FEASIBILITY STUDY OF AN INSTITUTIONAL BIOGAS PLANT FOR CENTRAL SEWAGE SYSTEM AT KNUST

BY

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CERTIFICATION

I hereby declare that this submission is my own work towards the MSc. Mechanical Engineering degree and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgment has been made in the text.

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ABSTRACT

Biogas generation is one of the most promising renewable energy sources in Ghana. Apart from its energy source, anaerobic digestion is a reliable method for waste treatment and the digested sludge can be used to enhance the fertility of the soil. This thesis looks at the possibility of constructing a biogas plant at the KNUST sewage treatment plant tapping its feedstock from the Primary Sedimentation Tank.

A laboratory experiment was done to determine the faecal sludge quality at the Primary Sedimentation Tank. The flowrate of the sludge was estimated based on the number of times the penstocks (valves) are operated to desludge the sewage which depends on whether the university is on vacation (35.72m^3/day) or in session (71.44m^3/day). These parameters were used to determine the biogas potential of the sewage using 10, 20 and 30 days retention time for plant sizes of 800m^3, 1600m^3 and 2400m^3 respectively. The Puxin biogas digester was selected for this design. It was estimated that 152344, 304689 and 358009 m^3 of biogas can be produced in a year and the power production was estimated to be 40, 80 and 100 kW for 800m^3, 1600m^3 and 2400m^3 plant sizes respectively. The annual greenhouse gas emission reductions were estimated at 1373, 2751 and 3234 tCO_2-e for the 800m^3, 1600m^3 and 2400m^3 plant sizes respectively.

A financial analysis was then conducted using UNIDO's COMFAR software to ascertain which one of the three designs was financially viable having environmental impact in mind the possible sale of the digestate as fertilizer from the biogas plant. The estimated total investment cost for the three designs were GH¢430,397.40, GH¢799,288.90 and GH¢1,093,262.78 for the plant sizes of 800m^3, 1600m^3 and 2400m^3 respectively. The financial results showed that the NPV for all the plants were negative which implied that none of the project was financially viable.

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ABBREVIATIONS

AD	Anaerobic Digestion
BOD	Biochemical Oxygen Demand
C/N	Carbon/Nitrogen Ratio
CDM	Clean Development Mechanism
CERs/ERUs	Certified Emission Reductions
ERUs	Emission Reduction Units
COD	Chemical oxygen demand
COMFAR	Computer Model for Feasibility Analysis and Reporting
CWSA	Community Water and Sanitation Agency
DC	Dosing Chamber
FAO	Food and Agricultural Organization
GHG	Greenhouse Gas
GTZ	German Agency for Technical Cooperation
GWh	Gigawatt hours
GWP	Global Warming Potential
HRT	Hydraulic Retention Time
IRR	Internal Rate of Return
JI	Joint Implementation
KNUST	Kwame Nkrumah University of Science and Technology
tCO_2-e	tonne of Carbon dioxide equivalent
$ktCO_2$-e	kilotonne of Carbon dioxide equivalent
kVA	Kilovolt Ampere
kW	kilowatt
kWh	kilowatt hour
LPG	Liquefied Petroleum Gas

lm	linear-meter
MW	Megawatt
NCWSP	National Community Water and Sanitation Programme
NPV	Net Present Value
OLR	Organic Loading Rate
PF	Percolating Filters
PH	Power of Hydrogen ion concentration
PPP	Potential Power Production
PST	Primary Sedimentation Tank
PURC	Public Utilities and Regulatory Commission
PVC	Polyvinyl Chloride
SD	Sustainable Development
SF	Sand Filters
SLT	Special Load Tariff
SNEP	Strategic National Energy Plan
SPS	Sludge Pumping Station
SSC	Small Scale CDM project
TS	Total Solids
TVS	Total Volatile Solids
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
V_d	Digester Volume
V_f	Daily Feed Rate
WC	Water Column

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DEDICATION

This work is gratefully dedicated to

Mr. and Mrs. Arthur

1 INTRODUCTION

1.1 PROJECT OVERVIEW

The world's energy situation, whether in developing or industrialized countries, is an issue frequently discussed under economic, technical and political aspects (IEA, 2005). While it has meanwhile become common knowledge that today's main resources of energy such as coal, crude oil, natural gas and even nuclear energy will become scarce within the next generation the renewable sources such as mini-hydro, wind, solar and bioenergy are gaining more and more importance in terms of research and development as well as implemented systems (WEA, 2000). The industrialised countries have paid more attention to this research using modern technologies and diverse human resources they find useful (GTZ, 2007).

The alternative sources which are of interest are the ones that are less expensive, environmentally friendly, renewable, clean and readily available. Each year some 590-880 million tons of methane are released worldwide into the atmosphere through microbial activities (GTZ and ISAT, 2007). About 90% of the emitted methane is derived from biogenic sources, i.e. from the decomposition of biomass. The remainder is of fossil origin (GTZ and ISAT, 2007).

Theoretically every organic material can be digested. The feedstock for anaerobic digestion include cattle dung and manure, goat dung, chicken droppings, abattoir by-products, kitchen waste, food processing factory wastes and human excreta. The choice of a feedstock for anaerobic digestion depends on a number of factors such as substrate temperature and feedstock availability, but the most vital reason for a choice is the feedstock availability. Sasse (1991) affirms that cattle dung is the most suitable material for biogas plants because of the methane-producing bacteria already contained in the stomach of a cow (GTZ, 2007).

It is important that renewable energy is given serious attention. This is because traditionally, woodfuels claim the largest proportion of biomass fuels (in some regions up to 90%) used in developing countries, where about 40% of the total wood cut annually is used for domestic purposes especially cooking and heating (GTZ, 2007). The total primary woodfuel (firewood and charcoal) consumed in Ghana was between 12.1-14.6 and 14.5-17.2 million tonnes in 2000 and 2004 respectively (Energy Commission, 2005).

The residential or household sector of the economy takes up on the average almost 50 % of the country's energy consumption. The significant residential sector share of the nation's energy demand is due to the high usage of woodfuels comprising mainly firewood (almost 76 %) and charcoal (Energy Commission, 2007). Estimating an average per capita consumption of 3kg of wood per day for energy (cooking, heating and boiling water) in rural areas in Asia and Africa, the daily per capita demand of energy equals about 13 kWh which could be covered by about $2m^3$ of biogas (GTZ, 2007.)

Domestic and community base biogas plants are usually constructed for a number of reasons including provision of fuel to rural households for cooking, heating and boiling water, source of organic manure for application on agricultural fields, mitigating the drudgery of community folks (usually women and children) in waste disposal and reducing the pressure on forest resources (GTZ, 2007). Most of the biogas plants constructed globally to date are based on cattle dung as the feedstock. Biogas plants based on nightsoil have not yet been established in large numbers. This is due to the unavailability of nightsoil at a single location in sufficient quantities and the fact that the focus for development of biogas technologies has largely been on technologies using cattle dung as the feedstock.

Usage and reuse of human excreta for biogas generation is an important way to get rid of health hazards from human excreta, besides use for cooking, lighting and electricity generation. Biogas plants in educational institutions are put up basically as a waste treatment facilicity, fuel for cooking and heating and to serve as a learning facility for students. It can also augment their power capacity so as to meet the growing electricity requirements.

