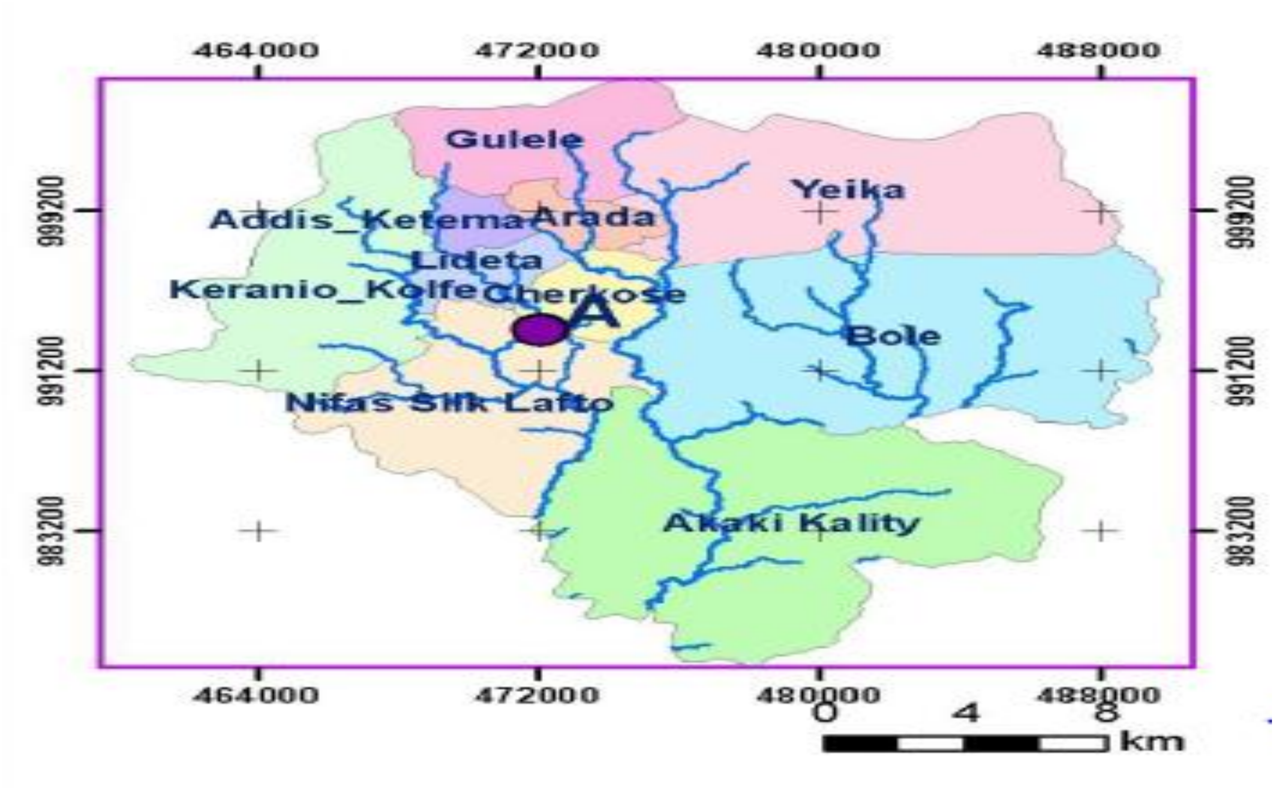


Figure 16- Addis Ababa Abattoirs enterprise location at A

3.2. Data collection.

For Identification of Addis Ababa Abattoir enterprise waste disposal the necessary data's were collected through questioner concerning type and amount of waste generated per day and the water used per slaughtered animals that was disposed to the environment excluding the waste used for animal food preparation.

3.3. Sampling and sample preparation

Freshly voided blood, stomach content, and manure of slaughterhouse wastes were our major feedstock for this study which were collected from Addis Ababa slaughter house. The sampling site which was the location of all the three slaughtering houses that is goat, sheep and cattle slaughtering effluent disposal mixed place. 4kg blood, 4kg manure and 15 kg of undigested stomach content were collected on six different days in the afternoon at 6:00 pm starting from August 2015 up to January 2016 until 42 experiments were finished. For each type of sample 3liter plastic bottles were used to collect. Freshly voided waste always collected for one batch was finished at once .The collected fresh sample was immediately fed to the digester and not to stay outside the reactor.

Sample preparation was done for two different purposes the first one was to know biogas potential of each type of waste without mixing each other without inoculum. The second one was by mixing the three types of wastes with desired proportion as shown in Table 8 with inoculum**. Sample** preparation for all 42 experiments run by mixing three type of wastes and that was done in the laboratory. Water was added for both procedures to obtain the desired total solid concentration 7-10% of inside reactor and the mixing ratio of the waste to water to be 1:1. The characteristics of the wastes were shown in the Table 9.

Inoculum

The inoculum used in this study was bio slurry of cattle dung which contains active microbes essential for anaerobic digestion process. The percentage of inoculum for anaerobic fermentation of the organic waste is approximately 20% of the volume of the feed sample. The pH, total solid and volatile solid of the inoculums were 7.1, 9% and 80.4% respectively. The inoculum was collected from household biogas digester in Addis Ababa city and fresh bio slurry directly used.

3.4. Experimental set up

The study was conducted in Environmental Engineering in school of chemical and Bio Laboratory at Addis Ababa institution of technology laboratory scale Anaerobic Digester set up as shown in Fig. 17.The experiments were carried on batch laboratory scale reactors with volume of 500 ml which put inside water filled water bath which helps to regulate temperature of the reactors and operated by setting water bath temperature separately at any desired value in the range 20 to 45 ^{O}C. Different designed temperatures were shown in the Table 8 . The bottles were closed by rubber stoppers equipped with glass tubes for gas removal and the glass was connected to gas line which conveys it to the gas bag. The volume of Biogas generated from the reactors was measured by gas syringe and the composition of the gas was evaluated by gas analyzer.

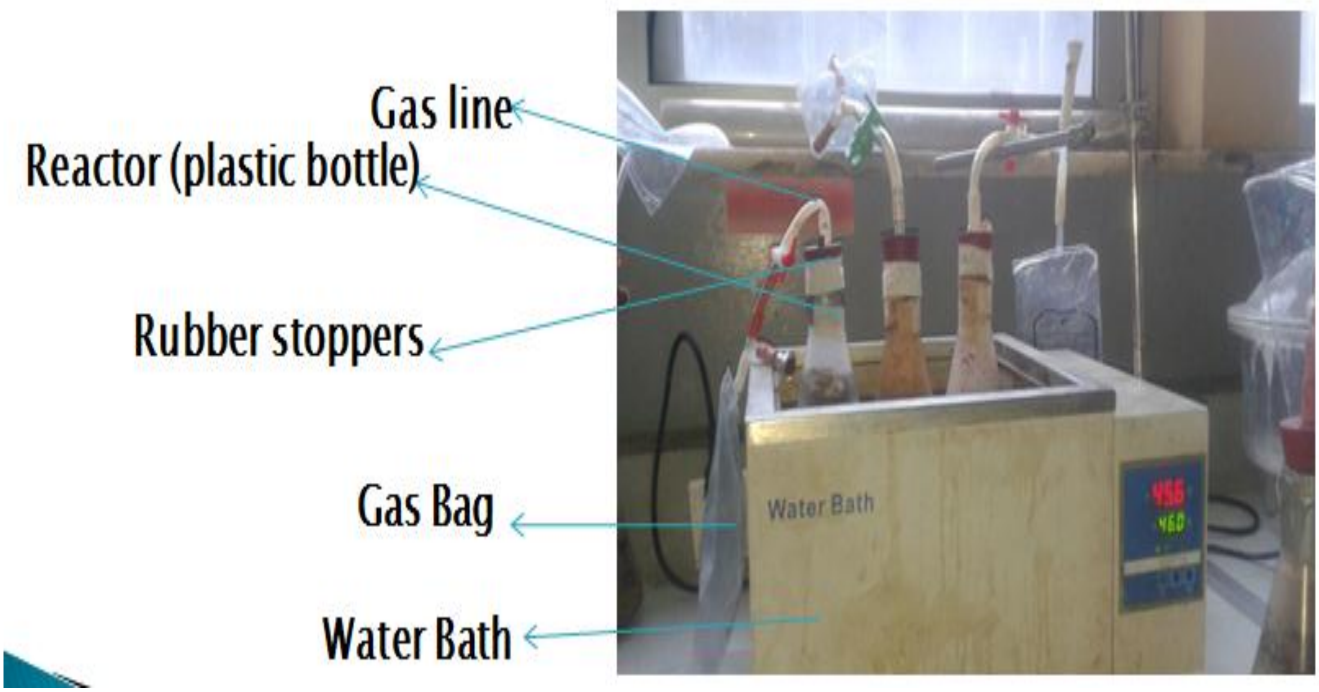


Figure 16**: laboratory scale Anaerobic Digester set up**

3.5. Laboratory Analysis

Characterization of sample was made by taking fresh voided blood, manure and undigested stomach content without mixing each other in order to know TS and VS of each type of waste which helps to decide amount of water added to the reactor to get optimal value of substrate total solid concentration in side reactor which is from7-10% (FAO/CMS, 1996).The waste was characterized with the following parameters using Standard Methods (APHA,1995), Total and Volatile Solids (TS and VS), Total Fixed Solids (TFS) and pH . DM was measured after drying at 105 °C for 24 h, and ash after heating to 525 °C for 5 h. VS was determined by subtracting the amount of ash from the amount of dry matter. Detail Waste Characterization Procedure explained at Annex 2.

Experimental procedure for evaluation of biogas production potential from each type of waste

In order to know the capacity of gas production from each type of waste by Mixing single type of slaughter house waste (manure, blood and undigested stomach content) with water. 500ml separate reactor was used and 350ml substrate volume feed to the reactor without inoculums. The experiment was carried out at optimum temperature range at 35.6^{0}c which was regulated by water bath and initial substrate pH 7.5 (Halimatun *et.al*, 2011). Measurement of pH of waste at feeding time and methane composition and volume of biogas was measured by Gas Analyzer and Gas syringe respectively at HRT 25, 35 and 45 days and the substrate was mixed once each day to maintain intimate contact between the microorganisms and the substrate.

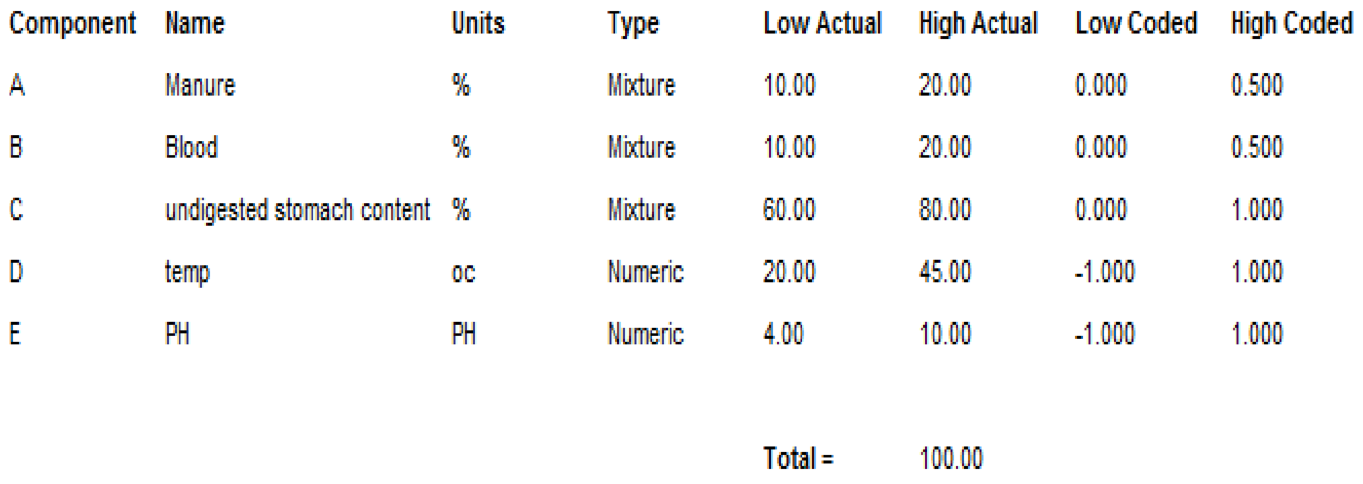
Experimental procedure for evaluation of biogas production potential from mixture of three type of waste

The study was planned to investigate maximum volume of biogas and methane composition by mixing three type of waste at different initial substrate proportions, temperature and pH adjusted based on design expert software shown in table 8 and Annex 4. The reactors had 500ml total volume and 400ml substrate volume fed to it. Initial pH was adjusted at the feeding time at designed level of 4, 5.5, 7, 8.5 and 10 by using Nitric acid and sodium hydroxide was used to adjust the initial pH of the feedstock (Gerardi, 2003). Volume of Biogas production and methane yield was measured by Gas syringe and Gas Analyzer respectively. The substrate was mixed once each day to maintain intimate contact between the microorganisms and the substrate.

3.6. Data Analysis

Crossed D-Optimal Designs is type of design expert software which was applied on the experiment which has Combinations of process factors and mixture components. It is a well-accepted statistical technique able to design and optimize the experimental process that involve choosing the optimal experimental design and estimate the effect of the several variables independently and also the interactions simultaneously (Mark J., 2002). This technique was used in the optimization of methane production and volume of gas production by using the Stat-Ease software with Design Expert v.6 and the experiment was applied to obtain optimum operating conditions for the factors involved. In this study two process factors: Initial pH and temperature. Three mixture component blood ratio, manure ratio and undigested stomach content were selected to study their effect on biogas production. First maximum and minimum in put value of mixture of blood, manure and un digested stomach content was given to the software with blood range (10%-20%) ,manure range (10%-20%) and undigested stomach content range (60%-80%).which was explained in table 8. Total amount of mixed substrate fed to the reactor that is 400ml and The Maximum and Minimum value of the waste was decided based on the article (Medina.et al, 2014) and available resource in Addis Ababa Abattoir Enterprise. According to this Crossed D-Optimal Design Software, 42 runs of experiments were conducted and the full experimental plan with respect to their actual and coded forms are listed in the table 7.

Table 7- Actual and Coded forms of the experiment



Component	Name	Units	Type	Low Actual	High Actual	Low Coded	High Coded
A	Manure	%	Mixture	10.00	20.00	0.000	0.500
B	Blood	%	Mixture	10.00	20.00	0.000	0.500
C	undigested stomach content	%	Mixture	60.00	80.00	0.000	1.000
D	temp	oc	Numeric	20.00	45.00	-1.000	1.000
E	PH	PH	Numeric	4.00	10.00	-1.000	1.000
				Total =	100.00		

From the input of maximum and minimum range of wastes the software was gave 42 run with different level. For manure and blood had three levels, for undigested stomach content, Temperature and pH had five level as shown in table 8 and Annex 4.

Table 8- **Level of process factor and mixture component.**

Name	Unit	level of process factor and mixture	Number of level
Blood	%	10,15,20	3
Manure	%	10,15,20	3
Undigestedstomach content	%	60,65,70,75,80	5
Ph	Ph	4, 5.5, 7, 8.5, 10	5
Temperature	^{0}C	20, 26.25,32.5, 38.5,45	5

ANOVA: Tables were generated for analysis of variance (ANOVA). The effects of individual linear, quadratic and other terms were determined. The significance of all the terms in the method was statistically evaluated and computed by the Prob>F at a confidence level of <0.0001. The model was recalculated based on stepwise deletion of terms that were insignificant.

In optimization research, R^2 and Adj-R^2 in order to study the accuracy of the final model. R^2 was used to determine the model's power in explaining the variation in experimental data. The R^2 values provide measurement of how much of variability in the observed response value can be explained by the experimental factors and their interactions. A good model (R^2 values above 90% are considered very well) explains most of the variation in the response. However, in crossed design the software output for these parameters were $R^2$and Adj-R^2 that make the final decision. Finally, optimum conditions were determined using a "Crossed D-Optimal" design by means of numerical optimization and contour plots for global optimization approach.

Optimization condition:

In this study, numerical optimization technique was adapted to optimize the process conditions. In this optimization, the desired goals for each response and factors were selected along with weight and importance allocated for each goal. For process variables optimization with high desirability. In this study, the optimal condition such as maximize CH_4 composition and amount of biogas production of encapsulated Temperature and pH was determined.

3.7. Estimation of production and potential to use as source of Energy

In order to know the equivalent demand of biogas that can be utilized in slaughter house, by considering the amount of energy production from optimal mixture of blood, manure and undigested stomach contents and process factors (PH and temperature) from the above experiment and then following procedure was employed to calculate the amount of energy that can substitute the consumption in each machine and equipment which was obtained from fuel and electricity to facilitate their activity.

Step one – First identify type of energy used in slaughter house to facilitate their activity and collect energy demand data of slaughter house.

Step two- Calculating the amount of biogas that covers energy requirement of the slaughterhouse machine to carry out its activity by considering the equivalent demand of biogas to the energy using source.

3.8. Digester Design for biogas production from slaughter house matter

After calculating the amount of biogas needs to cover energy consumption of the slaughter house process or equipment then sizing the digester which have the capacity to produce the required amount of energy, Type of digester and arrangement of digester is important to design the digester. Designing the size of the digester and selecting its type for slaughter house was done by calculating the quantity and quality of available waste to be disposed in to a digester in each day and the amount of energy needed to facilitate the activity.

Working volume of one digester = $Vgs + Vf = HRT * Q_d$

Where:

$V_{gs}+V_{f} =$ working volume of the digester in cubic meters

Q_d = Volumetric flow rate of substrate in cubic meters per day

HRT = retention time in days

Q_d= mass flow rate of substrate /density of substrate

In order to calculate total volume of digester and dimensioning using the following formula and assumptions (Chendu, 2006)

Total volume of digester V =Vc +Vgs +Vf+ Vs

Where Volume of gas collecting chamber = Vc

Volume of gas storage chamber = Vgs

. Volume of fermentation chamber = Vf

Volume of hydraulic chamber = VH

Volume of sludge layer = Vs

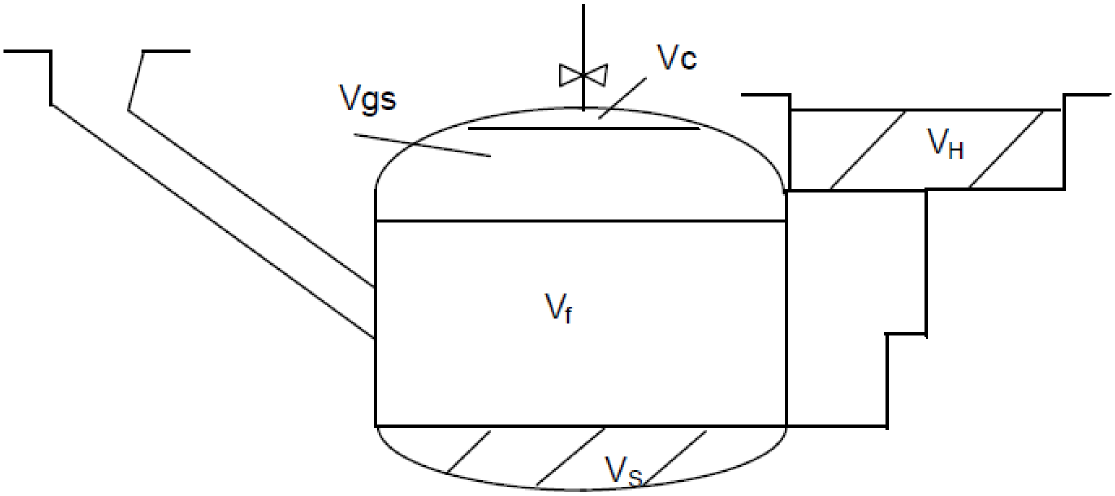


Figure 17- Cross-section of a Digester (Chendu, 2006)

Chapter four

4. Result and Discussion

4.1. Characterization of individual raw slaughterhouse waste

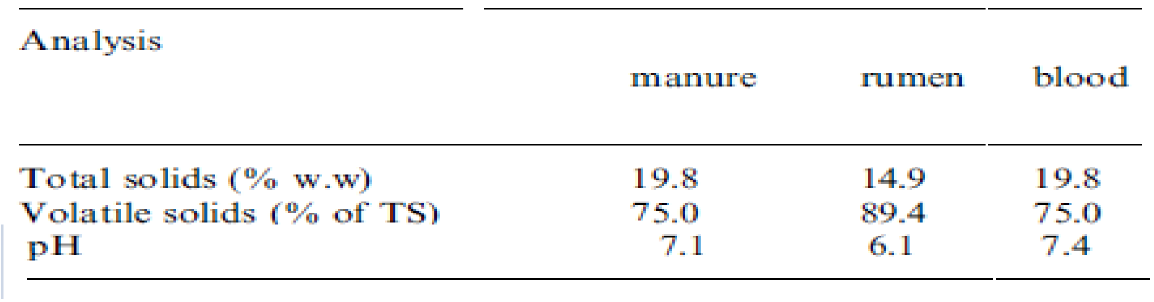
Characteristics of Blood, Manure and Undigested stomach content (rumen) used in the study were determined and the observed results as shown in Table 9.

Table 9-Characteristics of Blood, Undigested stomach content and Manure before Digestion

Type of waste	TS (%)	VS/TS (%)	Ash (%)	pH
Blood	11± 0.53	89.9± 0.9	10.1±0.54	7.8±0.5
Manure	18.95±0.25	81.53±1.2	18.5±0.77	7.5±0.2
Undigested stomach content (paunch manure)	15.35 ± 0.6	84.85±1.3	15.15±0.5	7.01±0.3

The total solid of Blood, Manure and undigested stomach content were 11%, 18.95% and 15.35% respectively and the volatile solid of the three wastes accounts 89.9%, 81, 53% and 84.85% of the total solid respectively. When compared to other studies the result of this study has slight variation because of several factors which include Feeding type of animal , type of on-site sanitation system, way of sampling system and amount of ageing that has taken place. According to the study (Rene Alvarez and Gunnar Liden, 2007) total solid and volatile solid content of blood and manure were explained in table 10:

Table 10: Comparison of the characteristics of wastes of this study to other reported elsewhere



Analysis	manure	rumen	blood
Total solids (% w.w)	19.8	14.9	19.8
Volatile solids (% of TS)	75.0	89.4	75.0
pH	7.1	6.1	7.4

Source- Rene Alvarez and Gunnar Liden, 2007

Other study reported that the total solid content of fresh manure was 16% while its volatile solid content was 79% (Eliyas Jigare, *et al*, 2011). Which is different from Ethiopia because of the feeding type of Animals. Most of time in Ethiopia leaves and grasses are used for animal feeding but in foreign countries buck wheat is used for animal food. The total solid concentration in the influent affects the rate of fermentation.