In Ghana there are institutional biogas plants in some secondary schools, health facilities and communities, but some of them have not been sustainable (SNEP, 2006). A public convenience facility visited by about 2,000 persons per day would produce approximately 60 m^3 of biogas a day, which can run a 10 KVA internal combustion engine-based power generator for about eight hours a day (APEIS and RISPO, 2003).

1.2 GHANA'S BIOGAS POLICY

The biomass resources available in Ghana include sawmill residue, agricultural waste, animal waste, municipal waste and energy crops. In Ghana, well tested applications for biomass-based technologies are cogeneration, biogas production from anaerobic digestion, and very recently bio-diesel production. According to SNEP (2006), Ghana government will promote biogas-for-heating in institutional kitchens, laboratories, hospitals, boarding schools, barracks, etc.

The SNEP strategic target is to achieve 1% penetration of biogas for cooking in hotels, restaurants and institutional kitchens by 2015 and 2% by 2020 (SNEP, 2006). This document did not mention programs for domestic biogas systems. Even though there is no clear policy on biogas in Ghana, there are national programs that can promote its infusion into homes and institutions. The government through the National Community Water and Sanitation Programme (NCWSP) has a medium to long term national strategy to extend safe water and improved sanitation facilities to rural communities and small towns in Ghana (EPRAP, 2006). The NCWSP indirectly provides a platform for biogas production through the Community Water and Sanitation Agency (CWSA).

The CWSA is committed to delivering close to 1,100,000 latrines in households, communities and institutions as part of "its strategy for breaking the cycle of transmission of excreta-related diseases". However, the Energy for Poverty Reduction Action Plan for Ghana (EPRAP) proposed that up to 50% of institutional latrines (approximately 800) and 20% of the communal latrines (1670) should be constructed as bio-latrines[1] and the associated benefits include the use of the digested waste as a fertilizer. The Ministry of Energy has a demonstration project at Appolonia, which used to produce gas for direct cooking in 27 homes. The biogas was also used to generate 12.5kW of electricity for the community, through a mini-grid (SNEP, 2005), but the plant is not functioning at full capacity due to lack feedstock materials (Bensah, forthcoming).

1.3 WASTE HANDLING AT KNUST

Kwame Nkrumah University of science and technology (KNUST) with a staff and student population of 24,188 (KNUST Basic Statistics, 2008) generates a colossal amount of waste (solid and liquid). The solid waste is dumped at a site far away from the inhabited part of campus and the liquid waste is sent to a sewage treatment plant which is owned and operated by the university. The biogas potential of the solid

[1] The bio-latrine is in principle the central part of a sanitary biogas unit for safe human faeces disposal, degrading the excreta anaerobically, thus producing the biogas and digested substrate that may be used as fertilizer. The main focus is however for sanitary aspects (German Appropriate Technology Exchange, 2000)

waste is very difficult to determine because of the method of collection, the glasses, plastics, cans, papers, etc are collected together. However, the liquid is of one kind hence its biogas potential is relatively easily determined. Antwi *et al* (2007) conducted a preliminary study on the biogas potential of the sewage treatment plant. Their study was also based on the population of people using facilities that are connected to the sewage treatment plant. The estimated methane from their study was 32769.88 kg/yr which could generate 25kW of electricity using a diesel genset. A group of teaching assistants and students at the college of Engineering, KNUST conducted a similar study. In their report they stated that based on the population in the halls of residence on campus of 7000, the biogas generated could produce about 98 kW of electricity (iTi Group, 2007).

1.4 POWER CONSUMPTION AT KNUST

KNUST is one of the sixteen (16) Special load Tariff (SLT) customers managed by the Ashante-East Division of the Electricity Company of Ghana (ECG). It is in the Medium Voltage (MV) category of the SLT customers. The power consumed by KNUST varies each month of the year due to the population fluctuation in each academic year. Figure 1-1 shows that maximum demand for power and energy utilisation is low in January, June and July.

This is because it is the period when KNUST is on vacation whiles the others shows significantly high values when school is in session. Table 1-1 shows the average monthly power consumption estimated for KNUST for 2008. The details are in appendix A-5.

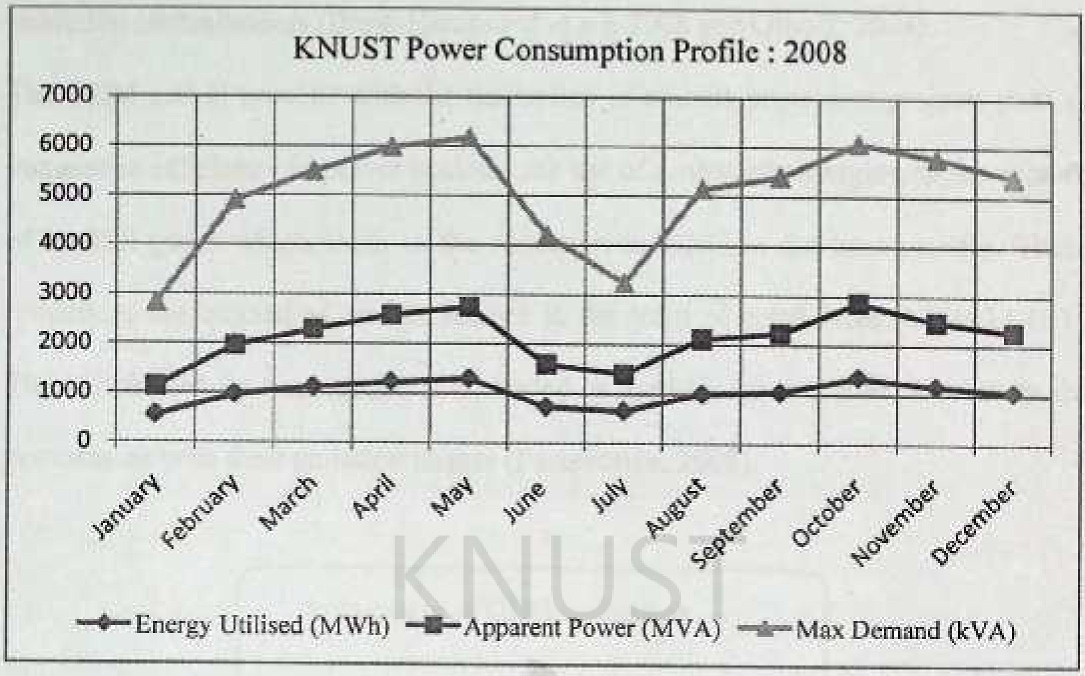

Figure 1-1: Monthly Power Profile of KNUST for 2008 (Source; ECG, 2009)

Table 1-1 Average monthly Power consumption at KNUST for 2008[2]

Parameters	Values
Energy Utilisation (MWh)	1012
Apparent power (MVA)	1131
Maximum Demand (kVA)	2912

1.5 CLEAN DEVELOPMENT MECHANISM

The Clean Development Mechanism (CDM) and Joint Implementation (JI) are project-based flexible mechanisms under the Kyoto Protocol within the framework of the UNFCCC in 1997 (Perspectives, 2008), designed with the dual aim of assisting developing countries in achieving sustainable development (SD) and

[2] The details is provided in Appendix A

assisting industrialized countries in achieving compliance with their GHG emission reduction commitments (Brew-Hammond *et a.l*, 2008 and Olhoff, 2004).

The CDM and JI proceed with the realisation of climate protection projects such as increase in efficiency in power stations, the use of renewable energies, or the capture of landfill gases which leads to the reduction in GHG in the host country. These reductions are quantified and accredited in the form of certificates (CERs/ERUs)[3]. The certificates, in turn can be sold, traded or used by other countries or states for compliance with their emission targets (Perspective, 2008).

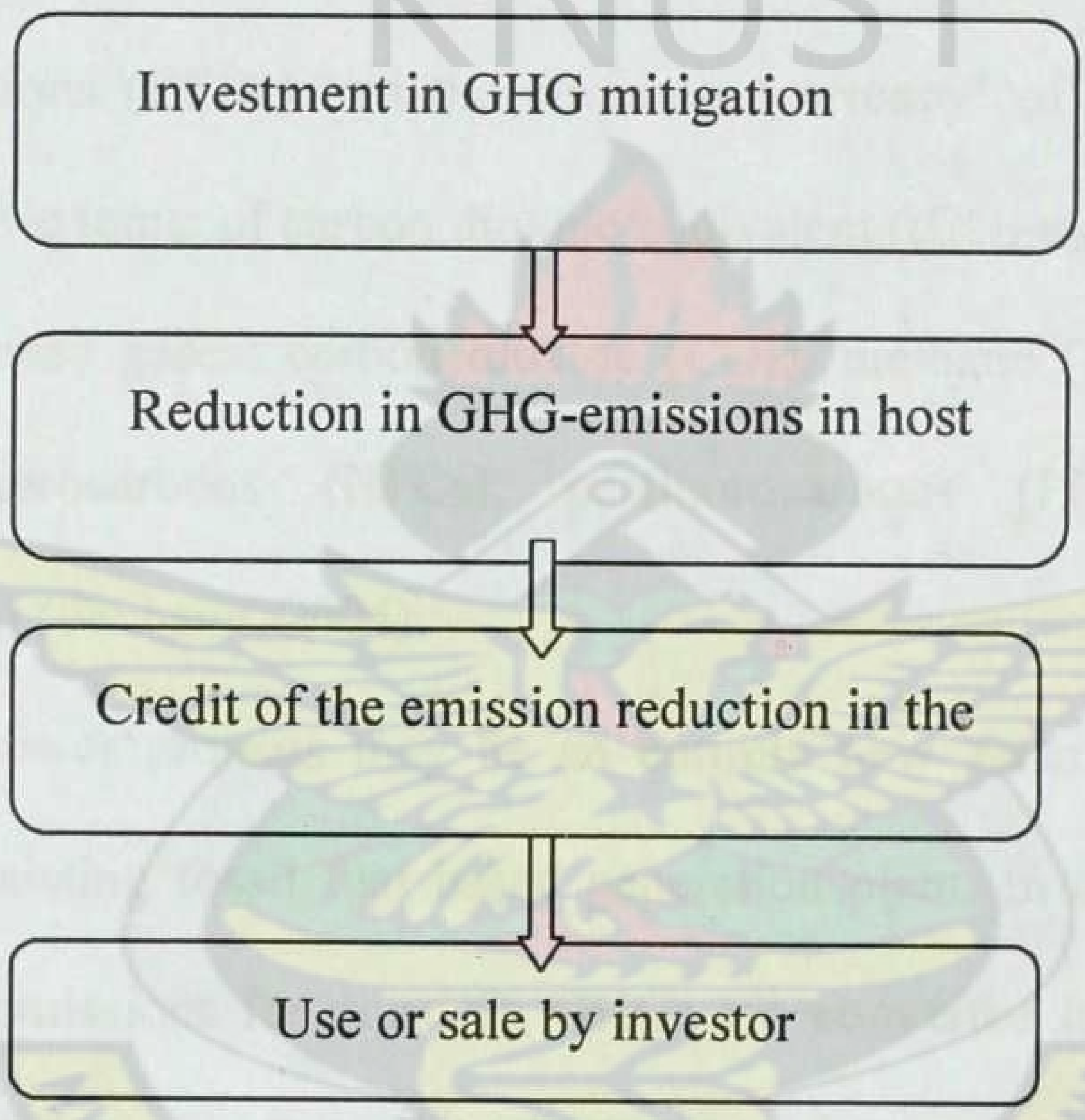

Figure 1-2: Flow chart project-based Kyoto-Mechanism (Source: Perspectives, 2008)

Under the Kyoto Protocol, the world's wealthier countries assumed binding commitments to reduce greenhouse gas emissions. Figure 1-2 is a flow chart design showing the project-based Kyoto-Mechanism. The funding channelled through the CDM should assist developing countries in reaching some of their economic, social, environmental, and sustainable development objectives. These objectives include

[3] CERs: Certified Emission Reduction are for CDM projects whiles ERUs: Emission Reduction Units are for JI projects.

clean air and water, improved land use, accompanied by social benefits such as rural development, employment, poverty alleviation and in many cases, reduced dependence on imported fossil fuels (Perspectives, 2008).

All of Africa (including South Africa and the countries of North Africa) remain at 3% of the market (Brew-Hammond *et al.*, 2008), and all the other countries of Sub-Saharan Africa account for just about one third of that number. These numbers clearly demonstrate the difficulty of expanding carbon business in much of Africa (Capoor *et al*, 2007).

The carbon credits that are generated by a CDM project are termed Certified Emission Reductions (CERs) and the common 'currency' of the Kyoto Protocol targets is one metric tonne of carbon dioxide equivalent (tCO_2-e) (Kamel, 2007). The six main greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs); perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) (Fenhann, 2004).

The renewable power projects may be an entirely new generation capacity or a replacement of existing fossil fuel based generation plant. In accordance with the Kyoto Protocol, emissions for non-CO_2 GHGs are converted into CO_2 equivalent, based on a Global Warming Potential (GWP) of methane of 21 (Sijm, 2000) which is then traded on the global carbon market.

The CDM project participants must choose whether the crediting period shall be 10 years or 7 years with a possibility to be renewed two times (a maximum of 21 years) (UNEP, 2002). Developing countries supplied nearly 450 $MtCO_2$-e of primary CDM credits in 2006 for a total market value of US$5 billion (€3.8 billion). Average price for CERs from developing countries in 2006 was at US$10/ tCO_2-e (with the vast majority of transactions in the range of US$8-14 / tCO_2-e) (Capoor *et al*, 2007).

1.6 RELEVANCE OF PROJECT TO NATIONAL DEVELOPMENT

The anaerobic digestion process has proved to be effective in reducing the number of pathogens present in faecal matter to a considerable extent. Bacteria such as Salmonella and E-coli found in raw faecal matter can cause typhoid fever and Gastroenteritis, respectively (EPA, 1995) as most farmers do not use good Agricultural Practices (GAPs). Studies carried out in China on the survival of pathogens showed that about 90 to 95 % of parasitic eggs are destroyed at the mesophilic temperature (20°C – 40°C) (FAO, 1996).