4.1.1. Bio gas production potential and methane composition of each type of slaughter house waste

Major Findings from anaerobic digestion of each type of slaughterhouse waste from 0.350 lit of substrate at optimal condition at temperature 35^0c and pH 7.5 (*Halimatun et.al, 2011)* as shown in table 11

Table 11 -Biogas potential and composition of methane for Blood, Manure and undigested stomach content

HRT	Blood		Manure		Undigested stomach content	
	Volume of bio gas(lit)	Methane composition (%)	Volume of bio gas(lit)	Methane composition (%)	Volume of bio gas(lit)	Methane composition (%)
25	0	0	2.2	53.4	0.8	34
35	0	0	3.2	66	2	46
45	0	0	1.6	57	1.2	54

The cumulative biogases produced during the digestion of the feed stocks for 45 days were presented in table11. From the digestion of Manure total production of bio gas volume 2.5liter, 3.2liter and 1.6 liter at HRT 25, 35 and 45 days respectively from 350ml of substrate. The maximum methane yield from manure was 66% at HRT 35 days.

From undigested stomach content total biogas volume 0.8liter, 2liter and 1.2 liter at HRT 25, 35 and 45 days respectively from 350ml of substrate. The maximum methane yield from undigested stomach content 54% methane yield at HRT 45 days.

From blood no biogas production and methane generation at equal volume of substrate and HRT to manure and undigested stomach content.

The quality and quantity of organic matter available for use in a biogas plant constitutes the basic factor of biogas generation. The volumetric yield of biogas per kilogram (kg) varies from one substrate to another depending on the composition as well as nature of the substrate. In addition, the percentage of methane obtained from the resultant biogas also varies independently according to type of biomass material (P. Weiland, 2010). Digestion rate of undigested stomach content is low compare to manure because of undigested stomach content is lignocellulose carbohydrate nature which cannot easily degrade by bacteria and resistant to hydrolysis hence need long time for digestion.

Biogas production from Blood was zero whereas manure and undigested stomach content good biogas potential from the same amount of substrate (350ml) because blood has naturally high amount of nitrogen. Which means C: N ratio of blood is three which is very small. The C: N ratio decreases and inhibits gas production because of ammonia accumulation inside the digester which indirectly affects composition of methane and retention time (Tadious, 2009).Energy rich proteinaceous waste products in large quantities into the AD process are not recommend in view of the increased risk of inhibition by ammonia (Etelka ,*et al*.,2010). In addition to this, this is a well-known source of sulfide formation during anaerobic degradation. The increased concentration of sulfides in the digester lead to higher concentrations of corrosive H_2S in the biogas and can further lead to sulfide inhibition of the methanogens. (Chen Y.,et.al, 2008).However, Protein is rich energy resource co-digest with materials with high carbon content to achieve a balanced process(WCECS, 2014). From literature protein by nature which has high biogas potential and composition 0.53 m^3/kg VS and CH_4:CO_2 is 60:40.

While manure has good potential of biogas which is C: N ratio 20:1the optimal Carbon/Nitrogen (C/N) ratio for anaerobic bio digestion is between 20:1 and 30:1. Manure without co-digestion with other substrate had better amount of gas production, short hydraulic retention time and methane composition compared to blood and stomach content are depicted in the Table 11.

4.2. Analysis

ANOVA for combined reduced Linear (mixture: A, B, and C) × quadratic model (process: D and E) are shown at **Annex 5.** The high R^2 (0.978) and adjusted R^2 (0.970) indicate a good explanation of the variability by the selected model for methane composition of encapsulated temperature and pH. In addition, the model F-value and Prob>F are 121.46 and <0.0001, respectively. The adequate precision measured the signal to noise ratio which compared the predicted values range at points of design to the average prediction error. A ratio greater than 4 was desirable for an adequate model. In this particular case, the ratio of 26.119 indicated adequate signal discrimination. That implies the model is significant. The crossed model (mixtures (Linear) × process (quadratic)) appears to be a reliable model for methane percentage (CH4 %) of biogas composition encapsulated of temp and pH from the crossed design.

4.2.1. Diagnostic Model

Before accepting any model, the satisfactoriness of the adopted model must be checked by an appropriate statistical analysis. The experimenter handbook by (Kraber*et al.*, 2002*)* stated that a good normal probability plot should show a linear straight line. The handbook also mentioned that good residuals versus predicted response plot should be random scatter whereas a bad plot of the kind will show a megaphone shape. A review on the normal probability plot for biogas yield as illustrated in Figure 19 revealed that the residuals generally fall on a straight line implying that the errors are distributed normally. On the other hand, the residuals versus predicted response as shown in Figure 20 revealed that they were random scattered without obvious pattern and unusual structure. This general impression implied that the model proposed was adequate and there was no reason to unsure any violation of the independence or constant variance assumption.

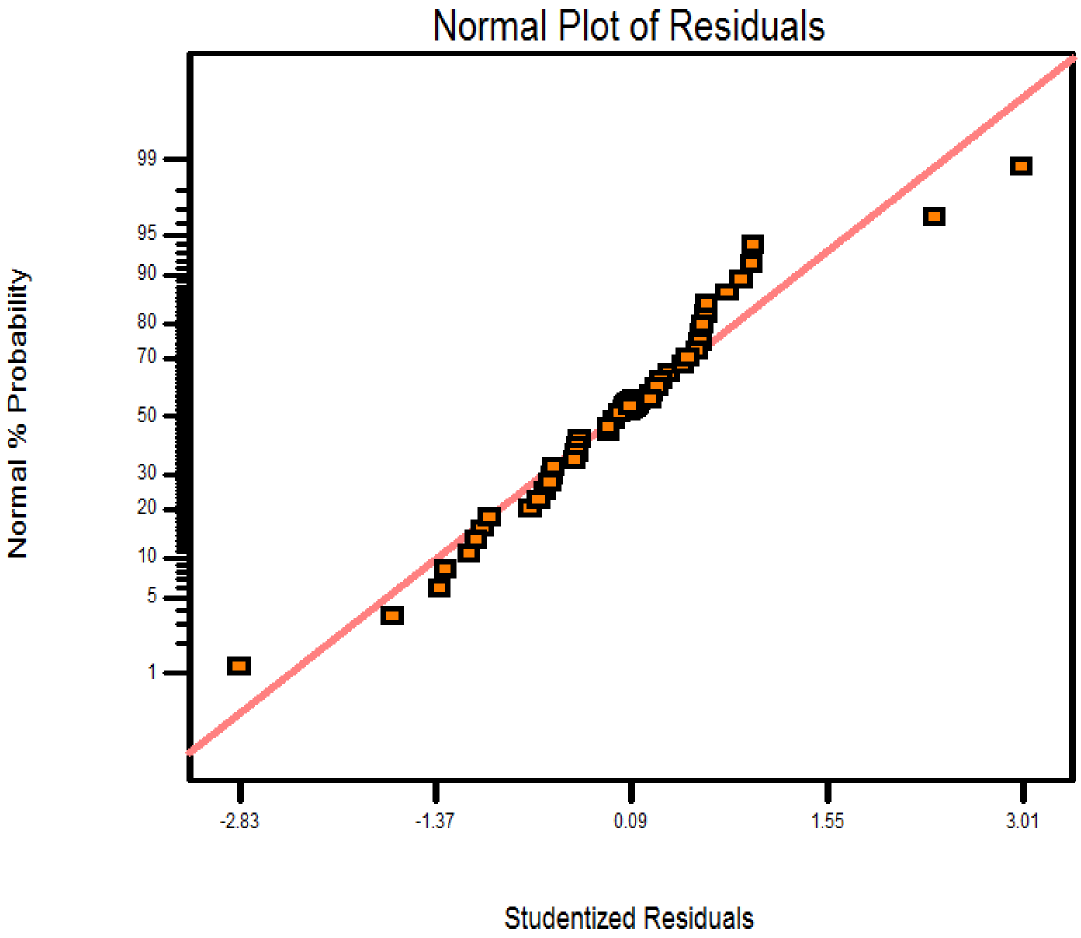


Figure 18**: Normal probability plot of residuals for methane yield data**

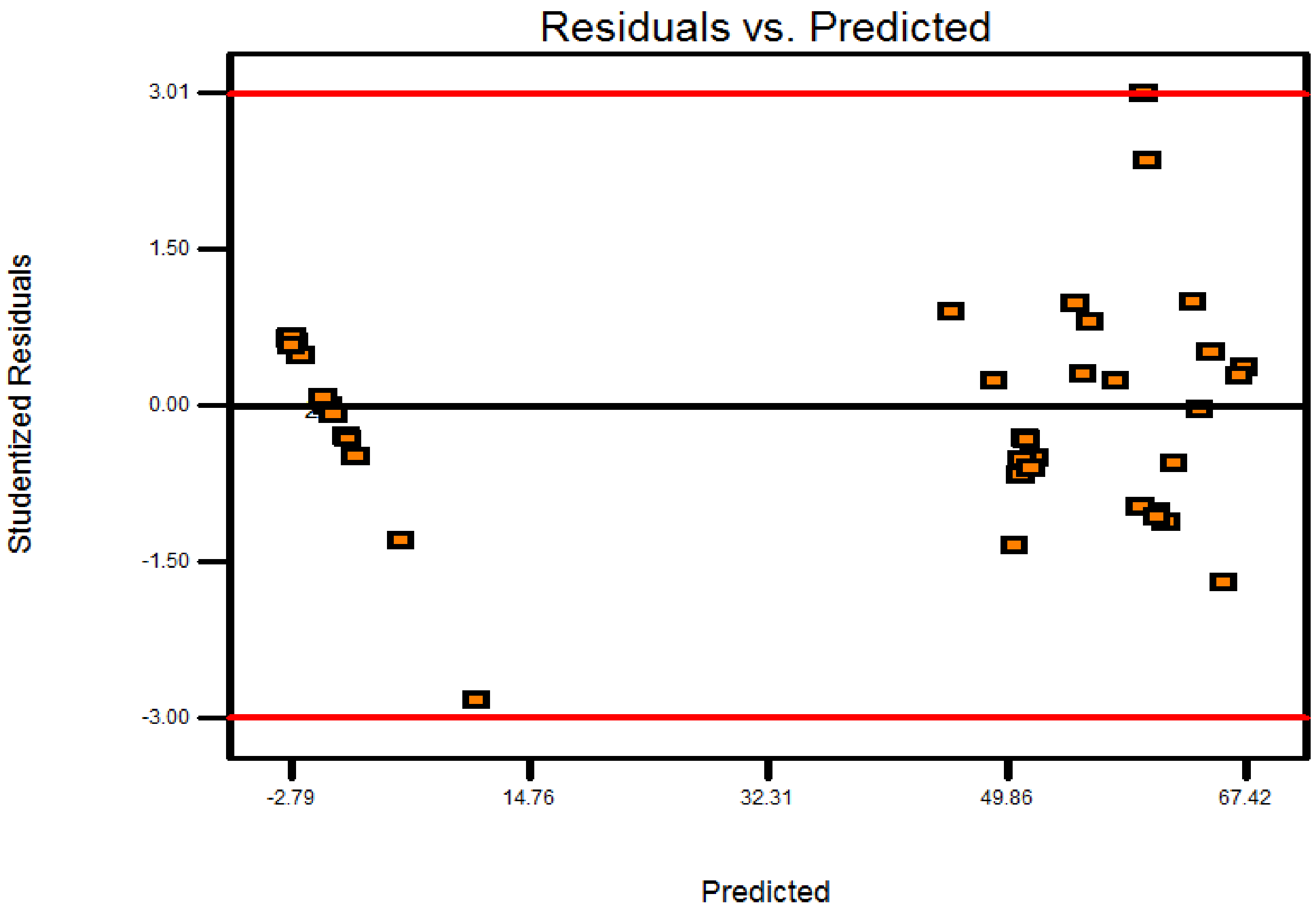


Figure 19: Residuals versus predicted response plot for methane yield data

4.2.2. Identification of optimal mix ratio of wastes with optimal process factor PH and temperature for highest methane production

For the determination of maximum methane yield in the study from mixture of Blood, Manure and Undigested Stomach content with different ratio with process factor temp and pH by Using Crossed D-Optimal design expert software which was implemented for the optimization of biogas production, a total of 42 runs were generated with different scenario. The volume of substrate solution fed to the reactor was 400ml which was solid substrate solution as shown in Table 12 and the selected substrate composition was manure 20 %, blood 20% and rumen 60% are explained in table 13 . Laboratory result data is shown in Annex 4 with the experimental values of methane yield and volume of resulting biogas production.

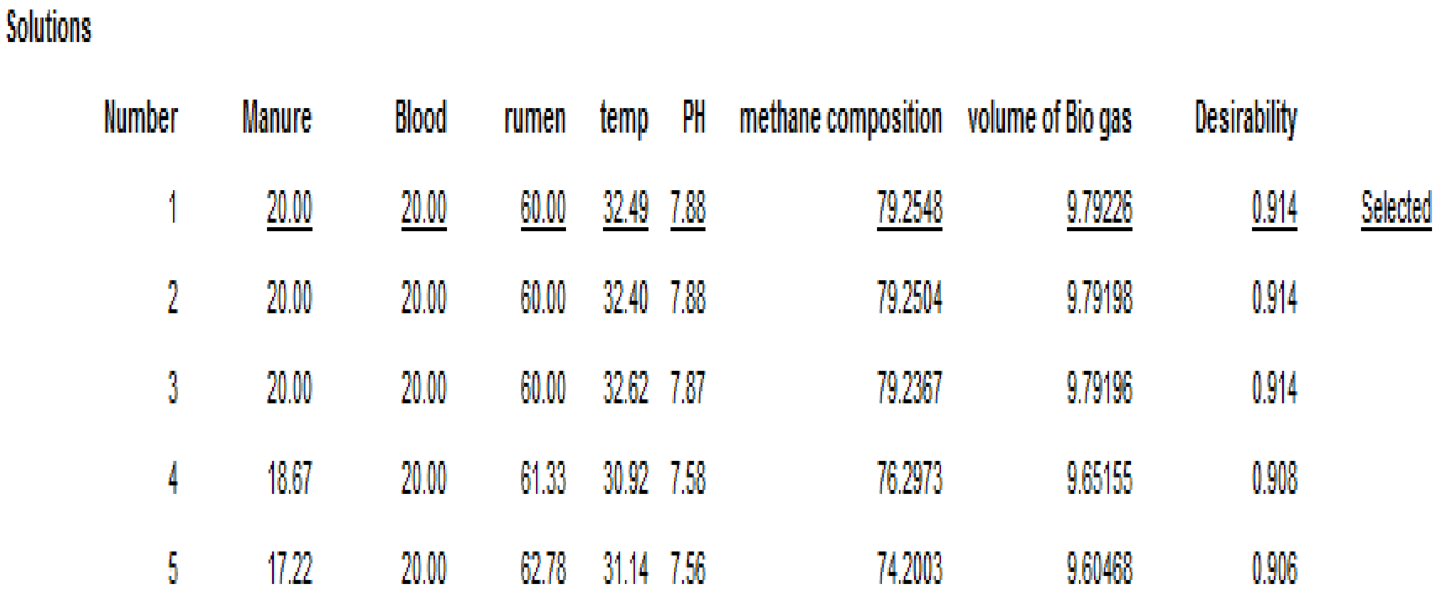
Table 12: Volume and Solid Concentration of the selected sample

No	Items	unit	Amount
1	Volume of sample solution	ml	400
2	TS concentration of sample	gm /400ml	30
		%	7.5
3	Volatile solid per total solid content of sample	gm /ts	25.67
		%	84.8
4	Selected Sample composition of substrate (Manure , Blood and Undigested stomach content)	%	20%,20%,60%

4.2.3. Optimization

The numerical optimization finds a point that maximizes the Desirability function. Table 13 presents the specific optimum conditions of methane composition by considering pH & temperature with the three substrate mixture and our goal is at optimum conditions to obtain Maximum methane yield and Biogas production. Table 13 showed that the suitable optimum formulation (manure 20 %, blood 20% and rumen 60%) and pH and temperature 7.89 and 32.31^{o}c respectively with the highest desirability of 0.914 have high value of methane composition and volume of biogas per feeding volume selected.

Table 13: Optimization conditions and desirability of model



Solutions

Number	Manure	Blood	rumen	temp	PH	methane composition	volume of Bio gas	Desirability	
1	20.00	20.00	60.00	32.49	7.88	79.2548	9.79226	0.914	Selected
2	20.00	20.00	60.00	32.40	7.88	79.2504	9.79198	0.914	
3	20.00	20.00	60.00	32.62	7.87	79.2367	9.79196	0.914	
4	18.67	20.00	61.33	30.92	7.58	76.2973	9.65155	0.908	
5	17.22	20.00	62.78	31.14	7.56	74.2003	9.60468	0.906	

Optimum Temperature

This study was conducted Room, Mesophlic and Thermophlic temperature ranges and input ranges minima and maxima temperature value from 20°c to 45°c to the Crossed D-Optimal Design Expert software which was Designed at 20°c, 26.25°c, 32.5°c, 38.5°c and 45°c and methane yield at these temp point was 65.56%, 76.1%, 79.2%, 76.10% and 66.41% respectively presented at Annex 6. Volume of biogas and methane composition at controlled pH and optimal mixture of substrate are shown in Figure 21 and Figure 22.

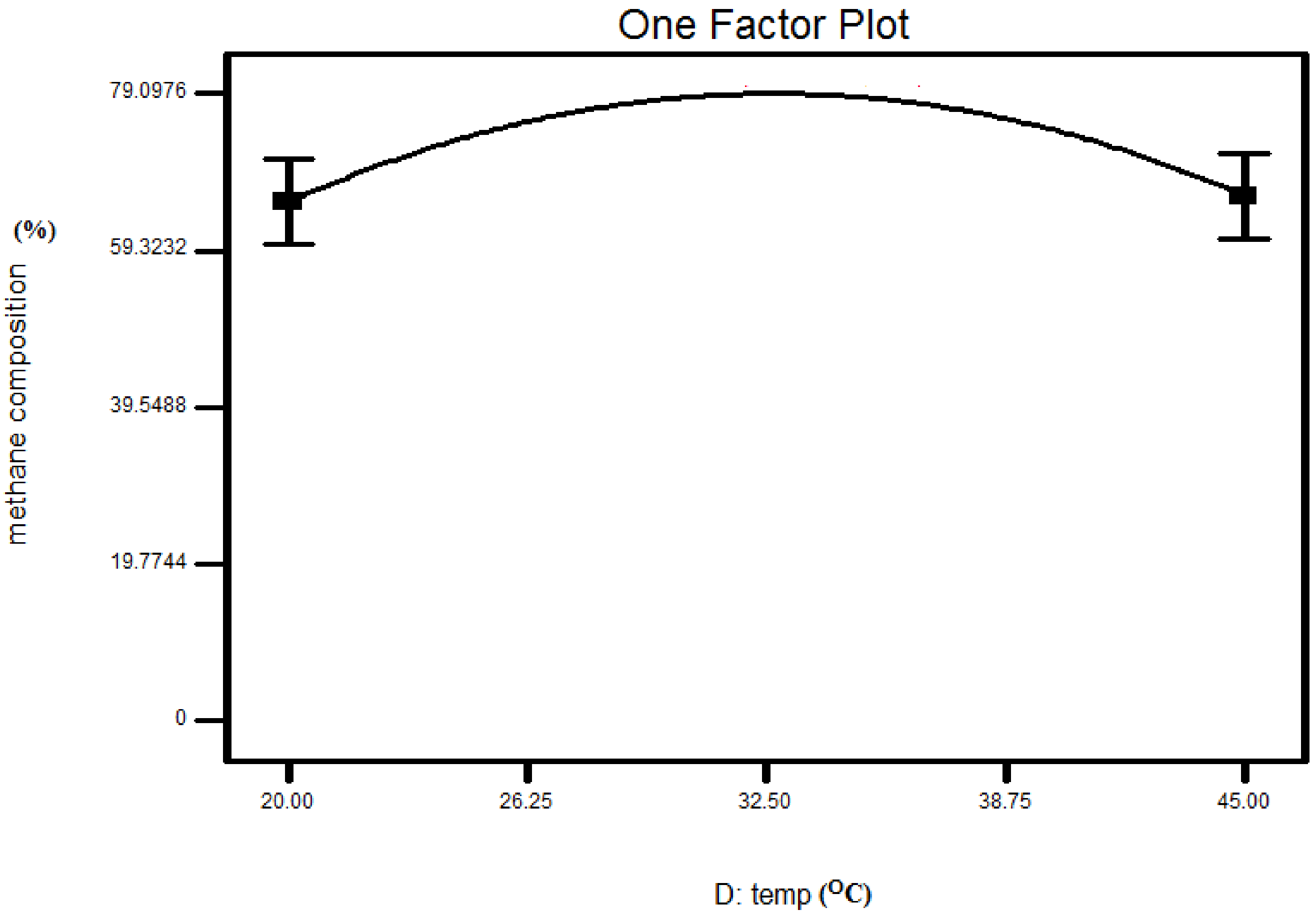


Figure 20- Methane yield versus temperature at selected pH and component of mixure