Ghana has its share of problems associated with solid and liquid waste disposal. As the number of pathogens and odour present would be reduced in the sludge after digestion, the disposal of digested sludge into the environment is one important solution to the waste disposal problems in Ghana. The digested sludge can also be used by farmers as fertilizer on their farms as the percentages of nitrogen and phosphorus after anaerobic digestion are maintained and the value of nutrients is also preserved (Adhikari, 2005 and Aklaku and Rockson, 2006).

This fertilizer will improve crop yield and also farmers do not need to spend money on chemical fertilizer which may eventually has adverse effect on the soil. Biogas is one of the well-tested applications for biomass-based technologies forming part of the largely untapped renewable energy resources in Ghana (EPRAP, 2006). The technology has been piloted in institutions such as schools, hospitals, prisons, etc where it has generally gained acceptability. This project seeks to affirm the energy and fertilizer potential of sewage generated in Ghana and it can serve as a platform for the development of similar projects in other institutions in Ghana.

1.7 PROJECT OBJECTIVES

The main objective of this project is to conduct a feasibility study of an institutional biogas plant at KNUST using as feedstock the sewage from KNUST sewage treatment plant.

The specific objectives of this project are:

- to determine the biogas potential of the sewage at the KNUST sewage treatment plant and its potential power production;
- to design a system for converting the biogas into electricity and to establish possible utilization of the by-products, especially the use of digestered sludge as fertilizer;
- to ascertain the financial viability of the biogas plant by performing cost benefit analysis on the project, including possible CDM financing, using the Computer Model for Feasibility Analysis and Reporting (COMFAR) software designed by UNIDO.

1.8 SCOPE OF WORK

Two main aspects of constructing a biogas plant at the KNUST sewage treatment plant are covered in this work. The first aspect relates to the feedstock analysis and biogas plant design and the second is the financial analysis on the project using COMFAR. The organization of this thesis provides information about the methodology used to meet these objectives.

Chapter 2 review literature about anaerobic digestion in general, which comprise of the various stages of feedstock digestion, general overview of biogas and parameters that affect anaerobic digestion. Chapter 3 looks at biogas plant technology in general which comprises hydraulic flow systems that typically occur in biogas production, types of biogas digesters and biogas plant auxiliary components. This informed the design parameters for the biogas plant proposed to be sited at the KNUST sewage treatment plant.

The actual design is presented in Chapter 4. As part of the design, a suitable location at the sewage treatment plant for the biogas digesters was identified. Samples of the sewage collected at the treatment plant were also analysed in the laboratory to establish the feedstock quality.

Some of the parameters measured included the Total solids (TS), Total Volatile Solids (TVS), Biochemical Oxygen Demand (BOD), etc, and were used to estimate the biogas potential of the sewage. The pathogens population in the sludge was also determined to justify the danger posed by the pathogens present in the dried sludge that is always disposed off into the environment when farmers use them as fertilizers. The flowrate of the sludge from the Primary Sedimentation Tank (PST) at the sewage treatment plant was determined to estimate the size of the biogas digesters and subsequently the type of design and plant layout. Different types of engines for electricity production were considered and a suitable one was selected for the design. The COMFAR software was then used to analyse the financial viability of a biogas plant to be sited on the KNUST sewage treatment plant using three different biogas plant size scenarios and it is presented in Chapter 5. Conclusions and recommendations of the thesis are presented in Chapter 6.

2 ANAEROBIC DIGESTION

2.1 BIOGAS

Biogas is primarily composed of methane (CH_4) and carbon dioxide (CO_2). In addition to CO_2, biogas also contains moisture and smaller amounts of H_2S, ammonia (NH_4), hydrogen (H_2), nitrogen gas (N_2) and carbon monoxide (CO) (USNRCS, 2007).

2.1.1 COMPOSITION

The composition of biogas largely depends on the type of substrate. Human excreta based biogas contains 65-66% CH_4, 32-34% CO_2 by volume and the rest is H_2S and other gases in traces (Elango *et al.*, 2006). The biogas composition for a municipal solid waste is composed of 68-72% CH_4, 18-20% CO_2, and 8% H_2S (Elango *et al.*, 2006). Biogas produced from agricultural facilities typically contains between 60-70% CH_4, CO_2 volume vary between 30-40 %.

2.1.2 PROPERTIES

Biogas is about 20% lighter than air and has an ignition temperature in the range of 650 to 750 °C[4] . Biogas has a density of 0.8kg/m^3 and methane has a density of 0.662 kg/m^3. Biogas is odourless and colourless and burns with clear blue flame similar to that of Liquefied Petroleum Gas (LPG) (FAO, 1996).

If the CH_4 content is considerably below 50 %, biogas is no longer combustible. The first gas from a newly filled biogas plant contains too little methane hence the gas formed in the first three to five days must therefore be discharged unused (Sasse, 1988).

[4] Diesel oil has ignition temperature of 350 °C; whiles petrol and propane have ignition temperature of 500 °C.

The CH_4content also depends on the digestion temperature. Low digestion temperatures give high methane content, but less gas is then produced (Sasse, 1988). The calorific value of biogas is typically between 20-25 MJ/m^3 which is about 55% lower than that of CH_4, which has a typical calorific value of 37.78 MJ/m^3. The flame temperature of biogas is 870 °C. The methane (CH_4) content and the calorific value are higher when biogas is generated through a longer digestion process.

CO_2 and N_2 contained are inert gases reducing the heating value of the biogas. Conversely H_2S is well far from inert, but highly corrosive (Poliafico, 2007). For all practical purposes, the volume of the source material remains unchanged, since only some 30-50 % of the organic substances (corresponding to 5-10% of the total volume) are converted into gas,(Barelli *et al.*, 2007)

2.2 FEEDSTOCK DIGESTION PRCOCESSES

Biological gasification (Biogas) originates from bacteria in the process of bio-degradation of organic material under anaerobic (without air) conditions. Theoretically every organic matter is degradable. The natural generation of biogas is an important part of the biogeochemical carbon cycle. Methanogens (methane producing bacteria) are the last link in a chain of micro-organisms which degrade organic material and return the decomposition products to the environment. In this process biogas is generated, a source of renewable energy.

In the Anaerobic digestion process, series of complex biochemical processes involving different types of bacteria take place in four consecutive steps as shown in figure 2-1. It is important that the environment for digestion be kept in a state of equilibrium to merit optimum digestion. Even though minor changes in the environment affect the process, equilibrium is always re-established.