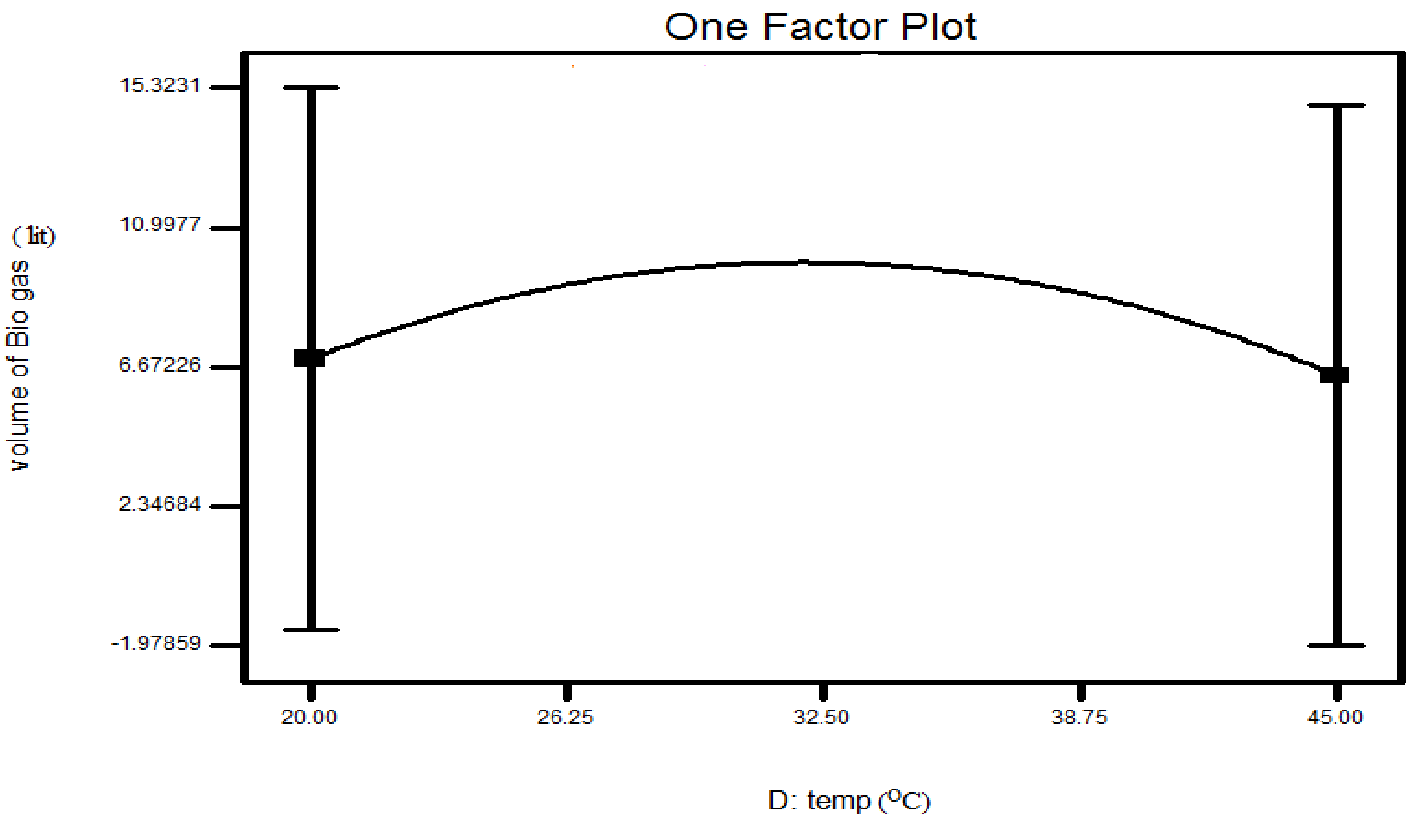


Figure 21: volume of Bio gas versus temperature at selected pH and component of mixure

In this study the optimal methane composition was found at temperature 32.5°c and methane yield 79.25%; in other words this temperature range is mesophlic temperature range which is recommend range in literatures. (Tchobanoglous et al. 2003) pointed out that reactor temperatures between 25 °C and 35 °C are generally the preferred optimal to support biological- reaction rates and yet provide a more stable treatment.

When the temperature was set at room temperature (20 °C) the volume of biogas and methane composition was decreased as shown in Figure22. **(** Tchobanoglous et al., 2003) reported that temperature ranges approaching to 20°c are not suitable for anaerobic Digestion and it takes long HRT for digestion and low gas production because the degradation of long-chain fatty-acids is often rate limiting. If long-chain fatty-acids accumulate, foaming may occur in the reactor and so inhibit process continuity **(** Tchobanoglous et al., 2003. Temperature in the range from 26 to 38 °C had better methane composition in the bio gas compared to temp lower than 26°c and temp greater than 38°c is explained in Figure 22**.**

When temperature increased to 45°c bio gas produced in short period of time but the amount of biogas product and methane composition was not as much as that of 26-38 °C because the rate of decomposition and gas production is sensitive to temperature.

In general the process becomes more rapid at high temperatures Despite this ‘thermophilic benefit’; whereas the digestion process becomes increasingly unstable with rising temperature and requires higher rates of heat inputs, and produces poorer-quality supernatant containing larger quantities of dissolved solids (Tchobanoglous et al. 1991).

When the temperature was reduced to 20^{o}c or increased to 45^{o}c, the efficiency of the treatment decreased markedly because of fatty acid formation and NH_3 accumulation inside the digester increased consequently inhibiting gas formation. (Schwitzguebel et al, 1999). Hence the temperature affects the success of the digestion process because the activities of the anaerobes causing Waste decomposition is temperature dependent

Optimal Initial pH of substrate

The pH considered in the study was initial pH of substrate when fed to the reactor from acidic to basic that was from pH 4 to 10. the output value of pH design of the Crossed D-Optimal Design expert software for experiment gave five pH level value 4, 5.5, 7, 8.5 and 10 and methane yield at these pH level was (10%, 52.2%, 74.6%, 78.44% and 64%) respectively depicted at Annex 7. Volume of biogas and methane composition at controlled temperature and optimal mixture of substrate is explained in Figure 21 and Figure 22.

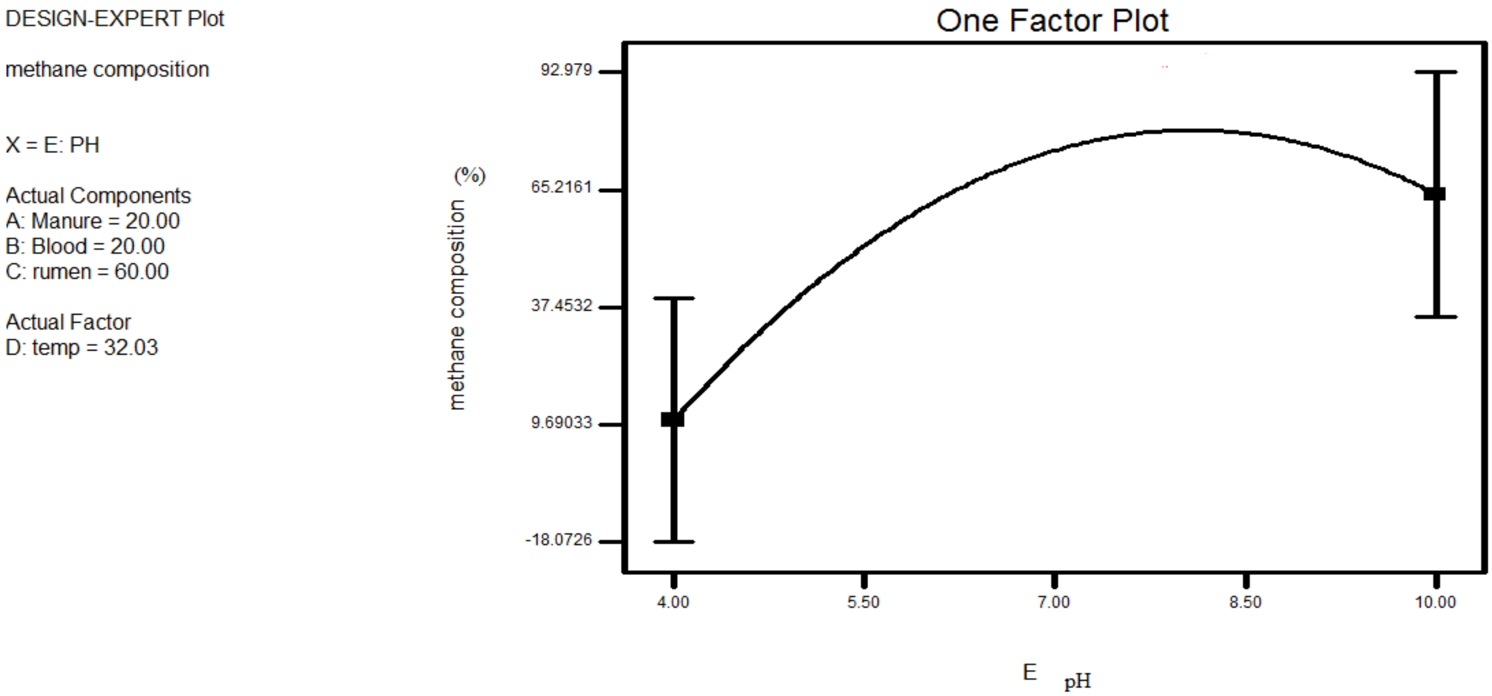


Figure 22: Methane yield versus pH at selected Temperature and component of mixure

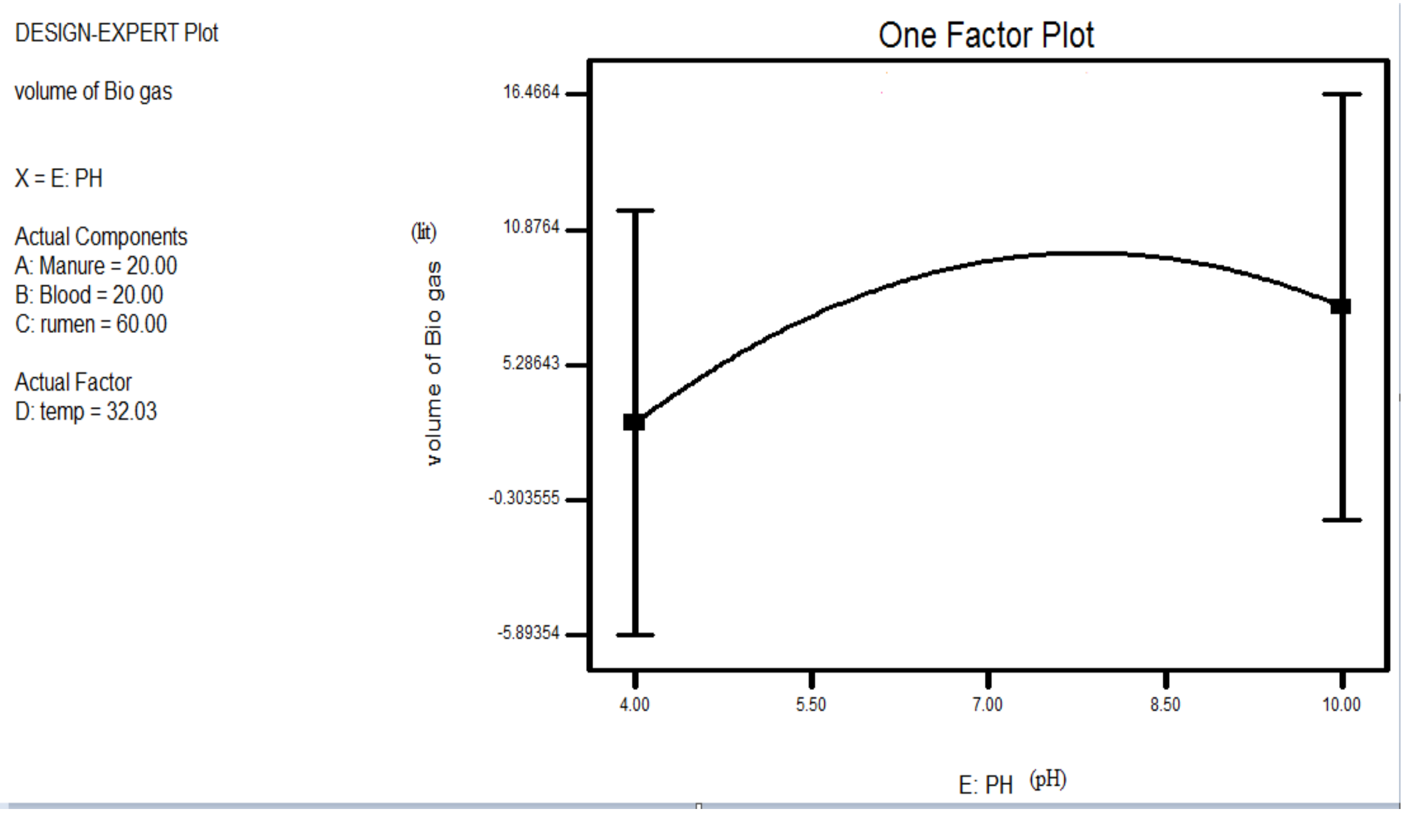


Figure 23 : Volume of biogas versus pH at selected costant Temperature and mixure of component

From pH 7.5 to 8.5 best gas productions and methane yield found and in this study optimal pH was 7.88 selected as shown on Table13 with best desirability value. In other study also pH 7.5-8 showed excellent performance of the system because 85% of total chemical oxygen demand was removed in anaerobic digester and a short hydraulic retention time (Schwitzguebel et al, 1999).

When pH was higher up 8.5 to 10 the amount of biogas decreases from the peak value but not like when pH approach to 4 because for adjusting the substrate pH from 8.5 to 10 was used NaOH. (Liew et al. 2011) carried out simultaneous solid-state pretreatment using NaOH on fallen leaves showed that the methane yield increased by 20% during batch tests. Which demonstrated that alkali pretreatment can increase gas yield from lingo-cellulose rich substrates. (M.Carlsson et al 2012) reported that lime or NaOH was used for treatment of lingo-cellulosic feedstock materials which are resistant to hydrolysis due to their structure and composition. So in our case our feedstock (slaughter house waste) had undigested stomach content which was lignocellulose material and batch type fermentation which was the reason to get good methane composition.

When Initial pH was set near to 7 had good biogas production and methane composition with good desirability value is explained at Annex7. The bacteria involved in anaerobic digestion have a pH range close to 7 for optimal activity. (HilkiahIgoni et al., 2008).

When initial pH value was below or equals 4 no biogas production and desirability value was low as shown in Figure 23and Annex 7. (HilkiahIgoni et al., 2008) said that the hydrogen-ion concentration of the culture medium has a direct influence on microbial growth because the digestion is inhibited by excessive acidity. In literature a decrease of pH to 6 and below caused a strong reduction of COD removal and biogas production, with a simultaneous accumulation of volatile fatty acids and ammonia. (Schwitzguebel et al, 1999).

Optimal Substrate mixture component

Based on 42 run and different experimental results as shown at Annex 4 **by** using the crossed D-Optimal Design Expert software was selected 20%blood, 20% manure and 60% undigested stomach content was the optimal Substrate composition explained at Table 13 and the counter plot at Figure 25 was taken from the software reported that methane yield and amount of biogas production at optimal temperature and pH at different substrate proportion. And also Methane yield at different pH, temperature and substrate mixture component is explained at Annex 7.

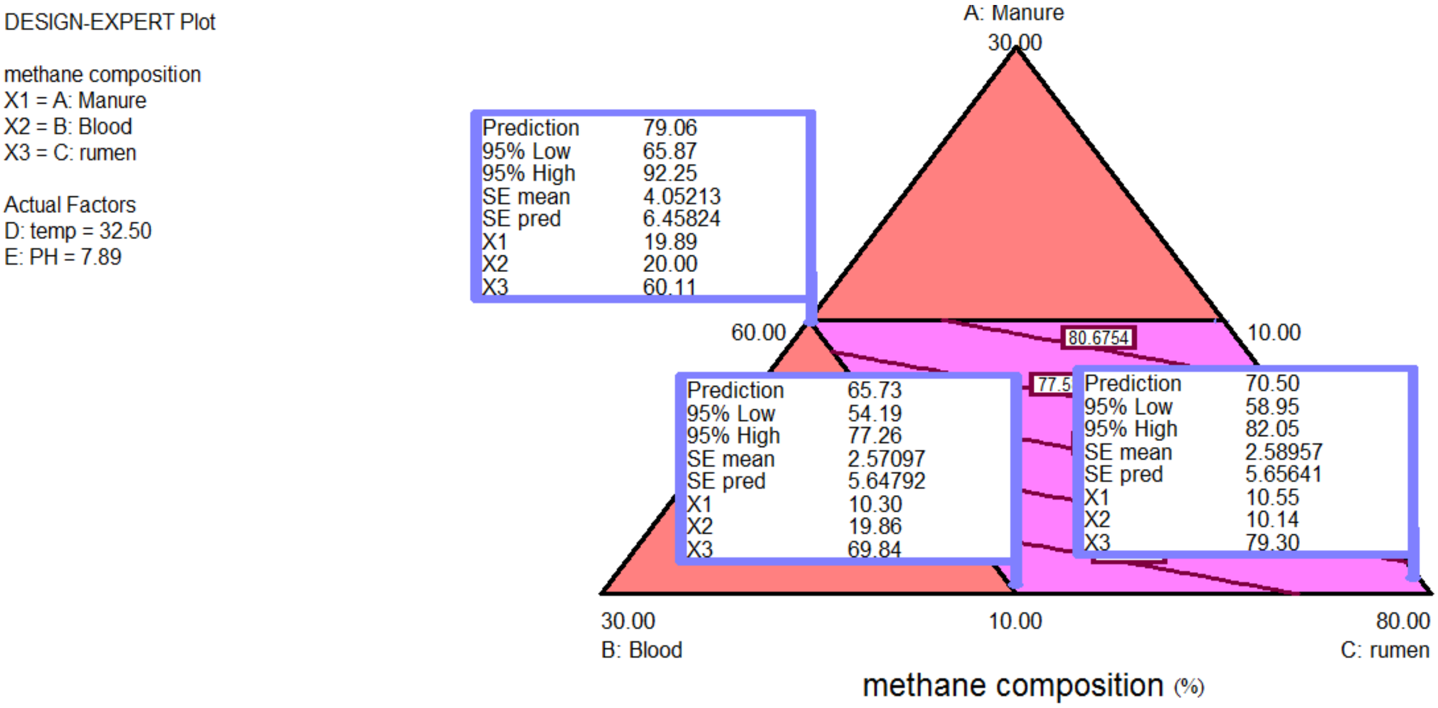


Figure 24: Methane yield at different substrate composition

According to Figure 25 and Figure 26 When approximate value of First proportion was set at (20% manure, 20% blood and 60% undigested stomach content volume) volume of biogas production and methane yield were 9.91litter and 79.25% respectively. Second proportion (10% manure, 20% blood and 70%) biogas production and methane yield were 9.3litter and 65.7% respectively. And the third proportion (10%manure, 10% blood, 80% undigested stomach content) volume of biogas production and methane yield were 8.3litter and 70.5% respectively.

The first proportion had better methane yield and volume of biogas than the second and the third proportions. As result of Composition of methane yield reduced with decreasing amount of manure (from 20 % to 10 %). Mixture made to have dominant amount of blood than manure amount of methane composition in biogas decreased to 65.5%. This implies additionally too much blood as substrate means low total solid content and mainly protein compounds have low biodegradability. Which means increasing biodegradability will give higher methane yield by co-digesting it with other easily biodegradable substrates like carbohydrates.

The third was better than the second by its methane yield due to the increased in amount of undigested stomach content from 70 to 80% which is Lingo-cellulose and a very common carbohydrate plant. The methane yield increased from 65.5% to 70.5% because of cellulose compound has capacity to minimize the negative impact of protein substrate as (blood) in side digester as shown in Figure 25.

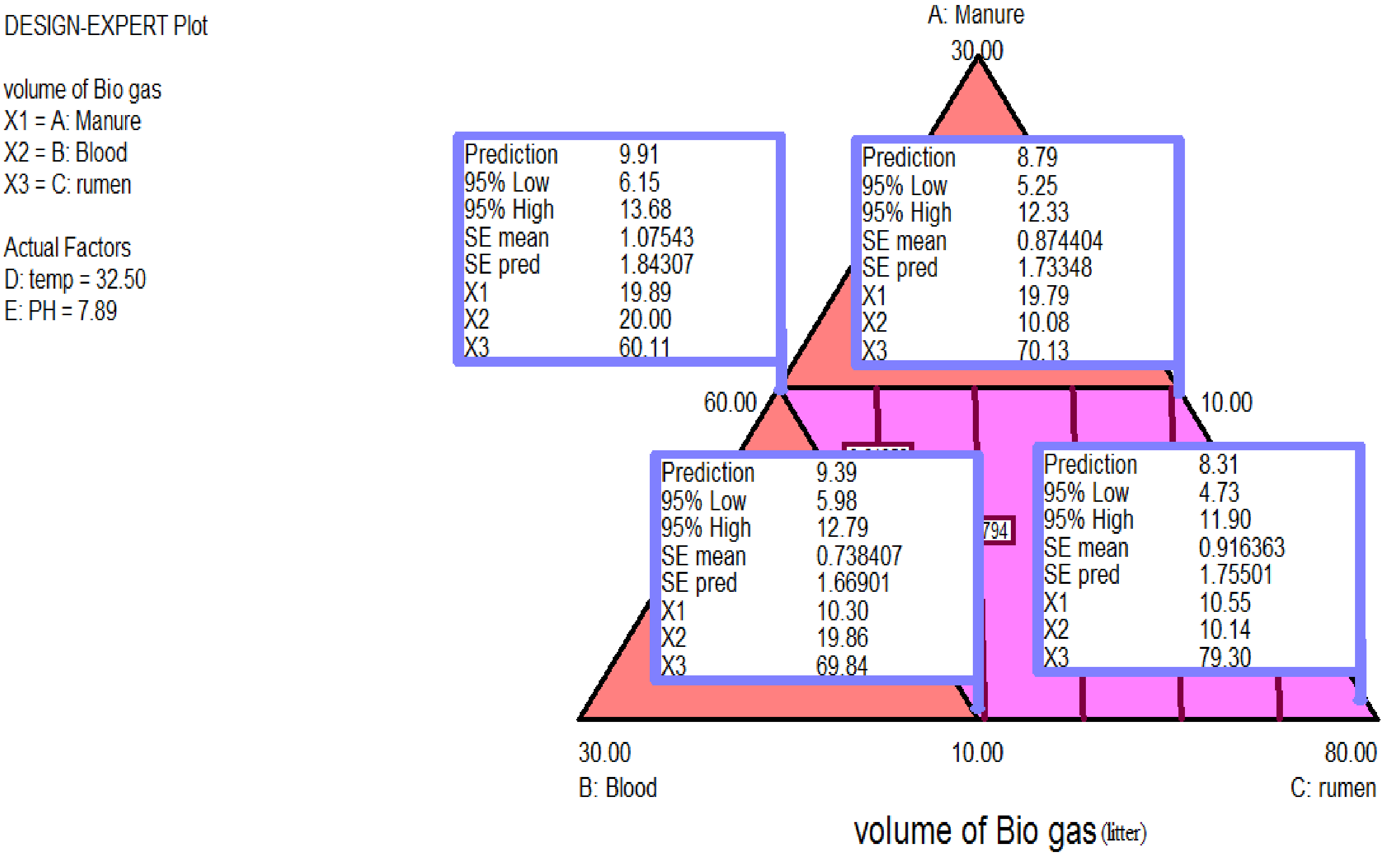


Figure 25**: Amount of Biogas produced at different substrate**

4.2.4. Energy potential of Bio Gas from Optimal condition of Substrate Digestion process

Based on 42 laboratory results by using the Crossed D- Optimal Design Expert it's identified that the best components that had high methane yield depicted at table13. From 20%:20%:60% manure, blood and undigested stomach content respectively at temp 32.49 and pH 7.88.

The amount of TS in 400ml solution of sample mixture fed to the digester was 7.5% which had 84.8% VS and 15.2% fixed solids (FS) or ash shown in Table 12. From this composition of substrate and process condition 79.2% methane was produced and volume of bio gas production 9.79lit from 25.67 gm. of volatile solid content of sample shown in table 12.Hence the maximum amount of biogas yield was 0.381 lit /gm of VS and amount methane was 0.302 lit/gm of VS.

According to other literature review (Yitayal, 2015) and (Thibault cailee, 2010) methane content of biogas 55-80% which depending on digestion process. According to (Singh,N, *et al*, 1990) the average biogas production from organic waste was in the range of 0.26–0.55 m^3/kg VS. Other studies put methane potential of organic waste digestion in the range of 0.2-0.5lit/gm.VS. (TL.Hansen ,*et al*,2004). Anaerobic digestion of blood and rumen paunch contents has methane yield 0.27m^3/kg TS (Banks and Wang, 1999).

When result of present Study compare to literatures has good approximate result value but one study vary from other because of volumetric amount of biogas and methane yield depending on the quality , quantity and nature of feedstock use and the anaerobic digestion process condition (P. Weiland, 2010).

4.2.5. Solid Waste generated by slaughterhouse and Optimum energy potential

Daily solid waste generates from Addis Ababa Abattoirs Enterprise and its total solid and volatile solid content of the waste before dilute with water.

Table 14: Minimum and maximum waste amount of AAAE

Waste	Mass (kg/day)	TS(kg/day)	VS/TS(kg/day)	%TS	%VS/ TS
Blood	6030-12060	663.3-1,326.6	596.3-1,192.6	11	89.95
Manure	6030-12060	1,142.7-2,285.4	931.6- 1,863.29	18.95	81.53
Rumen content	36,180-48,240	5,553.6-7,404.84	4,712-6,283	15.35	84.85
Total	48,240-72,360	7,359.6-11,016.8	6,244.6-9,338.9	15.2	84.8

=

Hence daily average waste disposal of Addis Ababa Abattoirs Enterprise equal to 60,300kg /day. The solid waste mix to water at 1:1 ratio to make total solid concentration 7.5% inside the digester and total average waste 120,600kg/day. According to characterization of sample (Table 9) Average TS and VS content of

AAAE waste disposed to environment is 9,188.2 kg TS from waste per day before mixing with waste water And 7,791.8 kg of VS per day from dry matter. The amount of bio gas that can be produced from daily waste is equal to 2968.7m^3 /day and amount of methane that can be produced per day is 2,353.1 m^3/ day.

Determination of Calorific Value and Energy Equivalent of Biogas

To Determine Calorific value of Biogas generated by AAAE waste contains 79.2 % of methane. Calorific value of 100 % methaneis 8560 KCal / m^3. (D.B. Salunkhe, 2012).

Determination of Calorific Value of Biogas

Calorific Value of Pure Methane = 8560 Kcal / m3

% of Methane in Biogas = 79.2 %

Calorific Value of Biogas = 8560Kcal/m^3 x 0.792= 6779.52Kcal / m^3

Caloric Value of Bio Gas =6,779.52kcal/m^3

Energy Equivalent of Produced Biogas is Equal to

1kwh=859.85kcal then value 6779.52/859.85 (kwh/m^3)=7.88kwh/m^{3}therefore 1m^3 biogas=7.88kwh

Electrical conversion efficiency = 35% and Boiler conversion efficiency = 85% (Charles, 2009).

Therefore for electricity application 1m^3 biogas = 7.88*0.35=2.76 kWh (elec) and

For Boiler application 1m^3 biogas =7.88* 0.85=6.7kwh (Boiler).

Energy Potential of AAAE Waste

From AAAE Waste produced biogases have a capacity to generate power is equal to:

1m^3 bio gas =7.88kwh

Total produced biogas m^3 per day=2968.7m^3 /day

Total energy generate per day= 2968.7*7.88kwh

=23,393.4kwh/day

Total energy generate per day=23,393.4kwh/day

4.3. Determining Biogas equivalent energy demand.

The process of AAAE classifies under three section slaughter section, rendering section and steam generation section. From the data collected from Addis Ababa Abattoirs Enterprise Energy type and consumption of Energy to carry out the activities in the slaughter house is explained in the table below:-

Table 15: Energy Consumption of Addis Ababa Abattoir enterprise (AAAE)

Process Unit	Type of energy	Unit	Average Energy Consumption per day	Cost(birr per day)
Slaughter , rendering unit and some boiler section	Electricity	Kwh	3300	1906.74
Slaughter section	Diesel for Generator	Lit/day or Kwh/day	59 or 224.2	1121
Boiler or steam generation section	Furnace oil	Lit/day	1572	25,152
	Gas oil	Lit/day	717	13,623
		Total		41,802.74

Unit price furnace oil 16 birr per lit, Diesel =19 birr/liter, Diesel generator =3.8kwhr/lit

From the data collected from AAAE they use furnace oil and gas oil for boilers for steam generation which is the highest energy intensive and expensive process that highly uses steam for cooking, vaporization, sterilization and drying of the by product. The steam and hot water section has 10,025,090 birr/year expense for purpose of purchasing furnace oil and diesel. The amount of gas oil 717lit/day and furnace oil consumption is 1,572 (lit/day) which have a caloric value 10,500 kcal/kg, 2-4% of sulfur , specific gravity 0.89 - 0.95, Water Content, %1.0 , density(0.89 - 0.95 gm./cc) and Ash content 0.1%.(energyefficiencyasia,2016)

Property of Furnace oil

Sulphur

The main disadvantage of sulphur in furnace oil follows the risk of corrosion by SO_2 formed during and after combustion, and condensation in cool parts of the chimney or stack, air pre-heater and economizer *(*energy efficiency Asia, 2016)

Ash

Furnace oil has higher ash levels. These salts may be compounds of sodium, vanadium, calcium, magnesium, silicon, iron, aluminum, nickel, etc. Excessive ash in liquid fuels can cause fouling deposits in the combustion equipment. Ash has an erosive effect on the burner tips, causes damage to the refractory at high temperatures and gives rise to high temperature corrosion and fouling of equipment (energy efficiency Asia, 2016).

Viscosity

The viscosity of furnace oil increases with decreasing temperature, which makes it difficult to pump the oil. At low ambient temperatures furnace oil cannot be pumped easily. Because of that AAAE furnace oil pre heated as it flows out with an outflow heater (energy efficiency Asia, 2016).

Determination Energy potential of Furnace oil

In order to Calculate the energy value of liter of furnace oil to kWh per m^3 as follows

1kwh=859.85kcal that is and 1kg furnace oil=10,500 kcal

1Kg of furnace oil =10,500/859.85kwh =12.21kwh changes to kWh per m^3. Then calculate Energy value of one kilogram of furnace oil in terms of kWh/ m^3.

Density=mass/ volume; V=1kg/0.92gm/cc=$10.86*10^{-4}m^3$

KWh/m^3 furnace oil = 12.21kwh/$10.86*10^{-4}$ =11,243kwh/m^3.and also from the literature heavy fuel oil 11.4kwh/lit (**www.livestrong**.com)

From this we have quantified daily energy consumption of boiler for steam generation in the form of kWh by considering conversion efficiency of furnace oil when used or applied on Boiler is 80% (livestrong,2016) Hence amount energy capacity of 1572 lit/day of furnace oil is= 11,243kwh/m^3* 1.572m^3/day

=17674kWh /day.

=0.8*17674 kWh/day

=**14,139.Kwh/day**

Determination Energy potential of Gas oil in kWh

From the literature gas oil caloric value is equal to 11.4kwh/lit (N Packer, 2011*)*.therefore from 717 lit/day gas oil Energy capacity is equal to 717lit/day*11.4kwh/lit= 8,173.8kwh/day. From this we have quantified daily energy consumption of boiler for steam generation in the form of kWh by considering conversion efficiency of gas oil when used or applied on Boiler is 80% (live strong, 2016) therefore8,173.8kwh/day*0.8=6,539kwh/day.

Total energy consumption of boiler = 14,139.Kwh /day+6,539kwh/day=20,678kwh/day, 1572 lit/day Furnace oil and 717 lit/day gas oil cover 20,678kwh/day power on boiler section for water heating in addition, in order to make the furnace oil easily used by boiler additional electric energy is used to melt and pump it to boiler**;** Energy consumption of the rendering system for steam generation is 85% of total energy consumption and its highly energy intensive system compared to other slaughter process units where electricity and diesel are used.

From the above results amount of total average energy consumption of AAAE to implement the activities without considering man power (manual mechanism) is 24, 202kWh/day. Then calculating the amount of biogas to cover the required amount of Energy is done as follow.

Amount of Biogas to carry out Boiler energy consumption or substitute furnace oil and gas oil-

Energy conversion efficiency of Biogas on Boiler=0.85

Amount of Boiler energy consumption=20,678.kwh/day

0.85*Amount of Energy generated from Bio Gas=20,678.6kwh/day

Amount of Energy required to be generated from Bio Gas=24,327.1 kwh/day to substitute furnace oil and gas oil.

Determination of volumetric value of Biogas required covering furnace oil as follows

1m^3=6.698kwh for boiler based on conversion efficiency

Required amount of energy demand from Biogas= 24,327.1 kwh/day

Volume of biogas demand for boiler=24,327.1 /6.698m^3=$\underline{\underline{3{,}632\text{m}^3}}$.

Amount of Biogas to substitute diesel demand for Generator –

Caloric value Diesel Oil - 10,800 kcal/kg and sulphur content of 0.05 - 0.25%

Efficiency in Electricity generation of Biogas on generator =0.35

Amount of Electricity Diesel generate per day=224kwh/day

0.35* Amount of Energy required from Bio Gas =224kwh/day

Amount of Energy required from Bio Gas =640kwh/day Equivalent Demand for Diesel generator.

Determination of volumetric value of Biogas required covering diesel as follows

1m^3=2.758 kWh Equivalent value of Bio Gas for electricity diesel generator based on conversion efficiency

Required amount of energy demand from Biogas= 640kwh/day

Volume of biogas demand for diesel generator =640/2.758 m^3=$\underline{\underline{232\text{m}^3}}$

Based on the above calculation the required amount of bio gas to cover Diesel generator and Boiler energy consumption is recognized but the produced biogas from the AAAE waste does not have enough potential to fulfill the requirement of both boiler ,electricity and diesel generator, Hence Selection of biogas for boiler application which has better conversion efficiency than diesel generator is needed; in addition to this during using furnace oil for boiler application energy intensive system is applied and additional energy is required to decrease the viscosity of oil to easily pump it. As a result this is economically and environmentally not recommended energy using system..

4.4. Design Digester for biogas production from slaughter house waste

The size of digester is calculated based on the energy demand of the organization, the chosen retention time and daily substrate input quantity. Retention time is the total time required by a given amount of feedstock to produce approximately 80 to 85% of total gas. HRT depends largely on temperature, For the complete mixing digesters are designed with a HRT of 20 days at optimal temperature (Rajesh & Sounak ,2013).

Amount of the available waste disposal to the environment and the total solid waste 60,300kg /day and 8,830.5 kg TS/ total waste per day which is 15%TS respectively. Therefore inside the digester TS content of ordinarily 6-9% solids concentration is best suited so that water to waste ratio is 1:1. for good Anaerobic digestion because of this reason the total waste disposed to the digester by adding equal amount of water is 120,600kg/day which has 7.5% TS inside the digester.

During design of the digester the study selected type of digester based on the study optimal process parameter results and feedstock characteristics, sizing the digester was done by considering the available waste generated per day and lastly decided the arrangement of the digester.

4.4.1 Selected digester

The selected digester type is complete mixed digester which is insulated and a controlled temperature at mesospheric or thermophilic range and anaerobically decompose organic wastes at 3-10 percent of total solid concentration and mixed with a motor driven mixer .A complete-mix digester will function with an HRT from 10 to 80 days. However, HRT between 12 and 20 days is most commonly used to economically produce 65-80% of the ultimate methane yield and a complete-mix digester is a heated, insulated above ground or in-ground circular, square or rectangular tank with a mixing system. The tank is covered by a fixed solid top, a flexible inflatable top, or a floating cover to collect and direct biogas to the gas utilization system. All covers are gas tight. (Rajesh & Sounak, 2013)

Hence in this present study TS concentration was 7.5 % which is best suited on this type of digester and our feedstock types have manure and undigested stomach content which easily form scum inside the digester so to prevent scum formation mechanical mixing is used to stir the digester and the digester temperature also controlled at 32.49c^0 based on the depicted reason nominated circular complete mixed digester with affixed solid top.

4.4.2. Digester Sizing and Dimensioning

Calculating the volume and dimensions of digesters were used the following formula and assumptions (Chendu, N, 2006),

Workiung volume of one digester = Vgs + Vf= HRT* Q_d

Where:

$V_{gs}+V_{f\,=}$ working volume of the digester in cubic meters

Q_d = Volumetric flow rate of substrate in cubic meters per day

HRT = retention time in days

Q_d= mass flow rate of substrate /density of substrate

$$=\frac{\frac{120{,}600kg}{day}}{1000kglm^3} \;=120.6\text{m}^3/\text{day}$$

Working volume = 120.6m^3/day* 20 day= 2412 m^3.

Then size of Separate digester construction is recommended so that during maintenance time it helps to solve biogas plant problem without stopping the system. In case one plant stops the other three continue to generate biogas. Since four separate digesters are constructed 4 x 603 m^3 working Digester volumes constructed separately. Hence now total volume of digester and dimensioning is calculated as follows (Chendu, 2006)

Total volume of digester V =Vc+Vgs+Vf+Vs

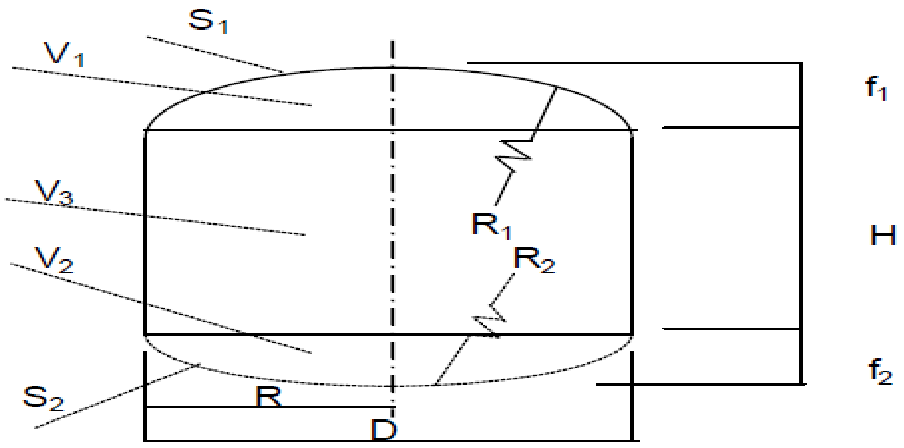
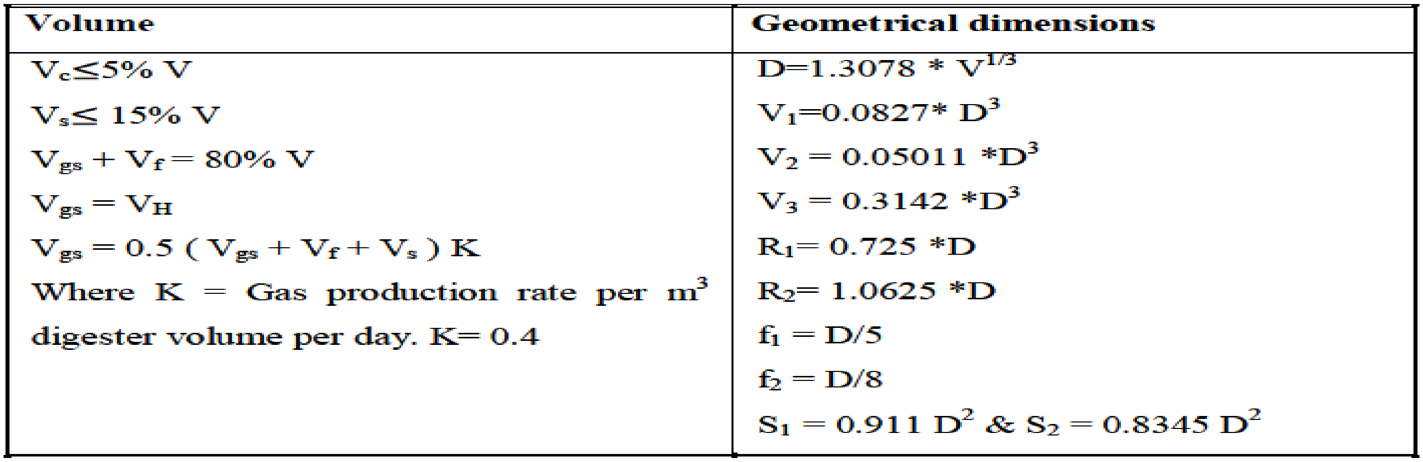


Figure 26-Geometrical dimensions of the cylindrical shaped biogas digester body(Chendu, 2006)

Table 16: Assumptions of Volume and Geometrical dimensions (Chendu, 2006)



Volume	Geometrical dimensions
$V_c \le 5\%$ V	D=1.3078 * $V^{1/3}$
$V_s \le$ 15% V	V_1=0.0827* D^3
$V_{gs} + V_f = 80\%$ V	$V_2 = 0.05011 *D^3$
$V_{gs} = V_H$	$V_3 = 0.3142 *D^3$
$V_{gs} = 0.5 (V_{gs} + V_f + V_s) K$	R_1= 0.725 *D
Where K = Gas production rate per m^3 digester volume per day. K= 0.4	R_2= 1.0625 *D
	f_1 = D/5
	f_2 = D/8
	$S_1 = 0.911\ D^2$ & $S_2 = 0.8345\ D^2$

Working volume of one digester = Vgs + Vf= HRT* Q_d =**603m^3**

From geometrical assumptions:

Vgs + V**f**= 0.80 V

V= 603/0.8 = 753.75m^3. (Putting value Vgs + Vf = 603m^3).Total volume of one Digester (V)=753.75m^3.Thenafter construction of four type of such volume of digester. It is dimension is calculated as follows based on the above assumption:-

D = 1.3078 V $^{1/3}$= 11.902 m.

$$V3 = \frac{3.14 * D^2 * H}{4} \text{(Putting } V_3=0.3142D^3\text{)}$$

$$H=\frac{4*0.3142*D^3}{3.14*D^2}=4.764\text{m}.$$

Now we find from assumption as we know the value of 'D' & 'H'

$V_1 = 0.0827\ D^3 = 139.4\ m^3$

$V_2=0.05011*D^3 =84.49m^3$

$V_3=0.3142*D^3=529.8$

$V_c = 0.05V = 37.69\ m^3$

f_1 = D/5 = 11.902/5= 2.38m

f_2 = D/8 = 1.49m

R_1 = 0.725 D = 8.63 m

R_2 = 1.0625 D = 12.65m

4.4.3. The amount of Energy required by Bio gas plant to facilitate digester activity

The energy required considered Heat needed to regulate digester temperature to adjust at designed temperature, power for mixer and power required for hot water pump.

Heat required for maintaining the required digester temperature

Assumption based on (Metcalf Eddy, 2004) and present study:

Specific heat capacity of sludge = 4,200 J/kg. ^{0}C

Daily flow to the reactor 120 m^3

Sludge temperature 13 ^{0}C

Compute the heat requirement for the sludge

$Qs = m_sCp\Delta T$

$= (120.6\ m^3/d)\ (1000\ kg/\ m3)\ (4,200\ J/kg.\ ^0c)\ (32.49^0c - 13\ ^0c) = 96.23 * 10^8 J/d = 111.4\ kW$

Compute the required heat exchanger capacity –

which is the sum of heat required for sludge and heat required for digester but the present study uses the complex mix digester which is well insulated and no energy loss so the required energy only for sludge heat = 111.4kw

The amount power required for Mixer

In order to calculate power consumption of mixer first it's necessary to calculate diameter of mixer and identify weather the system is turbulence or laminar which is checked by calculating the Reynolds number for the agitation system.