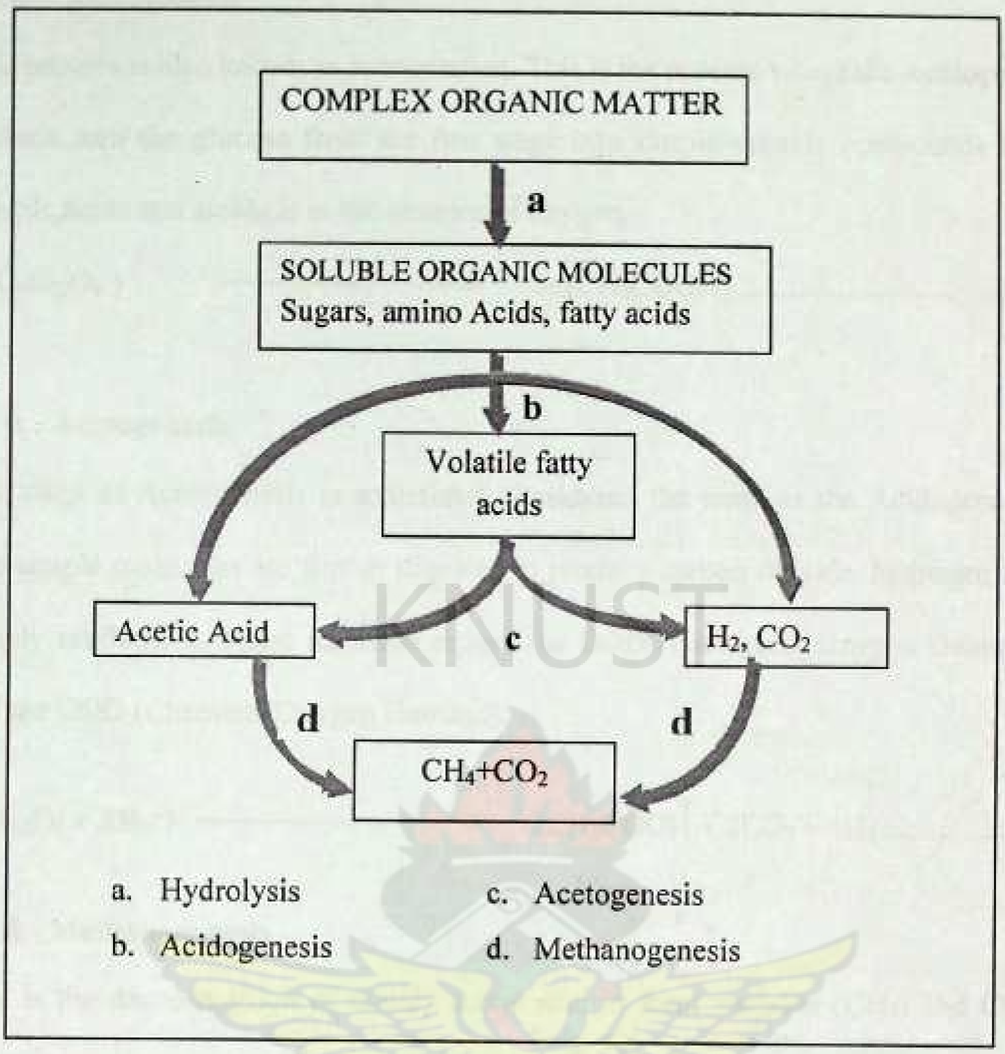

Figure 2-1: Anaerobic Digestion Process Scheme (Poliafico, 2007)

a. Hydrolysis

This is the first step in the biogas generation process where the organic matter is acted on externally by extracellular enzymes (protease, cellulose, amylase, and lipase) of micro-organisms in the presence of water. In this process bacteria decompose the long chains of the complex carbohydrates, proteins and lipids into shorter chains.

$$(C_6H_{10}O_5)_n + n(H_2O) \longrightarrow n(C_6H_{12}O_6) \quad \text{..................2.1}$$

b. Acidogenesis

This process is also known as fermentation. This is the process where the Acidogenic bacteria turn the glucose from the first stage into simple organic compounds like volatile acids and alcohols in the absence of oxygen.

$$n\,(C_6H_{12}O_6) \longrightarrow 3n(CH_3COOH) \quad \text{.................................2.2}$$

c. Acetogenesis

The stage of Acetogenesis is sometimes considered the same as the Acidogenesis. The simple molecules are further digested to produce carbon dioxide, hydrogen and mainly acetic acid. These reactions reduce the BOD (Biological Oxygen Demand) and the COD (Chemical Oxygen Demand).

$$C_6H_{12}O_6 + 2H_2O \longrightarrow 2CH_3COOH + 2CO_2 + 4H_2 \quad \text{..............2.3}$$

d. Methanogenesis

This is the decomposition of mainly acetic acid to form methane (CH_4) and CO_2. This process is successful only at a constant temperature. This is because unlike the acetogens and acidogens, the methanogens are very sensitive to environmental changes. The methanogenic bacteria belong to the archaebacter genus, i.e. to a group of bacteria with a very heterogeneous morphology and a number of common biochemical and molecular-biological properties that distinguish them from all other bacterial general (GTZ, 2007). Approximately 70% of the methane is formed from volatile fatty acids (VFA), 30% from hydrogen and CO_2 by methanogenic bacteria (Wellinger, 1999).

$$3nCH_3OOH \longrightarrow 3n\,CO_2 + 3n\,CH_4 \quad \text{....................2.4}$$

The overall reaction for the anaerobic process given by;

$$(C_6H_{10}O_5)n + nH_2O \longrightarrow 3\,nCO_2 + 3\,nCH_4 + 19\,nJ/mol \quad \text{....................2.5}$$

According to the above equation, the amount of carbon dioxide and methane produced is the same. However, because of the comparatively high solubility of carbon dioxide (i.e 1.8g/l at 20°C) as compared to methane (i.e 37mg/l at 20°C) most of the carbon dioxide is dissolved in the water leaving a fraction to escape with the methane (Peters and Timmerhaus, 1991).

2.3 ANAEROBIC DIGESTION PARAMETERS

2.3.1 SUBSTRATE TEMPERATURE

In principle anaerobic digestion can occur between 3°C to 70°C. Anaerobic digestion can occur in three temperature ranges; psychrophilic temperature range which lies between 3°C and 20°C, the mesophilic temperature range which is between 20°C and 40°C and thermophilic temperature range which is above 40 °C and 70°C(GTZ, 2007). The bio-methanation process is very sensitive to temperature. However, the degree of sensitivity depends on the temperature range (Poliafico, 2007). The optimum biogas production for the mesophilic digestion is 35°C (Ostrem, 2004) whereas the thermophilic process temperature is 55°C (Barelli *et al.*, 2007). However, the choice of a process temperature has its own advantages and disadvantages. For example the rate of bacterial growth and waste degradation is relativelyfaster under thermophilic conditions than mesophilic and psychrophilic. On the other hand, thermophilic digestion produces an odorous effluent. The mesophilic digestion is more robust and tolerates greater environmental parameter changes but also requires longer retention time (Dennis, 2001). The temperature of the substrate also contributes to the rate of biogas production as shown table 2-1.

Table 2-1: Biogas-producing rates of some materials at different temperatures (m^3/Kg TS)

Materials	(35°C), (m^3/Kg TS)	(8°C-25°C) (m^3/Kg TS)
Pig Manure	0.45	0.25-0.30
Wheat Straw	0.45	0.20-0.25
Green grass	0.44	0.20-0.25
Human waste	0.43	0.25-0.30
Rice Straw	0.40	0.20-0.25
Cattle Dung	0.30	0.20-0.25

(Source: BTC, 2007)

Most of the methane producing bacteria prefer mesophilic temperatures. Anaerobic digestion at mesophilic temperature enables and guarantees a stable digestion process and high biogas yields as shown in table 2-1.