To calculate diameter of mixer $D_m=D_T/3$ (Alpaslan Kocamemi, 2011)

Based on the above formula mixer diameter

$D_A= D_T/3=11.9/3=3.97=4m$

Reynolds number $Re=\frac{\rho n D^2}{\mu}$

D=diameter of impeller=4m

n = rev/sec =0.25rev/sec (ref) (Andreas Lemmer et al, 2013)

ρ =kg/m^3 =1000kg/m^3

μ =dynamic viscosity Ns/ m^2=7.62*10^{-4}Ns/m^2 (Nidal Mahmoud, 2011)

R=Reynolds number (unit less)

$Re=(1000\ kg/m3*0.6rev/s*(4m)^2)/(7.62*10^{-4}Ns/m^2)=12,598,400$

Reynolds number: Re> 10,000 implies turbulent flow

For turbulent flow and propeller mixer power impart in a tank is equal to

$P=k\boldsymbol{\rho}n^3D^5$

Where P: Power (watt)

K=impeller constant= 0.32 (Metcalf Eddy, 2004)

$\boldsymbol{\rho}$= Density kg/m^3

n= revolution per second (rev/s)

D= Diameter of impeller (m)

$P=0.32*1000*(0.25^3)*4^5$(watt)=**5kw**. Total number of mixers has 4 for all four complex mix digester which need 20kW.

Power needed for hot water pump

Turbine type shaft power = (volumetric flow rate * pressure drop) / intrinsic efficiency in the pump. Assuming 75% intrinsic efficiency in the pump and 2 times pressure drop of heat exchanger; to calculate the amount of power required we should first calculate volumetric flow rate

Mass flow of hot water, assuming change in temperature 17 ^{0}C

$Qw = mwCp\Delta T$;

$mw = Qw / Cp\Delta T$

$m_w = (96.23 * 10^8 \text{ J/d}) / (4{,}200 \text{ J/kg. } ^0\text{C} * 17\ ^0\text{C}) = 0.1347769 * 10^6$ kg/d

Volumetric flow rate $=m_w/\boldsymbol{\rho}_w=135m^3/d=0.00156m^3/se$

*Therefore the power needed by hot water pump = (0.00156m3/s * 2* 60799.26N/m2)/0.75 =* <u>*0.253kW*</u>

The amount of energy utilized on site to provide for the internal energy requirement of the plant digester heating, pumps, mixers which is the total amount of power required to facilitate the activity of anaerobic digestion is equal to-

Total Power required= power required (mixer+ hot water pump+ heat exchanger)

=0.253kw+20kw+111kw

=<u>131.2kw</u>

Hence the amount of energy required on the site=<u>3,148.8kwh/day</u>

The amount of biogas applicable on energy generation

=(total biogas generate energy)- (the amount of energy utilize on site)

= (23,393.4-3,148.8) kwh/day

=<u>20,244.6 kwh/day</u>

In the present study generated biogas is proposed for boiler which has better biogas conversion efficiency 0.85and highly energy intensive system from slaughter process

Therefore 20,244.6kwh/day*0.85=17,207.9kwh/day which means 2,568.34m^3

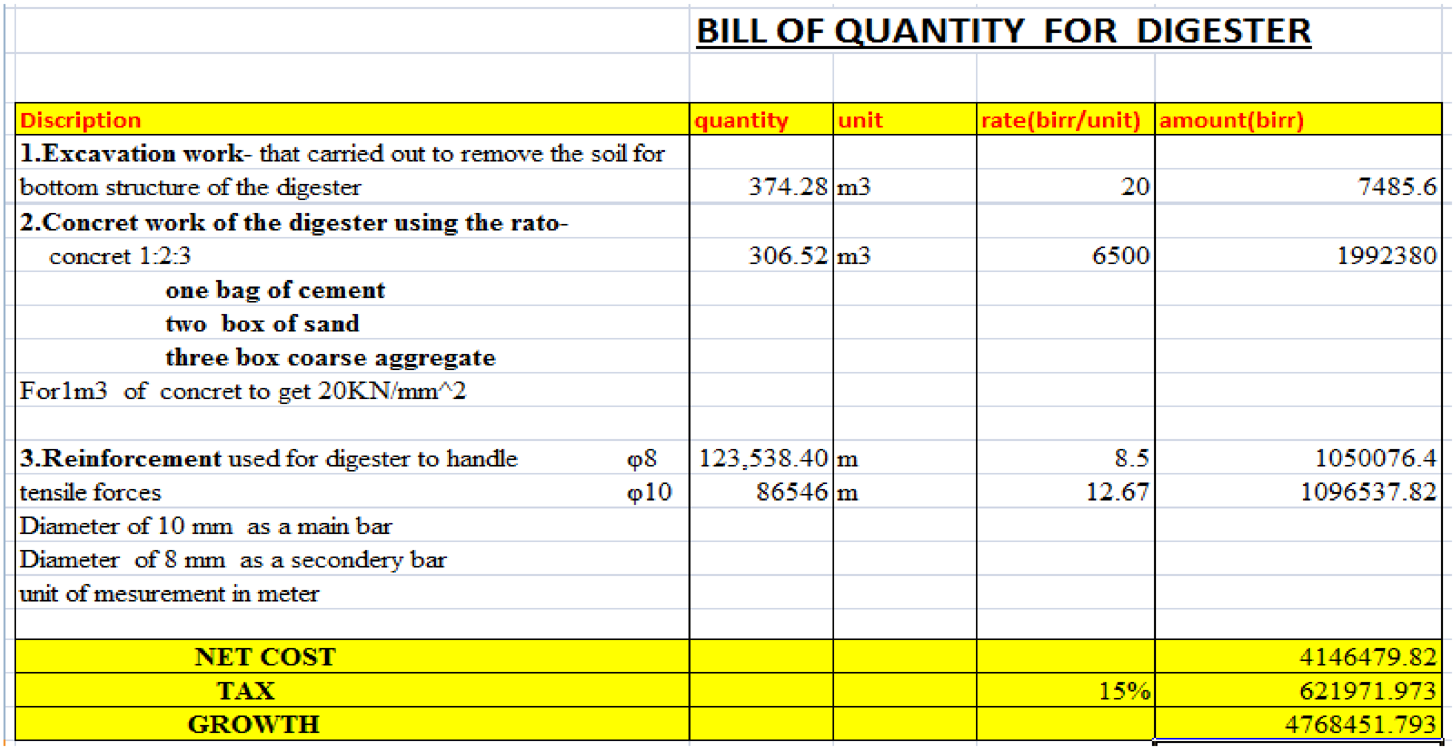
Then total amount of biogas demand to cover boiler energy consumption is 24,327.1 kwh/day which is equal to 3,631m^3.But the available biogas is 2,568.34m^3 which remains after the amount the digester utilizes to maintain the operating system of digestion. Hence according to this study the biogas to be produced from AAAE has a potential to cover 70,7% of boiler furnace oil and gas oil consumption.

4.5. Cost and Benefit of Biogas plant

4.5.1. Costing of the building materials and labor of digester

To calculate capital costs of establishing a biogas plant (a rough estimate of the cost of establishing heated biogas digester, without including the purchase or opportunity costs of land) and to reduce capital costs digesters are assumed to be built with local construction materials to local specifications. Table 17 shows a capital cost analysis in ETB for biogas digester based on the standard of construction material needs and labor cost calculated for constructing four digester plants having a volume of753.75m^3**.** Amount of cost estimated as follows**:**

Table 17**: Biogas digester construction cost**



BILL OF QUANTITY FOR DIGESTER

Discription		quantity	unit	rate(birr/unit)	amount(birr)
1.Excavation work- that carried out to remove the soil for					
bottom structure of the digester		374.28	m3	20	7485.6
2.Concret work of the digester using the rato-					
concret 1:2:3		306.52	m3	6500	1992380
one bag of cement					
two box of sand					
three box coarse aggregate					
For1m3 of concret to get 20KN/mm^2					
3.Reinforcement used for digester to handle	φ8	123,538.40	m	8.5	1050076.4
tensile forces	φ10	86546	m	12.67	1096537.82
Diameter of 10 mm as a main bar					
Diameter of 8 mm as a secondery bar					
unit of mesurement in meter					
NET COST					4146479.82
TAX				15%	621971.973
GROWTH					4768451.793

4.5.2. Cost of major equipment and total investment cost

Cost estimate of heat exchanger

To estimate the costs of heat exchanger first we need calculate the area which is equal to:

$A = Q/ (U \times \Delta Tm)$

Where:

A = Heat transfer area, m^2

Q - Heat transfer rate, W;

U - Overall heat transfer coefficient $W/m^2.^0C$

ΔT_{lm}- Log mean temperature difference (°C)

The log mean temperature difference ΔTm is:

$$\Delta T_{lm} = \frac{(T_1 – t_2) – (T_2 – t_1)}{\ln\frac{(T_1 – t_2)}{(T_2 – t_1)}} = °C$$

Where:

T_1= Inlet tube side fluid temperature

t_2= Outlet shell side fluid temperature

T_2= Outlet tube side fluid temperature

t_1= Inlet shell side fluid temperature

Value of T_1 and T_2 (Tewodros , 2009)

$$\Delta T_{lm} = \frac{(55-32.5)-(38-13)}{\ln\frac{(55 – 32.5)}{(38 – 13)}} = 25^0C$$

To estimate the true temperature difference from logarithmic mean temperature a correction factor is applied to allow for the departure from true counter current

$\Delta Tm = Ft * \Delta Tlm$

Where, Ft is temperature correction factor. It is normally correlated as a function of two dimensionless temperature ratios

$$R = \frac{T1-T2}{t2-t1} = 0.87$$

$$S = \frac{t2-t1}{T1-t1} = 0.46$$

From the graph in Coulson [Sinnott, R.K., 1999] Ft value with this dimensionless ratio is 0.9

$\Delta Tm = 0.9 * 25 = 22.5^OC$

Heat transfer area

Q = UAΔTm Assuming U = 800 W/m^2. ^{0}c [Sinnott, R.K., 1999]

A= Q/UΔTm=111.4kw/(800w/m^{2o}c*22.5^{o}c) =<u>6.2m^2</u>

Heat Exchanger type: shell/tube, floating head large area 6.2m^2 or 66.7 ft^2, carbon steel, internal pressure 150 psi rating cost 2014 US $ 11,200(Matche, 2014) with the 21.65 birr per Us dollar current exchange to ETB 242,480

Hot water pump Cost estimation

centrifugal pump, vertical turbine one stage discharge pipe diameter 4 inch made from cast iron and APi-610 with seal type packing cost 2014 $4,100 (Matche, 2014) which is equal to 88,765 ETB.

Mixer cost estimation

Cost estimate for propeller top entering with 6.7hp working in atmospheric pressure mixing chamber agitator is $8,100 (Matche, 2014).Which is equal to 175,365ETB. For four mixers it becomes 701,460 ETB

Cost estimate of Biogas Boiler

Capital cost of Biogas boiler with boiler capacity 5380kw cost £ 65,000 (Allardyce et.al, 2014) with the 1.43 US dollars per pound it comes $92,950 which is equal to 2,012,370ETB.

Fixed Capital Investment is the summation of direct cost and indirect cost calculated as follows

FCI = Direct Costs + indirect Costs

Direct cost

Direct cost or total physical cost of the plant which is Process equipment cost can be calculated by factorial method (all in ETB)

Total purchase cost of major equipment items (PCE)

Shell and tube heat exchanger =242,480

Boiler = 2,012,370 ETB.

Hot water pump = 88,765

Mixer = 701,460

Total PCE = <u>3,045,075ETB</u>

Based on reference table 6.1 in Coulson (Sinnott, R.K., 1999.) the other cost estimated by factors of the equipment which is The major direct cost to be added to PCE are detailed below;

Equipment erection (f1) = 0.4; Piping (f2) = 0.7; Instrumentation (f3) = 0.2; Electrical (f4) = 0.1

Therefore the total physical plant cost (PPC) or direct cost is

PPC = PCE (1 + f1 + f2 + f3 + f4) = 3,045,075ETB * (1+0.4+0.7+0.2+0.1) = 7,308,180 ETB

The major indirect cost: design and engineering (f10) = 0.3; contingencies (f12) = 0.1

Fixed capital cost (FC) = PPC (1 + f10 + f12) = 7,308,180 ETB * (1+0.3+0.1) = 10,231,452 ETB

Total investment required of the project = Fixed capital Cost + Digester Construction cost

=10,231,452 ETB +4,768,451.8ETB

= 14,999,903ETB.

4.5.3. Annual cost

Maintaining proportion of raw materials, water for mixing materials, feeding and operations of the plant, preventative and on-going maintenance, storage and disposal of the slurry, gas distribution and utilization, and administration are all different operating costs associated with running a biogas plant. Annual operating cost, reference table 6.6 from Coulson (Sinnott,, 1999.) Assuming operating time 300 days in a year, and they are two basic costs. In this category Table 18 shows the running costs.

Table 18: Annual cost

Items	Description	Cost
Maintenance cost	10% of fixed capital cost	1,023,145.2
Operating labour one extra man a day	1500 birr per month	18,000per year
Plant over heads =	50% of operating labor and maintenance cost	520,572.6
Insurance	1% of fixed capital	10,231
Fixed cost		**1,571,948.8**
Variable costs (ETB)		
Raw materials		not applicable
Miscellaneous materials,	10% of maintenance cost	102,314.52
Utility - Electric power	0.37 birr/kWh * 43.2 kW * 8hour/day *300 day/year	38,361.60
Variable cost		**140,675.6**

Annual operating or Total Production cost (TPC) = variable cost + fixed cost

= 1,571,948.8 +140,675.6=1,712,620 ETB

4.5.4. .Economic benefits of the production, use and sale of energy

Economic benefit of Biogas includes sources of heat, enriched fertilizer and waste-management (to control odor and convert methane emissions to usable energy). A cost-benefit of the use of methane digesters for AAAE is explained as follow

4.5.4.1 Annual income

A. Biogas

the produced biogas from Addis Ababa Abattoir Enterprise can cover 70.7% of boiler furnace oil and gas oil consumption and generate heat which equals to 17,207.9kwh/day (2,568.34m^3 biogas).The steam and hot water section has 10,025,090 birr/year expense for purpose of purchasing furnace oil and diesel for boiler hence the budget allocated for purchasing furnace oil is reduced by 70.7% which is equal to 7,087,740.ETB

B. Organic Fertilizer

Amount of organic matter discharge from digester is (Q_S)

Q_S=Q_f-Q_g

Where Q_s= Amount of organic matter discharge from digester is

Q_f= Dry matter feed to digester

Q_g=Dry matter convert to biogas

Therefore, the daily biomass input is 60,300kg.

Total solid content of slaughter house waste is, TS = 0.15

Volatile solid content of slaughter house waste is, VS per daily biomass = 0.13.

Q_S=Q_f- Q_g

Q_S= (0.15*60,300kg/day-0.13*60300kg/day)=1206kg/day.

Assuming 238 days in a year by considering 72 non Slaughtering days of AAAE day (Tuesday and Thursday) from a week and 55days of orthodox fasting time.

The mass of bio slurry per year is equal to 1206kg/day*238=287,028kg/year

The lowest cost of manufactured fertilizer that is widely used throughout the country by farmers is Urea which is 961.8 birr/100kg and selling price of bio slurry is 5% of urea (Girmay, 2015)

Selling Cost of bio slurry per year= 287,028kg/year*9.62*0.05=138,060birr/year

C. Cost benefit from Waste management

Annual waste management cost of Addis Ababa Abattoir enterprise is in average 494,343 ETB which is without including the cost of Addis Ababa city Administration to clean the waste from river and downstream users. Hence Total Annual income from biogas production is ETB 7,719,140.

4.5.4.2. Cost-Benefit Analysis

Cost-benefit analysis (CBA) includes assessment of the financial and economic feasibility of a proposed study to Addis Ababa Abattoirs enterprise. The analytical tools that can be used include:

- Benefit-Cost Ratio
- Net Present Value
- Payback Period

The Net Present value (NPV) = Total benefits during the lifetime of the project (P_b) less The Present costs during the lifetime of the project ($Pc_)$ are determined as

$$\mathrm{NPV} = \mathrm{Pb} - \mathrm{Pc}$$

$$Pb = \frac{Ab\{(1+r)^n - 1\}}{r(r+1)^n} \ ,$$

Where A_b= Annual benefit=7,719,140ETB

P_b=total benefit during the lifetime of the project

r= discount rate at r=12% (Ebrahim Ali 2006).

n= number of year

$$\mathrm{Pc} = Ic + \frac{A \quad \{(1+r)^n - 1\}}{r(r+1)^n}$$

Ic = Initial cost

A=Annual cost

Pc= Present costs during the lifetime of the project

$$\mathrm{Pc} = 14{,}999{,}903 + 1{,}712{,}620\,\frac{((1+0.12)\text{^}15 - 1))}{0.12(1+0.12)^{15}}$$

<u>Pc=25,903,100ETB</u>

P_b=7,719,140 *6.81

=52,567,400 ETB

NPV=P_b-P_c

=52,567,400 -25,903,100 ETB

NPV=<u>26,664,300ETB</u>

Benefit-Cost Ratio

The benefit-cost ratio (BCR) is the ratio between discounted total benefits and costs.

$$BCR = \frac{P_b}{P_c}$$

=52,567,400/25,903,100ETB

==**2.03**For a project to be acceptable, the ratio must have a value of 1 or greater.

Simple Payback period (SPB) - is the time required for the sum of the cash flows from the annual savings to cover the initial cost (without discounting). This is an indicator of liquidity and risk

$$\text{SPB} = \frac{Capital\ Cost}{Annual\ Savings}$$

Annual Saving= Annual Benefit-Annual Cost

= (7,719,140-1,712,620) ETB

=6,006,520ETB

SPB= 14,999,903/6,006,520

= 2.49=**2.5year that is 2year and five month. It is** acceptable payback period.

Chapter Five

Conclusion

The present study emphasizes on production of Biogas from three different sources namely, manure, undigested stomach content and blood, the characteristics of each of the three items were investigated in detail comparatively. The results obtained can be summarized as follows: Biogas production from blood alone is so difficult; it must be mixed with another organic waste. The best and straightforward organic waste in a slaughterhouse is manure and undigested stomach content which comes from stomach of dead animals and includes higher amount of anaerobic bacteria hence blood mixed with manure and undigested stomach content at optimal proportion can produce attractive amount of Biogas But the amount of methane yield decreases when concentration of blood is higher than that of manure.

This study focuses on the optimization of process parameters such as substrate composition, initial pH and Temperature for the maximal biogas production .Optimization of those variables was carried out by Crossed D-Optimal Design Expert software. The initial pH and temperature had significant individual effects on bio gas yield. The optimum conditions for maximizing the biogas yield were a substrate concentration of 15% TS, from manure-blood-undigested stomach content mixture with proportion of (20/20/60 %) respectively, an initial pH of 7.89 and Temperature 32.5^{o}c in which maximum biogas yield of 0.381 lit /gm. Out of which 79.2% is methane was obtained with calorific value 6779.52 Kcal / m^3 which has energy generating potential of 7.88kwh/m^3.

From the study we conclude that AAAE waste have excess amount of undigested stomach content , blood and manure Disposed to the environment which pollutes Akaki river and also the subsurface and underground water of the area , contributes to global warming as well as health related problems to downstream duelers. While this waste has a potential to generate 23,393.4kwh/day of energy which could cover 70.7% of boiler furnace oil and gas oil consumption and generate heat equal to 17,207.9kwh/day and save 7,087,740.ETBbirr/year of its budget. In addition to this from bio slurry we can generate 287,028kg/year organic fertilizer which sell minimum sale price 138,060 birr/year and saves waste management cost.

Study cost benefit analysis has shown that net present value of the biogas plant is positive for boiler application and benefit cost ratio is 2.03 which is greater than one and the simple payback period is 2year and five month hence this study application is feasible and profitable.

Generally benefit we get from biogas cannot be explained enough in words or money benefit which has great contribution to transfer natural resources for future generation without contamination by treating toxic waste before dumping to the environment , to get green energy resources with zero greenhouse gas emission as a result making the environment clean , neat and healthy .

Chapter Six

Recommendations

This study suggested that the organization should use bio gas for rendering plant for steam generation and for slaughter section for diesel generator to reduce the cost of energy and minimize its discharge of pollutant wastes to the environment, to reduce foreign currency of the country and to substantially solve the energy problem of the organization.

Organic fertilizer should be produced at large from bio slurry with high NPK value. From this the organization can get profit by selling organic fertilizer and contribute its part in reducing foreign currency of the country from buying of synthetic fertilizer and also reduce risk of climate change because of synthetic fertilizer.

We recommend that the government and AAAE give attention for avoiding the direct disposal of the waste to the river without any treatment so this biogas technology is the best remedy to solve such kind of problem in Addis Ababa city and can make it free from unpleasant smell, good sanitation condition, health and also free from ground and surface water pollution

It is here by recommended that some pilot test and further work has to be done in improving bio methane composition of the biogas produced from organic decomposed waste by means of up grading system of Bio gas by scrubbing of $CO_2$and H_2S which maximize its methane composition. In addition to this by co-digestion of its own waste with food waste and fruit & vegetable wastes by collecting from hotels and fruit-vegetable market areas available around kera can upgrade the biogas production quality because of vegetable waste is rich in carbon that can normalize blood nitrogen content of slaughter house waste to achieve a balanced process.

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Annex 1: Questionnaires Form for Addis Ababa Abattoirs Enterprise

Addis Ababa University
Addis Ababa Institute of Technology
Energy center

Questionnaires to be provided for the respondents of slaughter house staff

General Directions,

The main purpose of this questionnaire is Identification ofthe amount of wastes disposed to the environment as well as determining quantitatively the category of wastes and the actual amount of solid and liquid wastes that can be used for bio gas production, amount of energy consumption and type of energy use to carry out the activities. The result of the questionnaires will be used to know which type of wastes necessary for biogas production and evaluate solid to water ratio of slaughter house wastes disposal for bio gas production and to identify energy intensive process unit and to know highly used energy type in the organization.

Please read each item carefully and give your honest response to each item. So, please check that you have given your response to all items.

Very much grateful to you for taking time and filling out this questionnaire.

Genet Tsegaye
Energy Technology Graduate Student

I. Please write down your opinion /idea briefly to the following survey questions

1. Name of slaughter house –Addis Ababa Abattoirs Enterprise

2. How many Animal slaughtered per day?

A. Goat__

B. Sheep_

C. Cattle

3. Explain amount of water used per each type of animal per day? per month? per year?

A. Goat - __________*lit per day,* ____________*lit per month,* _____________*lit per year*
B. Sheep- __________*lit per day,* _________ *lit per month,* ___________*lit per year*
C. Cattle-______________*lit per day* _____________ l*it per month,* ____________*litper year*

4. Explain type and amount of waste dispose from slaughter house ,

<table>
<tr><th rowspan="3">Type of animal</th><th colspan="8">Amount of Wastes per day per type of animal</th></tr>
<tr><th colspan="2">Blood(kg)</th><th colspan="2">Manure(kg)</th><th colspan="2">Un digested Stomach content</th><th colspan="2">Others</th></tr>
<tr><th>Per day</th><th>Per month</th><th>Per day</th><th>Per month</th><th>Per day</th><th>Per month</th><th>Per day</th><th>Per month</th></tr>
<tr><td>Goat</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Sheep</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Cattle</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Others , if any</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

- If possible, please write the amount of wastes per year per animal type.

5. Which type of waste used in slaughter house? For what purpose?

6. Do you have treatment plant for the wastes? What types of treatment methods are used?

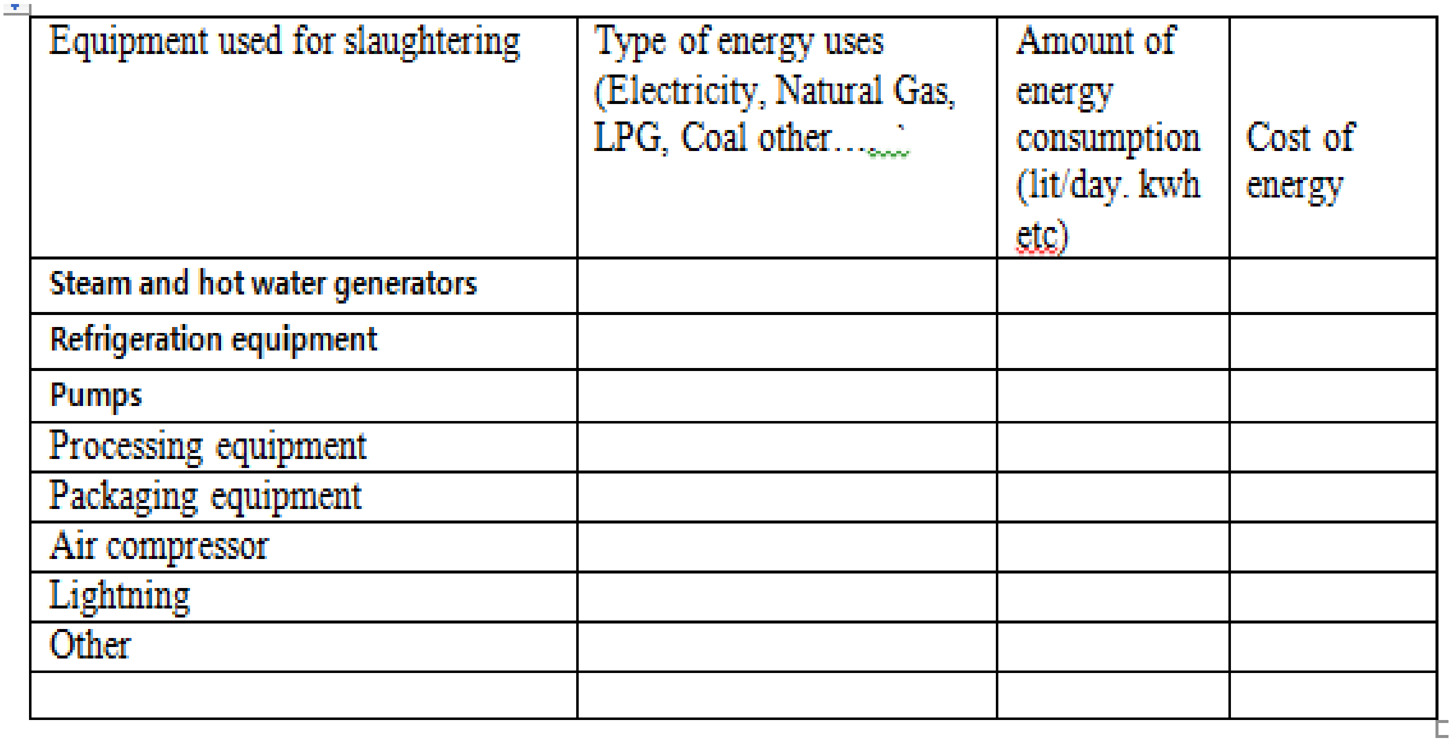
7. Do you have bio gas plant? What is the size, type of wastes used, amount of gas produced/energy?

8. What is the power consumption of your company per month? Its cost in Birr?

9. How many days power interruption occurred per month? Could you please explain the problems faced on slaughter process and like activities during power interruption?

10. Does the bio gas cover your electricity consumption? If not, what do you think the reasons?

11. Energy Consumption of slaughter house



Equipment used for slaughtering	Type of energy uses (Electricity, Natural Gas, LPG, Coal other…..)	Amount of energy consumption (lit/day. kwh etc)	Cost of energy
Steam and hot water generators			
Refrigeration equipment			
Pumps			
Processing equipment			
Packaging equipment			
Air compressor			
Lightning			
Other			

12. Amount of energy consumption per day and per month in each process equipment lit/day, kwh, and explain for what purposes

Natural gas ________________

Electricity _______________

Liquefied petroleum products___________________________________

Annex 2: Laboratory Experiment procedures on determination of total solid and volatile solid of the sample

APHA, Standard Methods for the Examination of Water and Waste water- 20th Edition. Method 2540E.

Apparatus used

Evaporating dishes

Desiccator,

Oven operating at 103-105 $_0$C

Weighing balance

Dish Tongs

Beaker

Muffle furnace for operating at 550 $_0$C

Measuring procedure

Step one -Preparation of evaporating dish

- ✓ Heat clean dish to 103 to 105 $_0$C oven for 1h
- ✓ Ignite clean evaporating dish at 550 $_0$C for 1h in a muffle furnace for VS
- ✓ Store and cool dish in desiccators until needed
- ✓ Weigh immediately before use

Step two-Sample analysis and evaluate value of TS and VS.

- ✓ measured volume of sample to a pre weighed dish
- ✓ Evaporate sample on oven for 24 hr
- ✓ Cool dried sample in desiccator to balance temperature, and weigh
- ✓ Measure TS of sample.
- ✓ Ignite the residue produced by method APHA in a muffle furnace
- ✓ Transfer to a desiccators for final cooling in a dry atmosphere.
- ✓ Measure VS of sample.

Calculation

$$mg\ total\ solid / L = \frac{(A-B)}{Sample\ volume, ml} X100$$

Where:

A = weight of dried residue + dish, mg, and
B = weight of dish, mg.

$$mg\ volatile\ solid / L = \frac{(A-B)}{Sample\ volume, ml} X100$$

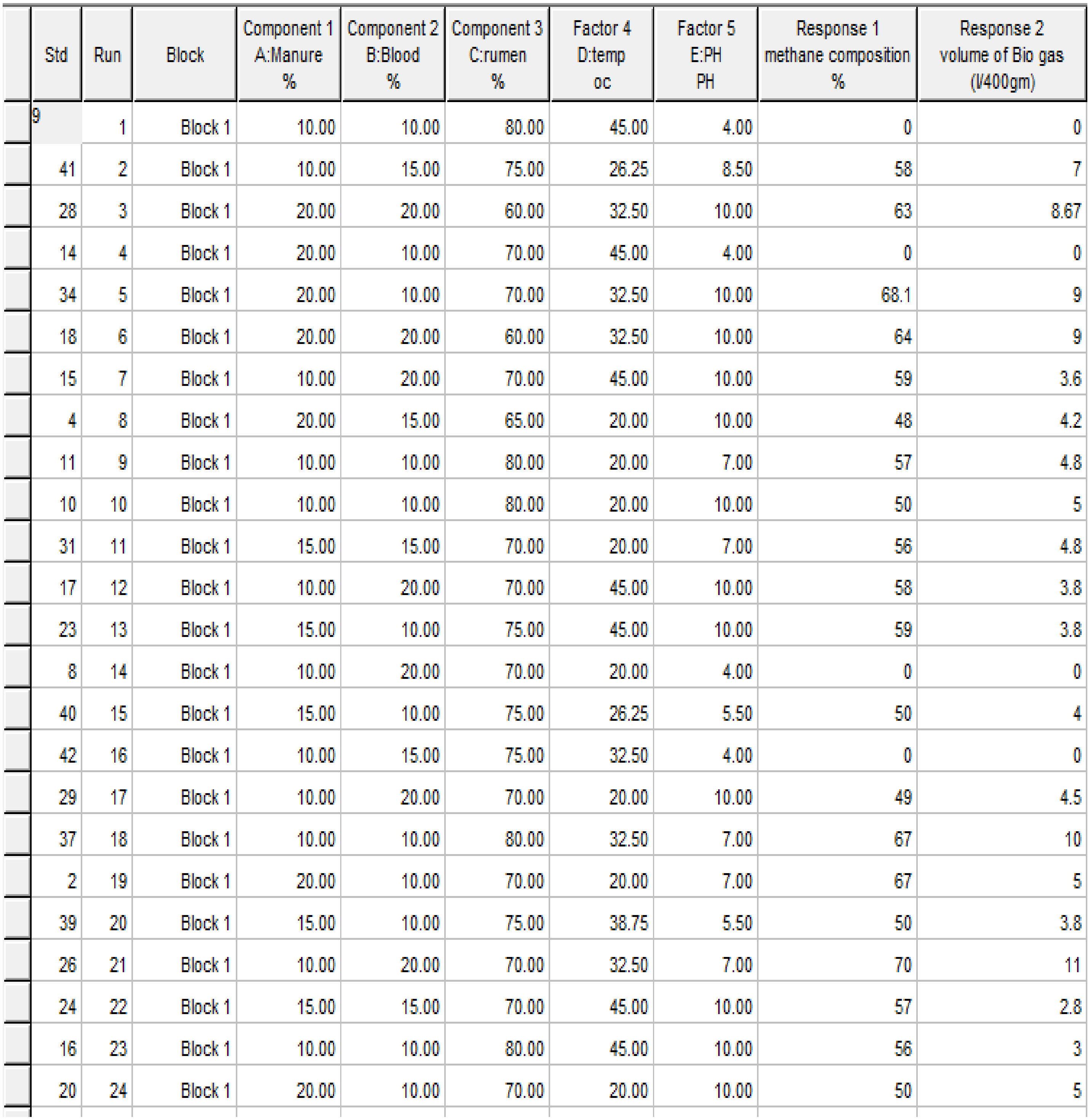
Where:

A = weight of dried residue + dish before ignition, mg
B = weight of residue + dish after ignition, mg.

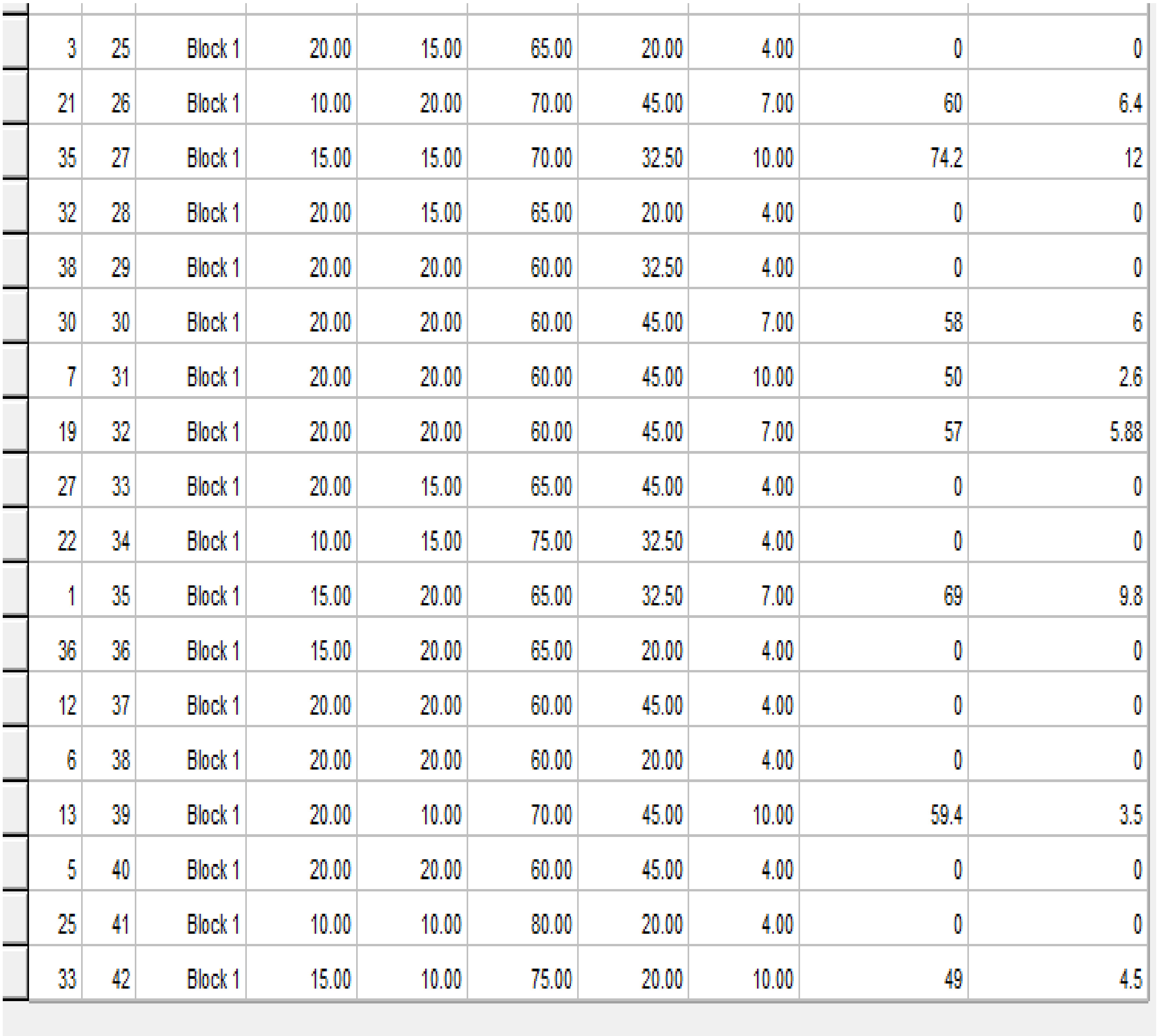
Annex 3: Individual biogas production potential of slaughterhouse waste of Laboratory result

HRT	Blood		Manure		Undigested stomach content	
	Volume of bio gas	Methane composition (%)	Volume of bio gas(lit)	Methane composition (%)	Volume of bio gas(lit)	Methane composition (%)
25	0	0	2.2	53.4	0.8	34
35	0	0	3.2	66	2	46
45	0	0	1.6	57	1.2	54

Annex4: laboratory results of methane yield and amount of biogas Production from mixtures of blood, manure and undigested stomach content

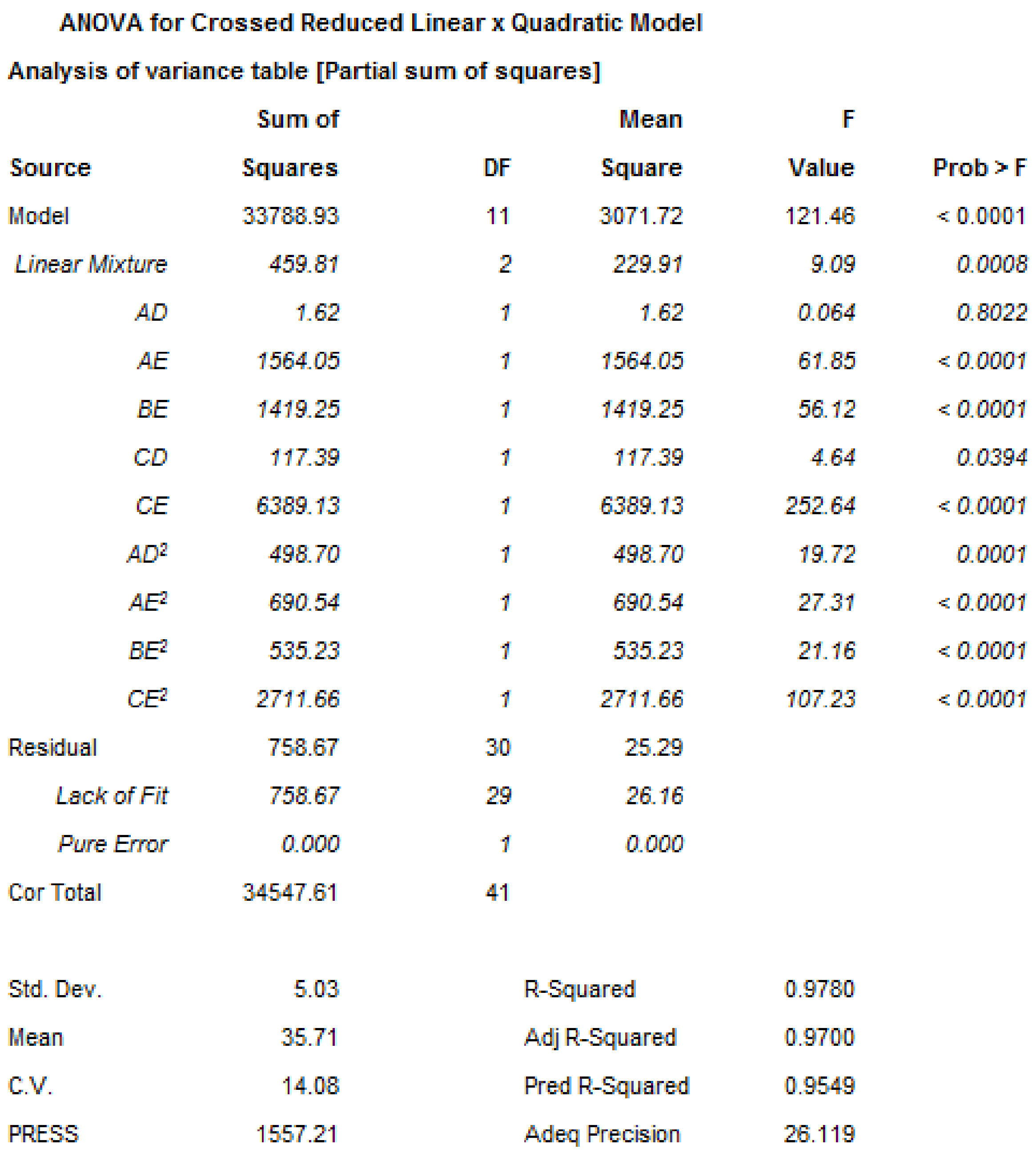


Std	Run	Block	Component 1 A:Manure %	Component 2 B:Blood %	Component 3 C:rumen %	Factor 4 D:temp oc	Factor 5 E:PH PH	Response 1 methane composition %	Response 2 volume of Bio gas (l/400gm)
9	1	Block 1	10.00	10.00	80.00	45.00	4.00	0	0
41	2	Block 1	10.00	15.00	75.00	26.25	8.50	58	7
28	3	Block 1	20.00	20.00	60.00	32.50	10.00	63	8.67
14	4	Block 1	20.00	10.00	70.00	45.00	4.00	0	0
34	5	Block 1	20.00	10.00	70.00	32.50	10.00	68.1	9
18	6	Block 1	20.00	20.00	60.00	32.50	10.00	64	9
15	7	Block 1	10.00	20.00	70.00	45.00	10.00	59	3.6
4	8	Block 1	20.00	15.00	65.00	20.00	10.00	48	4.2
11	9	Block 1	10.00	10.00	80.00	20.00	7.00	57	4.8
10	10	Block 1	10.00	10.00	80.00	20.00	10.00	50	5
31	11	Block 1	15.00	15.00	70.00	20.00	7.00	56	4.8
17	12	Block 1	10.00	20.00	70.00	45.00	10.00	58	3.8
23	13	Block 1	15.00	10.00	75.00	45.00	10.00	59	3.8
8	14	Block 1	10.00	20.00	70.00	20.00	4.00	0	0
40	15	Block 1	15.00	10.00	75.00	26.25	5.50	50	4
42	16	Block 1	10.00	15.00	75.00	32.50	4.00	0	0
29	17	Block 1	10.00	20.00	70.00	20.00	10.00	49	4.5
37	18	Block 1	10.00	10.00	80.00	32.50	7.00	67	10
2	19	Block 1	20.00	10.00	70.00	20.00	7.00	67	5
39	20	Block 1	15.00	10.00	75.00	38.75	5.50	50	3.8
26	21	Block 1	10.00	20.00	70.00	32.50	7.00	70	11
24	22	Block 1	15.00	15.00	70.00	45.00	10.00	57	2.8
16	23	Block 1	10.00	10.00	80.00	45.00	10.00	56	3
20	24	Block 1	20.00	10.00	70.00	20.00	10.00	50	5