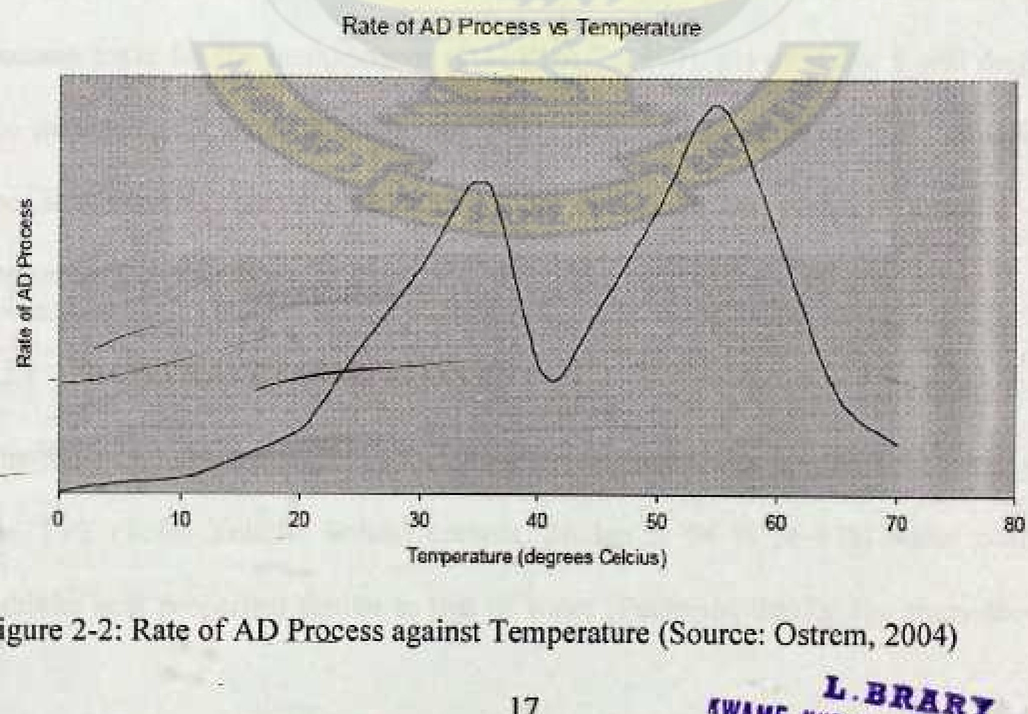

Figure 2-2: Rate of AD Process against Temperature (Source: Ostrem, 2004)

Thermophilic temperatures enable greater loading rates due to the faster degradation of the organic substrates, but at the same time require a higher energy input for the digester heating and may cause an increase in process instability (Hopfner-Sixt *et al.*, 2006). The rate of biogas production depends on the substrate temperature as shown figure 2-2. The higher the temperature the higher the rates of production even within the mesophilic range of temperature except around 40°C where the rate is unusually low.

2.3.2 pH

PH of a digester is the measure of the amount of free hydrogen ions present in the digester. The bacteria population in a biogas digester flourishes over a pH range of 6.5 to 8.0 with optimum range of 6.8 to 7.2 (Barelli *et al.*, 2007). The acidogens bacteria produce organic acids into the digester but this is buffered by the bicarbonate produced by the methanogens.

Once the fermentation has stabilised, the pH normally takes a value of between 7 and 8.5 which is as result of the buffering effect of the (CO_2 and HCO^-_3) and (NH_3 and NH^+_4) (GTZ, 2007). If however, the PH level drops below 6.2, the medium will become toxic for the methanogens (CAEEDAC, 1999). pH of above 8 will destroy the methanogenic bacteria (Puchajda, 2007). This will result in the rapid growth of the acid forming bacteria producing more acid than the methane forming can consume (Dennis, 2001).

2.3.3 SUBSTRATE SOLID CONTENT

The most important parameters for characterizing substrates are the TS content and the TVS (Total Volatile Solids) content. Sludge at 94 % or 97% water content exhibits heat properties similar to that of water (Puchajda, 2007). The slurry should neither be too thick (more than 14%) nor too thin (less than 6%) but should be 8-10 % of Total Solids (TS) content (Devkota, 2003). Sludge thickening before digestion results in sludge volume reduction which reduces digesters' volumes and heat requirements for the process. For instance, increasing the TS content of sludge from 3% to 6%, brings approximately 50% reduction in sludge volume.

Alternatively, using the same volume of digester, sludge thickening and corresponding sludge flow reduction may allow for longer retention time of the digestion. This therefore provides additional TVS destruction and additional biogas production (Puchajda, 2007). Good dilution values of 6-7 % of TS are generally suitable for most biogas plants (Poliafico, 2007). According to FAO (1996), the dilution should be made so as obtain TS range of 7 to 10 %.

If the feedstock has TS less than 3%, the solid particles will settle down into the digester also if it is too thick (more than 15%), the particles impede the flow of gas formed at the lower part of digester. In both cases, gas production will be less than the optimum. Table 2-2 shows the faecal quality of some selected cities.

Table 2-2 Faecal sludge quality in different cities

	Accra Septage	Accra Public Toilet	Bankok Septage	Manila Septage	US EPA Septage
COD(mg/l)	7,800	49,000	14,000	37,000	43,000
BOD (mg/l)	600 - 1500	7600	-	3800	5000
TS (mg/l)	11900	52500	16000	72000	38800
TVS (%)	60	69	69	76	65
pH	7.6	7.9	7.7	7.3	6.9
COD/BOD	6 -12	6.4	-	9.7	9
COD/TS	0.7	0.9	0.9	0.5	1.1

(Source: Heinss *et al*, 1999)

The gas yield of an organic material depends on the type of substrate and the volatile solids present as shown in table 2-3.

Table 2-3: Gas yields and methane content for some kinds of substrates.

Substrate	Gas yield (l/kg VS)	Methane content (%)
Pig	340 - 550	65-70
Vegetable residue	330 - 360	-
Sewage sludge[5]	**310 - 740**	-
Poultry droppings	310 - 620	60
Grass	280 - 550	70
Fallen leaves	210 - 290	58
Barnyard dung	175 - 280	-
Cane trash (bagasse)	165	-
Cow	90 - 310	65
Sheep	90 - 310	-

Source: Information and advisory service on appropriate technology (ISAT) and GATE (GTZ), 1996.

2.3.4 CARBON /NITROGEN RATIO

Carbon –Nitrogen ratio (C/N) is the measure of the amount of Carbon and Nitrogen present in a feedstock (Poliafico, 2007). The concentrations of carbon and nitrogen determine the performance of the anaerobic digestion process, as one or the other usually constitutes the limiting factor. Whereas carbon constitutes the energy source for the microorganisms, nitrogen serves to enhance microbial growth (Igoni *et al.*, 2007). C/N ratio ranging from 20 to 30 is considered optimum for anaerobic digestion with about 25 being the best (Dennis, 2007).

[5] The lower limit (310 l/kg TVS) was used in the analysis.

A very high C/N ratio promotes the increase in the population of the methanogens which results in the increase in the consumption of N_2 to meet their protein requirements and hence will not react with leftover carbon content of the substrate resulting in a low gas production. On the other hand, if the C/N ratio is low the nitrogen will later accumulate as ammonia to amounts that will be toxic for the methanogens.

The C/N ratio of sewage depends primarily on the diet of the people in the locality. A feasibility study conducted for a biogas plant in Hungry reported a C/N ratio in the range of 5 to 10 for human waste (Agar *et al.*, 2006). However, in China the C/N ratio for human waste is 29 (Agar *et al.*, 2006). C/N ratio of nightsoil in Philippians is about 6.72 (PAES, 2001 and Kuria *et al.*, 2008).

2.3.5 HYDRAULIC RETENTION TIME

The hydraulic retention time (HRT) represents the time the feedstock spends in a digester. The longer HRT, the higher the amount of gas produced (Poliafico, 2007).The advantages of multiple stage digesters are that, there is shorter retention time but there are construction cost implications. The HRT can accurately be defined for batch type facilities than in continuous systems (GTZ, 2007). The longer the retention time the higher the percentage yield of biogas. Extra long HRT increase the gas yield by as much as 40% (GTZ, 2007).

Table 2-4 shows the conversion rate of gas production of some substrates at a given retention time at 30°C. The values indicate that the longer the HRT, the higher the yield. A 60-day HRT for human waste will produce a yield at 100% conversion which is not very different from 94.1% conversion for the 30-day HRT. However, biogas production at the highest speed is at 10-day and 20-day HRT but with low yield.

Table 2-4: The conversion rate of biogas production with common fermentation materials

Retention Time	Amount of biogas produced expressed as percentage (%) per time		
Time (Days)	Human Waste	Pig manure	Cow dung
10	40.7	46.0	34.4
20	81.5	78.1	74.6
30	94.1	93.9	86.2
40	98.2	97.5	92.7
50	98.7	99.1	97.3
60	100	100	100

(Source: Biogas Training Center, China)

For continuous flow digester systems, digester volume (V_d) is arrived at by multiplying the daily feed rate (V_f) with the slurry retention time (R) thus:

$$V_d = V_f * R \qquad (2.1)$$

2.3.6 ORGANIC LOADING RATE

The organic loading rate (OLR) measured in kg TVS/m^3/day, is the quantity of TVS fed into a digester per unit volume of digester per unit time.

High values of OLR require more bacteria and this could find the system not prepared and at the same time could encourage acid production, which in turn decrease the pH and harm methanogenic bacteria. However, increasing the OLR will reduce the digester size but at the same time will reduce the percentage of TVS converted to gas (Poliafico, 2007). Even though the TVS determines the strength of waste, it is not the only parameter that determines if a digester has a high or low OLR, but rather the combination of waste strength, digester volume, and HRT.

2.3.7 AGITATION

In the anaerobic digestion process many substrates require some sort of agitation or mixing to stabilise the process within the digester. Slow stirring is highly recommended. High solid content substrates do not require mechanical agitation or requires limited agitation. There is a certain agitation through the rising of the gas though the substrate or addition of fresh substrate. This is natural agitation is not always enough (PAES, 2007). Well agitated substrate can, leaving other parameters constant, increase its biogas production by 50% (GTZ, 2007).

2.3.8 INHIBITORY / TOXIC MATERIALS

Methanogenic bacteria are probably the most oxygen sensitive organism known. Any avenue for inflow of oxygen into the digester should be sealed because substantial amounts of oxygen can affect the digestion process. However, small amounts of air (up to 0.01v/v of digester content) will not affect anaerobic digestion (Mignone, 2005). Short Chain Organic (Volatile) acids are the by-products of the non-methanogenic phase of the anaerobic digestion process.

A typical process is the acidogenesis. Acidogenic bacteria turn glucose into simple organic compounds such as volatile acids (propionic, formic, lactic, butyric acid, etc), ketones (ethanol, methanol, glycerol, acetone, etc) (Poliafico, 2007). A digester containing a high volatile-acid concentration requires a somewhat higher-than-normal pH value. If the pH value drops below 6.2, the medium will have a toxic effect on the methanogenic bacteria (GTZ, 2007). Performance of methane forming bacteria is a key factor for a digester (Pankaj, 2006).

2.3.9 STATE OF DIGESTED SLUDGE

Anaerobic digestion modifies the properties of the waste by transforming the Carbon(C), hydrogen (H) and oxygen (O) into Carbon dioxide (CO_2), methane (CH_4) and water (H_2O) and the fermentation reduces the C/N ratio increasing the fertilizing effect. Also the nitrogen appears mineralized and thus suitable for plants. Well-digested slurry is practically odourless and does not attract flies as well as deactivating pathogens and worm ova (Barelli *et al.*, 2007).

Compared to the source of material, digested slurry has a finer, more homogeneous structure, which makes it easier to spread. There is an increase in the ammonia content in the digested manure, which means that the amount of nitrogen available for plants is increased in the degassed manure (Sorensen, 2004). However, when the effluent is dried, most of the nitrogen is lost (Alam *et al.*, 2003). In many ways digested human excreta is better than artificial fertilizers.

This organic fertilizer encourages the formation of humus (decomposed vegetable matter) which is essential for optimum soil structure and water retention, contains trace elements which help protect the plant from parasites and disease, promotes the development of small organisms (microbes) which convert the minerals to forms that the plants can use; and improves the soil structure, making it easier to cultivate and to resist the effects of erosion (Franceys, *et al.*, 1992). It can also be put into ponds as feed for algae, fish or ducks (Alam *et al.*, 2003).

3 BIOGAS PLANT TECHNOLOGY

This chapter is divided primarily into three sections. The first section looks at the different types hydraulic of flow systems and the types of digesters that are suitable for biogas production. The second section looks at the auxiliary equipment associated with biogas production. The third section looks at the different types of biogas-fuelled engines and safety at a biogas plant site.

3.1 HYDRAULIC FLOW SYSTEM

3.1.1 CONTINUOUS SYSTEM

With continuous-feeding digesters, a small quantity of raw material is added to the digester every day usually at regular intervals either manually or automatically. In this way the rate of production of both gas and sludge is more or less continuous and reliable. This system is especially efficient when raw materials consist of a regular supply of feedstock from nearby source (Barelli *et al.*, 2007).The substrate must be a fluid and homogeneous (GTZ, 2007), with a suitable solids content of between 5-10% (Sasse *et al.*, 1991). The effluent is automatically through the overflow whenever new material is filled into the digester and most of the Bacteria are conserved.

3.1.2 BATCH SYSTEM

With batch digesters, a full charge of raw material is placed into the digester which is then sealed off and left to ferment as long as gas is produced. When gas production has ceased, the digester is emptied and refilled with a new batch of raw materials. Batch digesters have advantages where the availability of raw materials is sporadic (Barelli *et al.*, 2007).

Batch digesters have disadvantages, in that a great deal of energy is required to empty and load them; also gas and sludge production tend to be quite irregular. The sludge in a batch reactor is normally not mixed, so the contents of the digester stratifies (the different layers typically are layers of gas, sludge scum, supernatant and the active layer) (Poliafico, 2007).