3	25	Block 1	20.00	15.00	65.00	20.00	4.00	0	0
21	26	Block 1	10.00	20.00	70.00	45.00	7.00	60	6.4
35	27	Block 1	15.00	15.00	70.00	32.50	10.00	74.2	12
32	28	Block 1	20.00	15.00	65.00	20.00	4.00	0	0
38	29	Block 1	20.00	20.00	60.00	32.50	4.00	0	0
30	30	Block 1	20.00	20.00	60.00	45.00	7.00	58	6
7	31	Block 1	20.00	20.00	60.00	45.00	10.00	50	2.6
19	32	Block 1	20.00	20.00	60.00	45.00	7.00	57	5.88
27	33	Block 1	20.00	15.00	65.00	45.00	4.00	0	0
22	34	Block 1	10.00	15.00	75.00	32.50	4.00	0	0
1	35	Block 1	15.00	20.00	65.00	32.50	7.00	69	9.8
36	36	Block 1	15.00	20.00	65.00	20.00	4.00	0	0
12	37	Block 1	20.00	20.00	60.00	45.00	4.00	0	0
6	38	Block 1	20.00	20.00	60.00	20.00	4.00	0	0
13	39	Block 1	20.00	10.00	70.00	45.00	10.00	59.4	3.5
5	40	Block 1	20.00	20.00	60.00	45.00	4.00	0	0
25	41	Block 1	10.00	10.00	80.00	20.00	4.00	0	0
33	42	Block 1	15.00	10.00	75.00	20.00	10.00	49	4.5

Annex 5: Analyses of the laboratory Result via crossed D-Optimal Design Expert soft ware



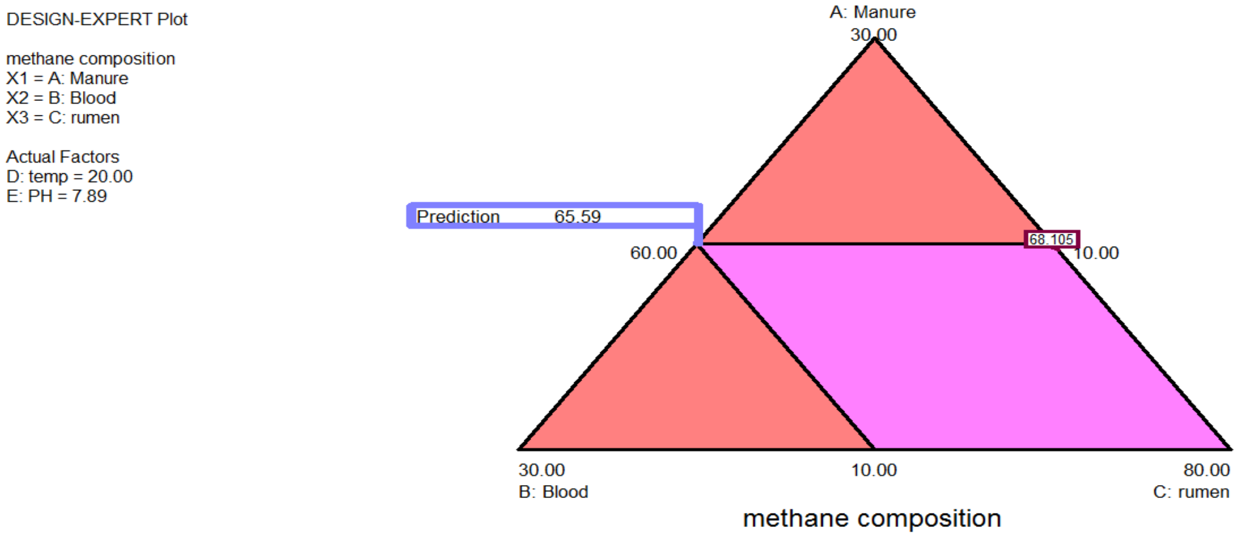
ANOVA for Crossed Reduced Linear x Quadratic Model

Analysis of variance table [Partial sum of squares]

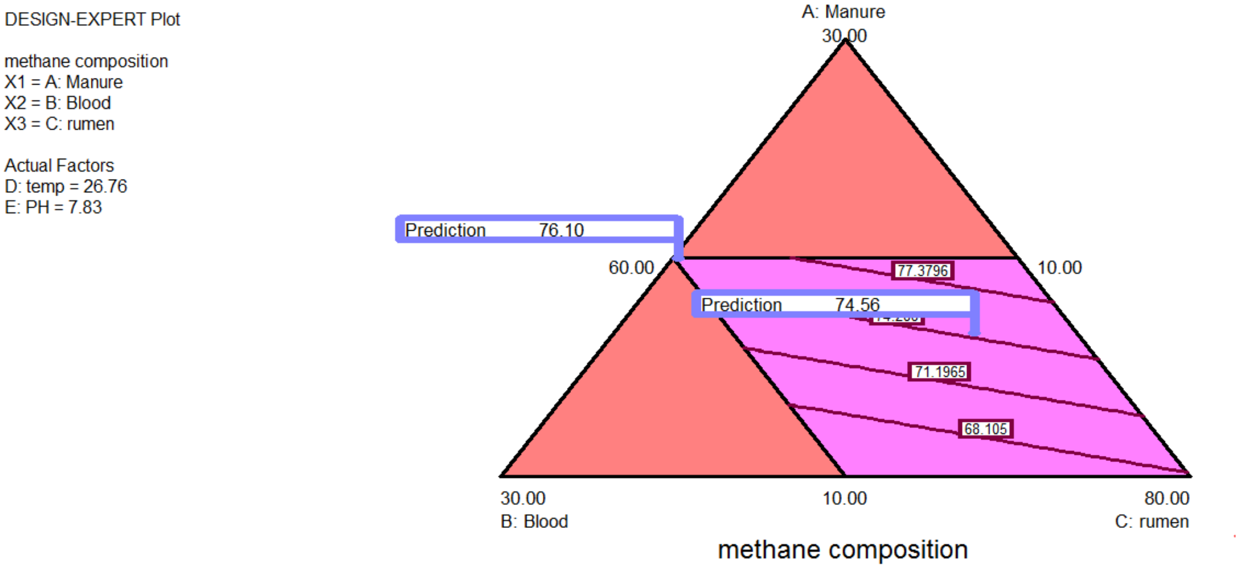
Source	**Sum of Squares**	**DF**	**Mean Square**	**F Value**	**Prob > F**
Model	33788.93	11	3071.72	121.46	< 0.0001
Linear Mixture	*459.81*	*2*	*229.91*	*9.09*	*0.0008*
AD	*1.62*	*1*	*1.62*	*0.064*	*0.8022*
AE	*1564.05*	*1*	*1564.05*	*61.85*	*< 0.0001*
BE	*1419.25*	*1*	*1419.25*	*56.12*	*< 0.0001*
CD	*117.39*	*1*	*117.39*	*4.64*	*0.0394*
CE	*6389.13*	*1*	*6389.13*	*252.64*	*< 0.0001*
AD^2	*498.70*	*1*	*498.70*	*19.72*	*0.0001*
AE^2	*690.54*	*1*	*690.54*	*27.31*	*< 0.0001*
BE^2	*535.23*	*1*	*535.23*	*21.16*	*< 0.0001*
CE^2	*2711.66*	*1*	*2711.66*	*107.23*	*< 0.0001*
Residual	758.67	30	25.29		
Lack of Fit	*758.67*	*29*	*26.16*		
Pure Error	*0.000*	*1*	*0.000*		
Cor Total	34547.61	41			

Std. Dev.	5.03	R-Squared	0.9780
Mean	35.71	Adj R-Squared	0.9700
C.V.	14.08	Pred R-Squared	0.9549
PRESS	1557.21	Adeq Precision	26.119

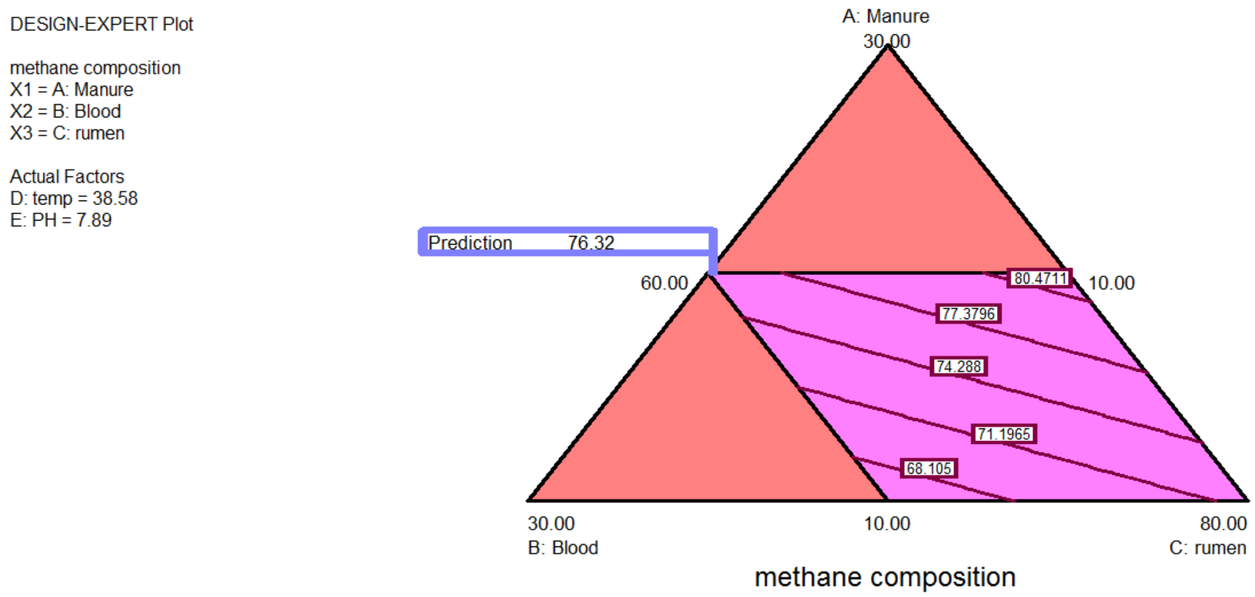
Annex 6: Methane Composition at different temperature and at selected pH and at different Substrate composition



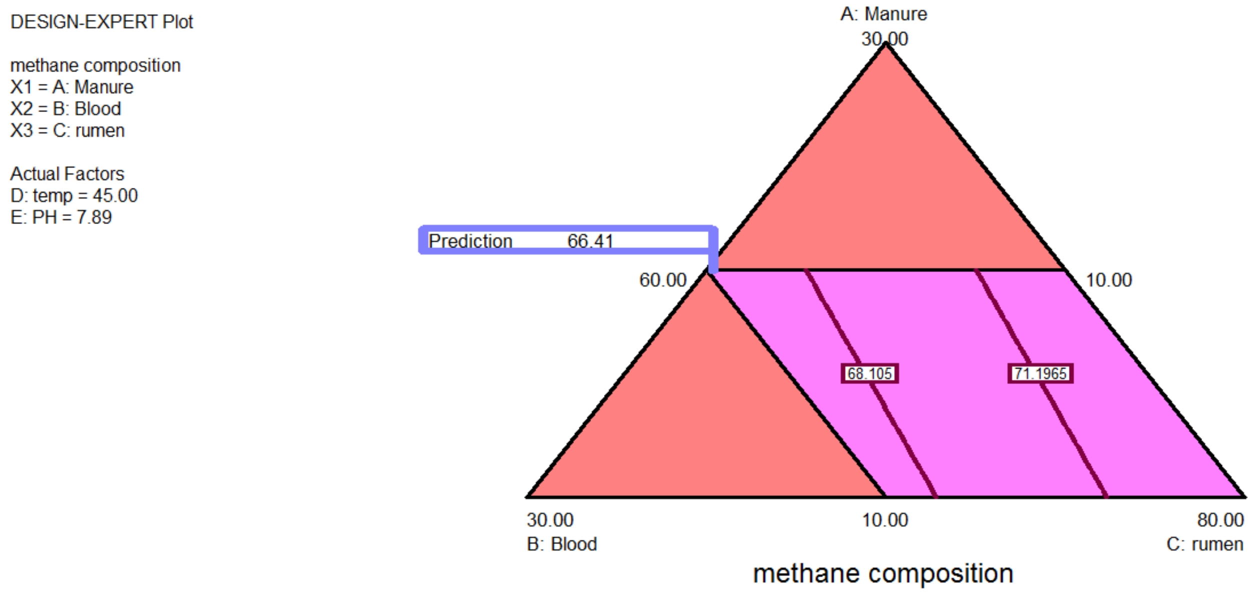
A. Methane composition at Selected pH and at T=20^{O}C



B. Methane composition at Selected pH and at T=26.76^{O}C

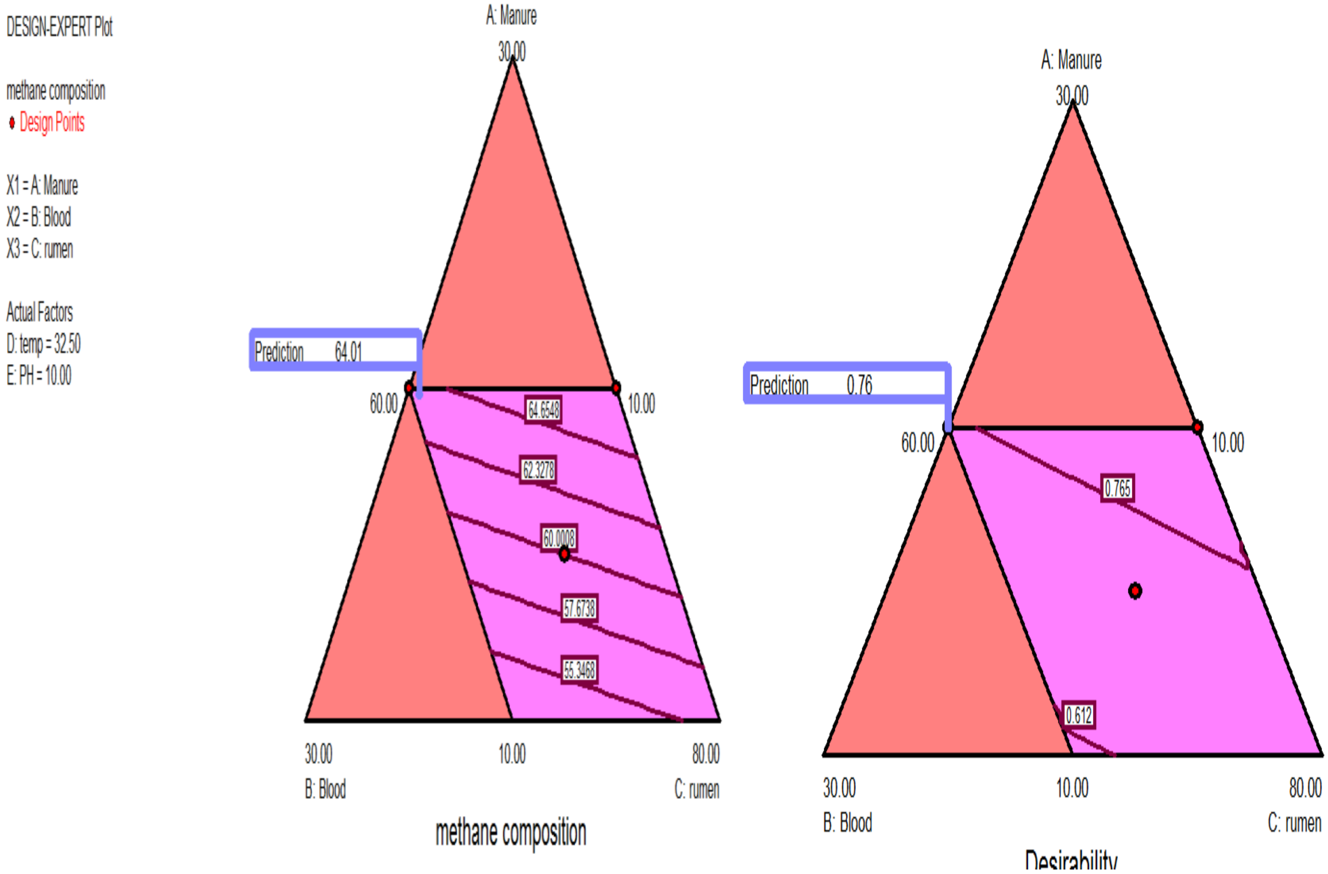


C. Methane composition at Selected pH and at Temperature=38.5^{O}C

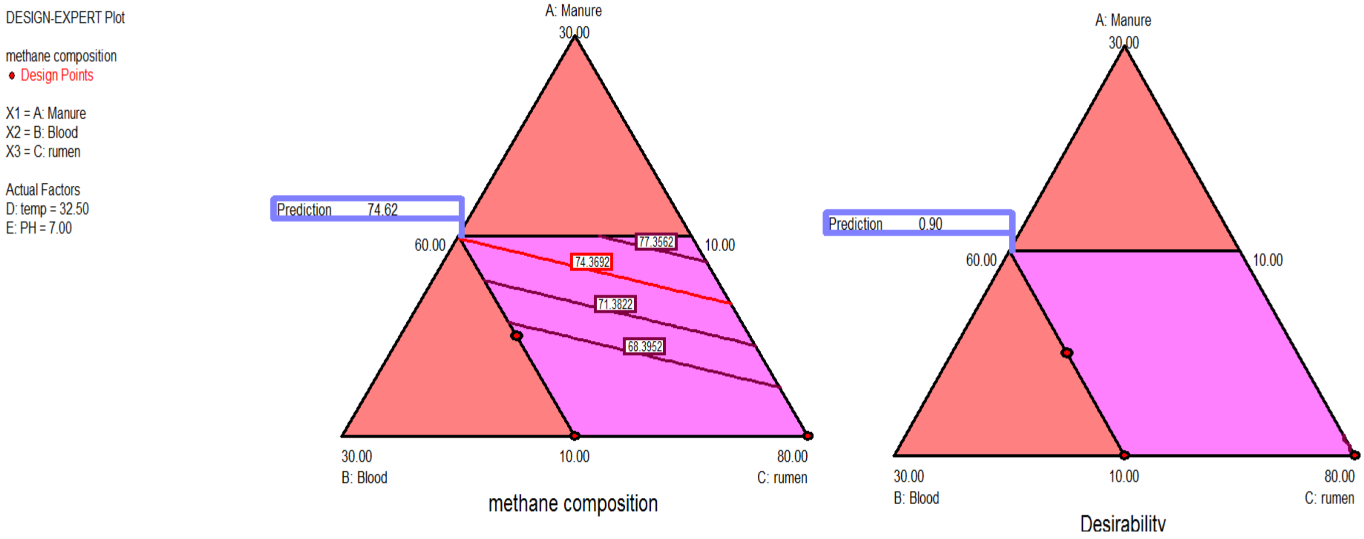


D. Methane composition at Selected pH and at Temperature=45^{O}C

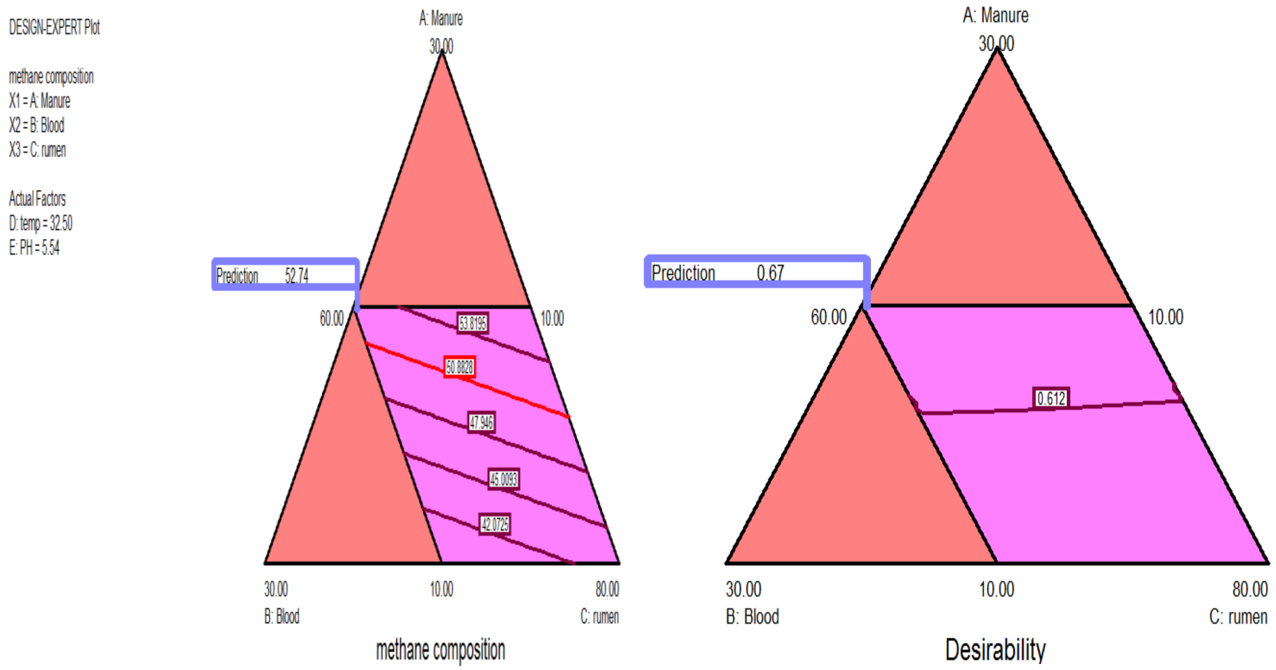
Annex 7. Desirability and Methane composition at selected temperature and different pH



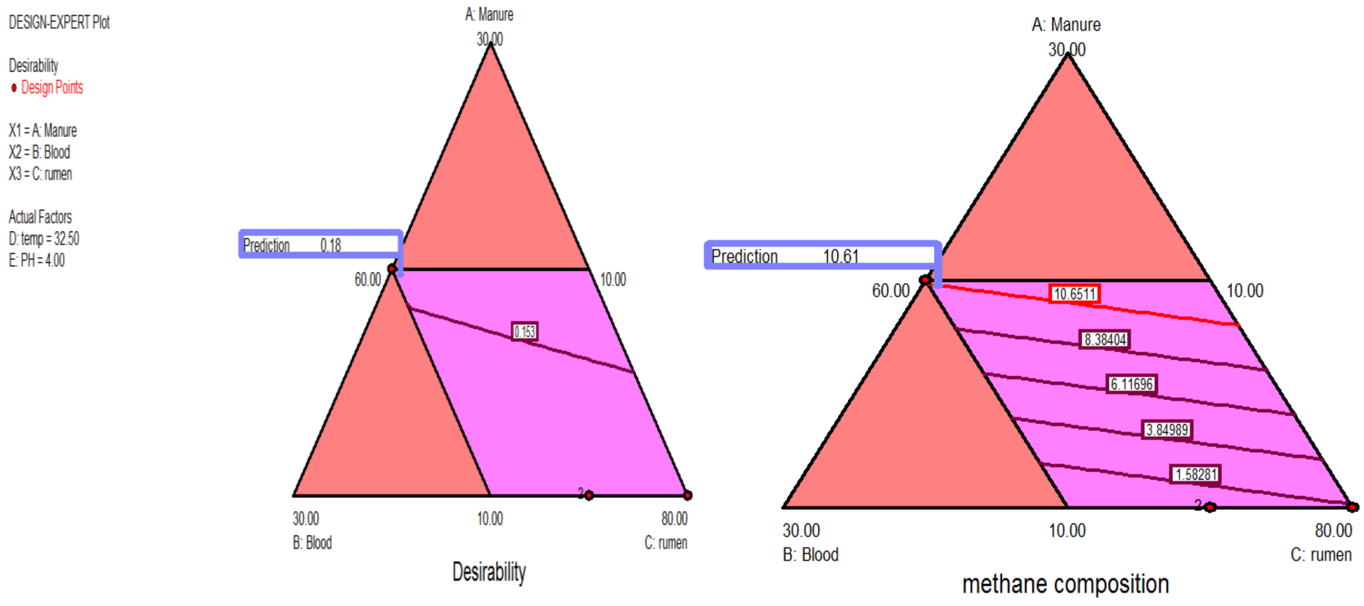
A. Desirability and Methane composition at selected temperature and pH=10



B. Desirability and Methane composition at selected temperature and pH=7

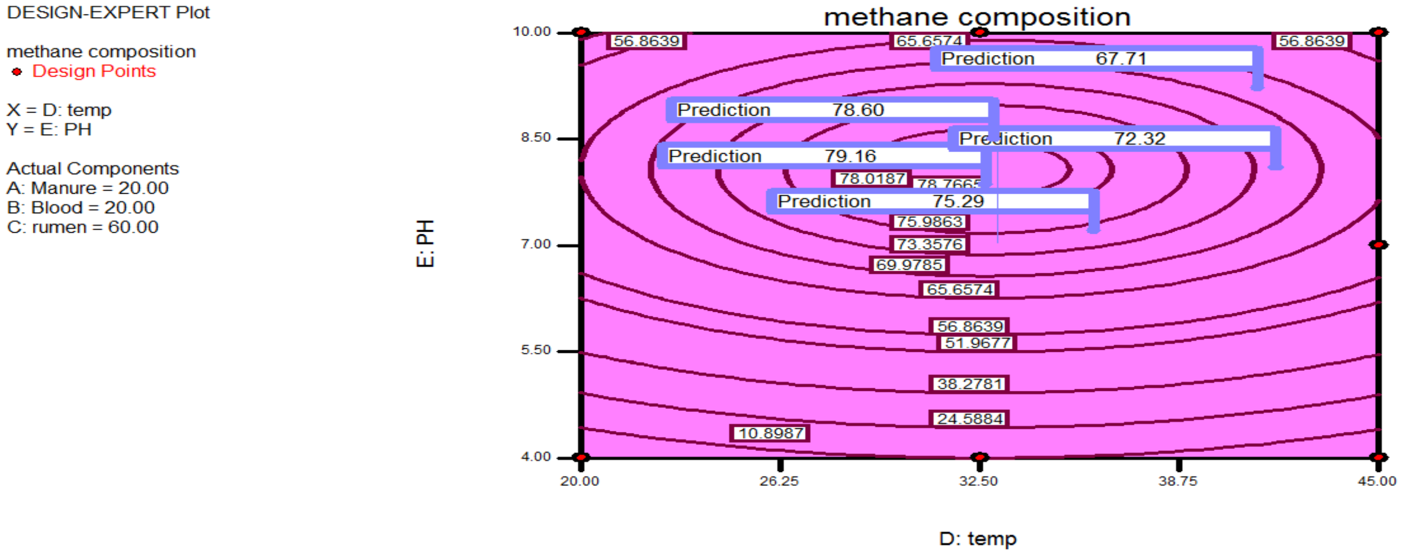


C. Desirability and Methane composition at selected temperature and pH=5.54

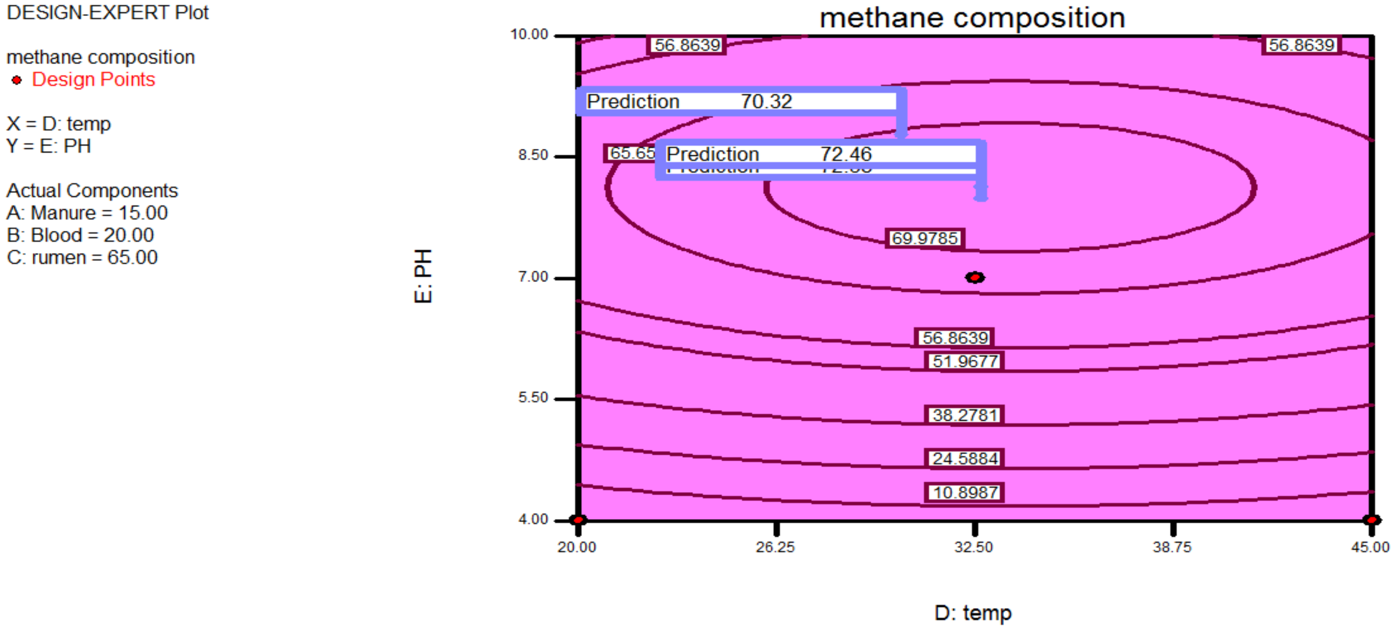


D. Desirability and Methane composition at selected temperature and pH=4

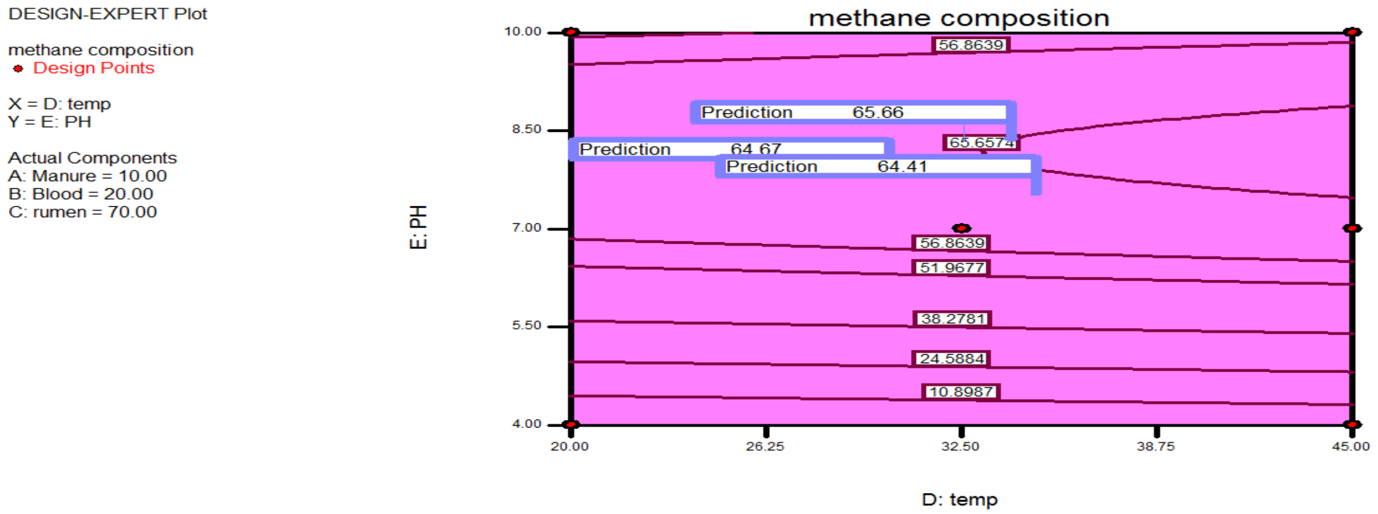
Annex 8: Methane Composition at difference temperature and pH and Substrate composition



(A) Methane composition at different ph and temp and at 20%manure,20%blood and 60 %undigested stomach content.

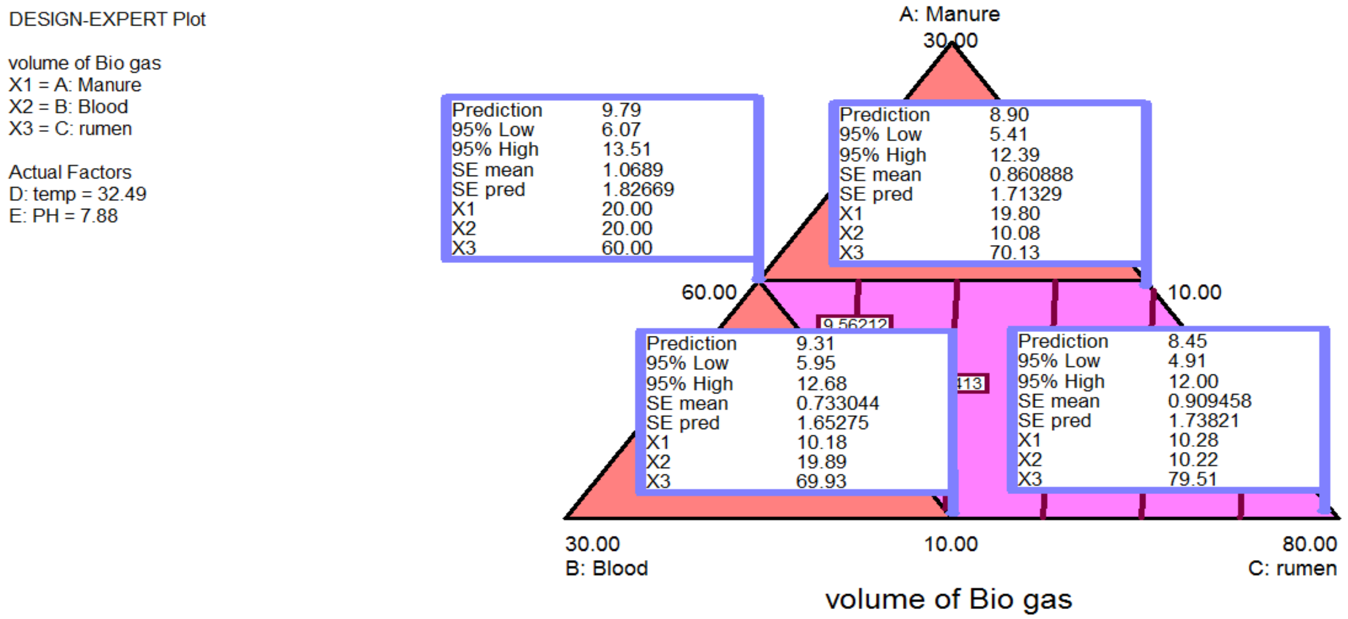


(B)Methane composition at different ph and temp and at 15%manure,20%blood and 65 %undigested stomach content



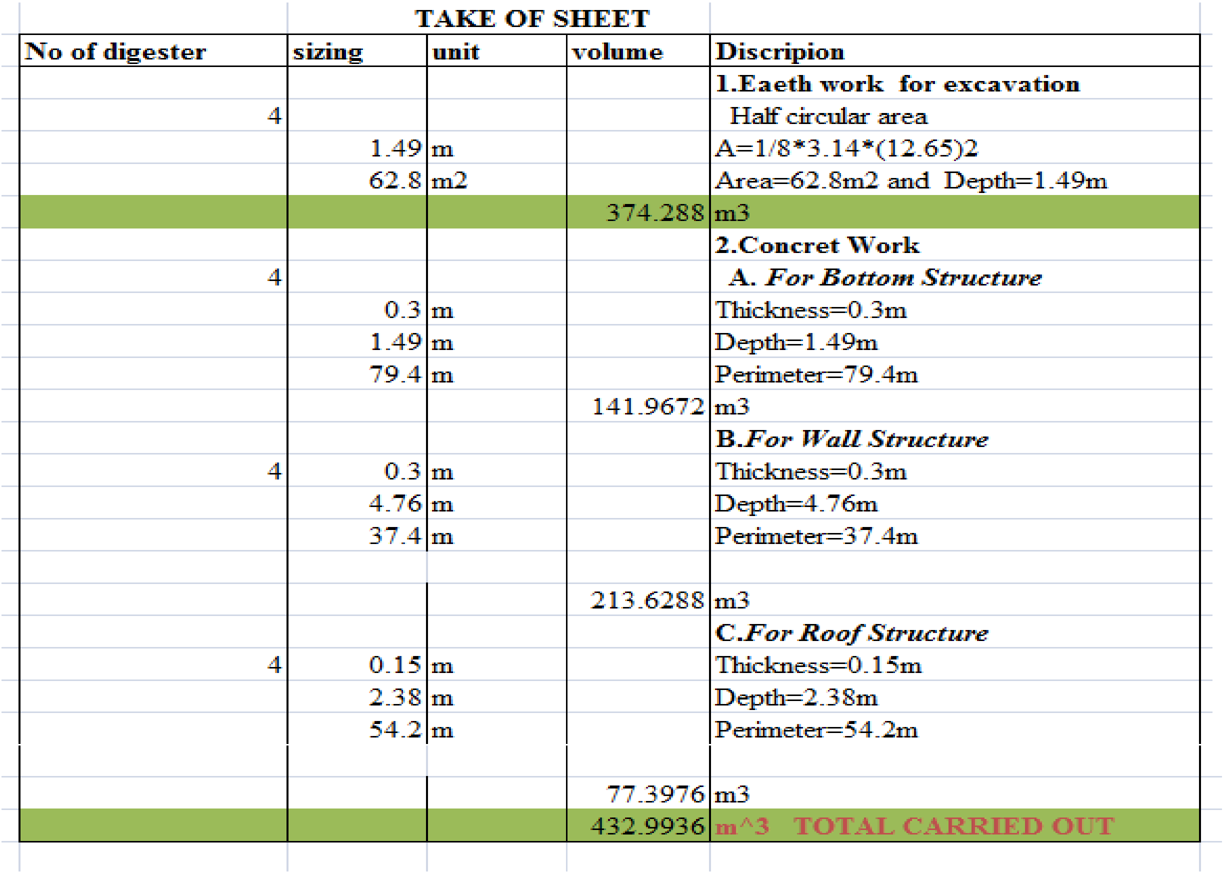
(C)Methane composition at different pH and temp and at 10%manure, 15%blood and 70 %undigested stomach content

Annex 9: Volume of Bio Gas at different Substrate



Annex-10 Take of Sheet for Digester construction

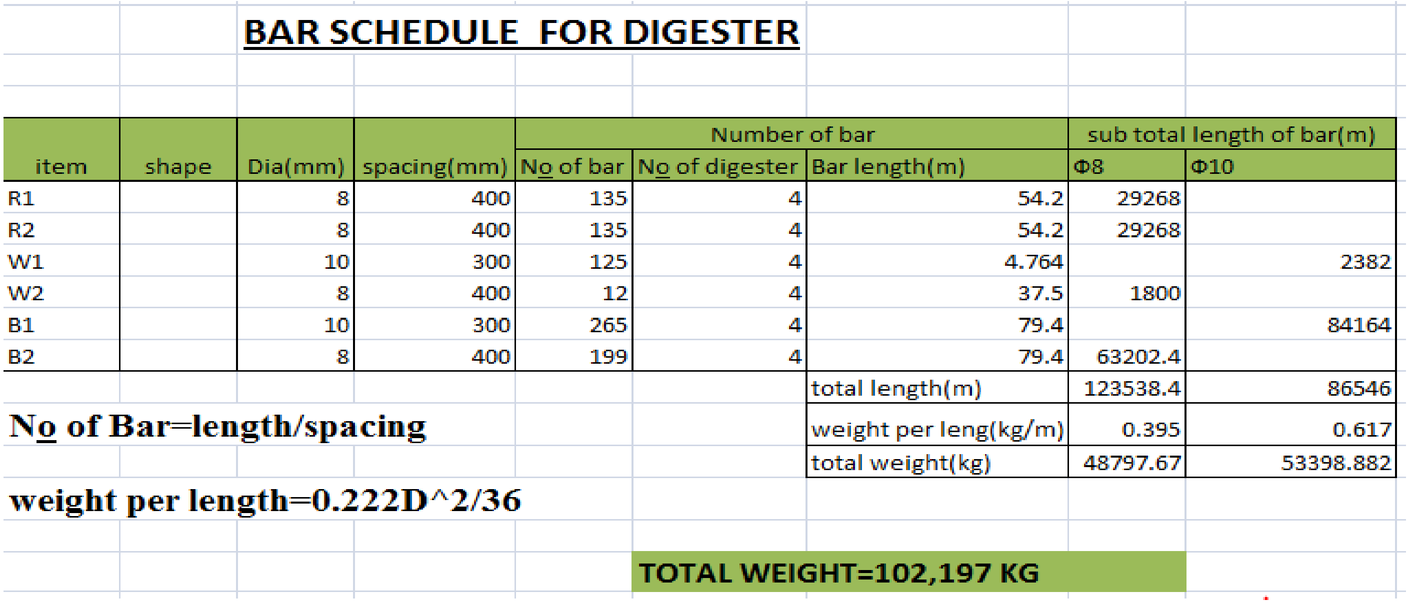
A. Table - take of sheet for digester construction material



TAKE OF SHEET

No of digester	sizing	unit	volume	Discripion
				1.Eaeth work for excavation
4				Half circular area
	1.49	m		A=1/8*3.14*(12.65)2
	62.8	m2		Area=62.8m2 and Depth=1.49m
			374.288	m3
				2.Concret Work
4				***A. For Bottom Structure***
	0.3	m		Thickness=0.3m
	1.49	m		Depth=1.49m
	79.4	m		Perimeter=79.4m
			141.9672	m3
				B.For Wall Structure
4	0.3	m		Thickness=0.3m
	4.76	m		Depth=4.76m
	37.4	m		Perimeter=37.4m
			213.6288	m3
				C.For Roof Structure
4	0.15	m		Thickness=0.15m
	2.38	m		Depth=2.38m
	54.2	m		Perimeter=54.2m
			77.3976	m3
			432.9936	m^3 **TOTAL CARRIED OUT**

B. Table- Total Length of Bar for Biogas construction



BAR SCHEDULE FOR DIGESTER

				Number of bar			sub total length of bar(m)	
item	shape	Dia(mm)	spacing(mm)	No of bar	No of digester	Bar length(m)	Φ8	Φ10
R1		8	400	135	4	54.2	29268	
R2		8	400	135	4	54.2	29268	
W1		10	300	125	4	4.764		2382
W2		8	400	12	4	37.5	1800	
B1		10	300	265	4	79.4		84164
B2		8	400	199	4	79.4	63202.4	
						total length(m)	123538.4	86546
						weight per leng(kg/m)	0.395	0.617
						total weight(kg)	48797.67	53398.882

No of Bar=length/spacing

weight per length=0.222D^2/36

TOTAL WEIGHT=102,197 KG

Annex 11 –Major Equipment picture of Slaughter and Rendering Section

A. Slaughter section


Compressor and Evaporator of Refrigerator


Breaking Ribs

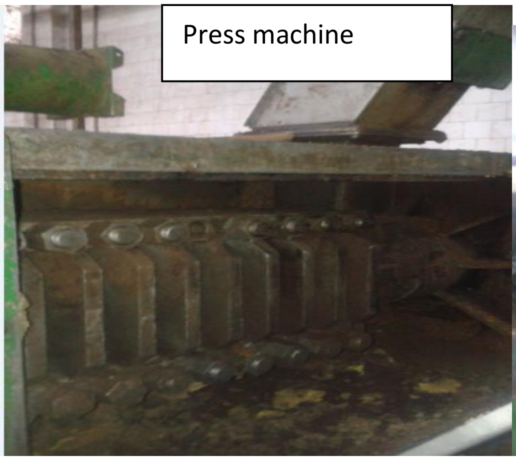

Circular Breaking Ribs


Circular Breaking Ribs


Weight Winch

B. Rendering section Major Equipment


Gridding Machine


Press machine


Cooker

C. Major equipment of Boiler section


Boiler


Furnace tanker


Fat Melting Machine