3.1.3 PLUG FLOW SYSTEM

The plug flow system is the simplest form of anaerobic digestion. Consequently, it is the least expensive. The system includes a mixing pit and the digester itself. In the mixing pit, the addition of water or recycled effluent adjusts the proportion of solids in the substrate slurry to the optimal consistency (Dennis *et al.*, 2001). However, the solids content should be about 11-13% (Ostrem, 2004). The waste enters on one side of the reactor (rectangular shaped system) and exits on the other. Since bacteria are not conserved, a portion of the waste must be converted to new bacteria, which are subsequently flushed out with the effluent (Dennis *et al.*, 2001).

3.2 BIOGAS DIGESTERS

3.2.1 FIXED-DOME DIGESTER

A typical fixed-dome plant is a simple digester consisting of a single, variously shaped but typically cylindrical tank (Poliafico, 2007) enclosed and usually constructed underground (Alam *et al.*, 2003) with a fixed, non-movable gas space (gasholder) as shown figure 3-1.

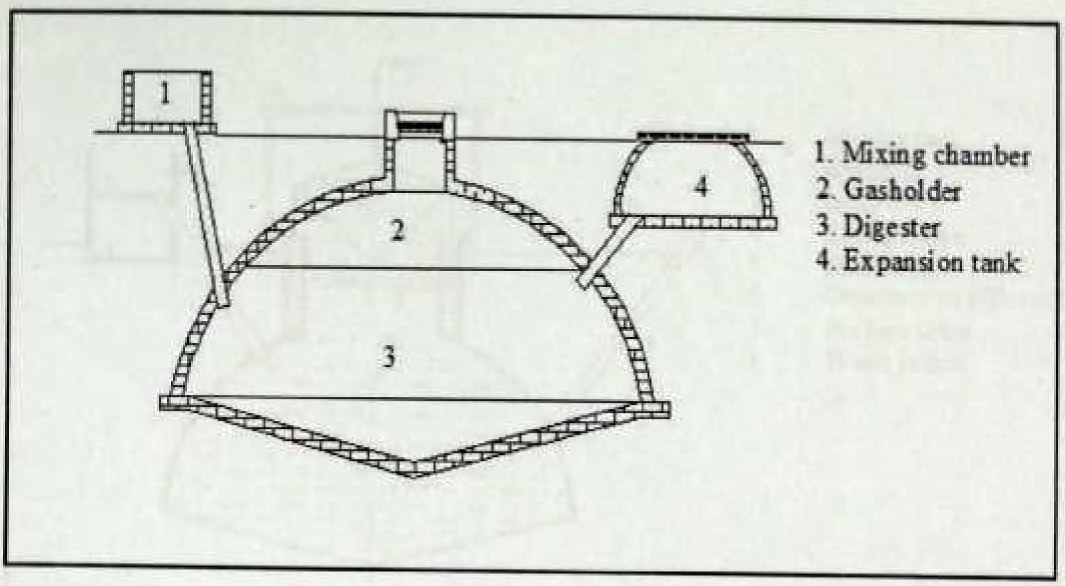

Figure 3-1: A typical fixed-dome digester (Sasse *et al.*, 199)

The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank next to the digester (GTZ, 2007). It is usually constructed with bricks. Gas pressure increases with the volume of gas stored.SIf there is little gas in the holder, the gas pressure is low. Difference in level between sludge in digester and sludge level in compensation tank is equal to the pressure of gas. The size of the digester can be from 4 m^3 to about 50m^3(Alam *et al.*, 2003). Experience shows that size larger than 50m^3 pose maintenance problems (Sasse *et al.*, 1991).

3.2.2 FLOATING DRUM DIGESTER

Floating-drum plants consist of an underground digester and a moving gas-holder. The gasholder floats either directly on the fermentation slurry or in a water jacket of its own (Alam *et al.*, 2003). The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored. The gas drum is prevented from tilting by a guide frame as shown in figure 3-2; in some cases the drum floats in a water jacket so as not to get stuck (Sasse *et al.*, 1991).

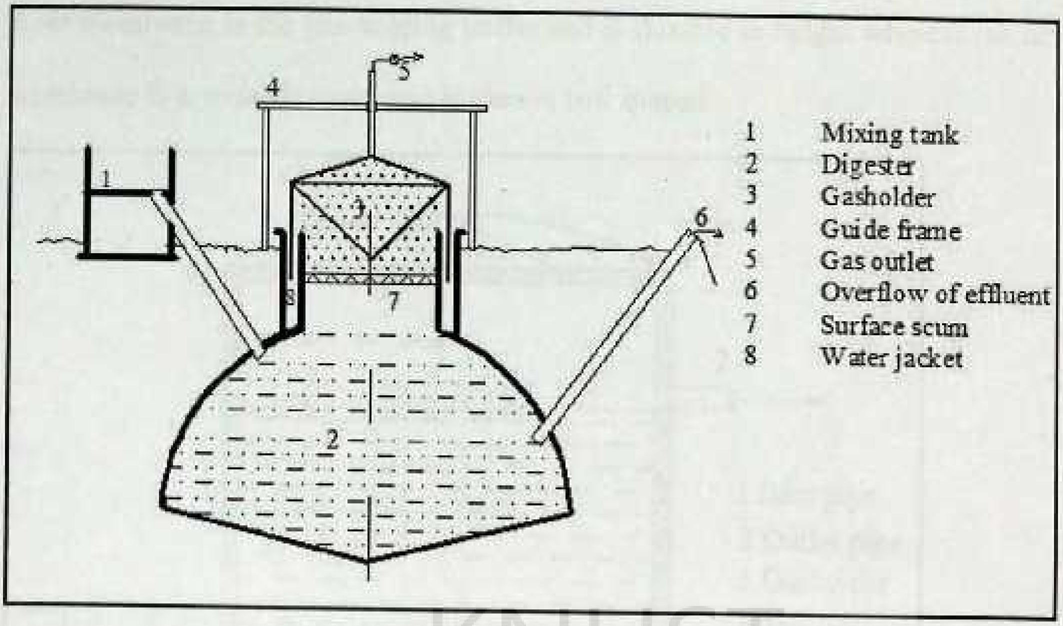

Figure 3-2: A typical floating drum (Sasse *et al.*, 199)

Difference in level between sludge in the digester and sludge level in the compensation tank is equal to the pressure of which is just like the fixed-dome digester (PAES, 2003). The maximum design capacity of floating drum digesters is about 50m^3.

3.2.3 VERTICAL-MIXING DIGESTER

The size of vertical-mixing digesters can be designed to have a capacity of between 500 and 3,000 m³ and the height is often 5m to 6 m. The diameter varies between 10 and 20 m. This system can handle solid content of between 3%-10%. The tank can be equipped with a heating system which circulates hot water through tubes fixed along the walls; this is to maintain the temperature of the sludge (Torsten *et al.*, 2007).

The stirrer is either completely immersed or equipped with a motor located outside the tank. The top of the tank is fitted with a double membrane, gas holder roof. The inner membrane is the gas-holding buffer and is flexible in height whereas the outer membrane is a weather cover and is always ball shaped.

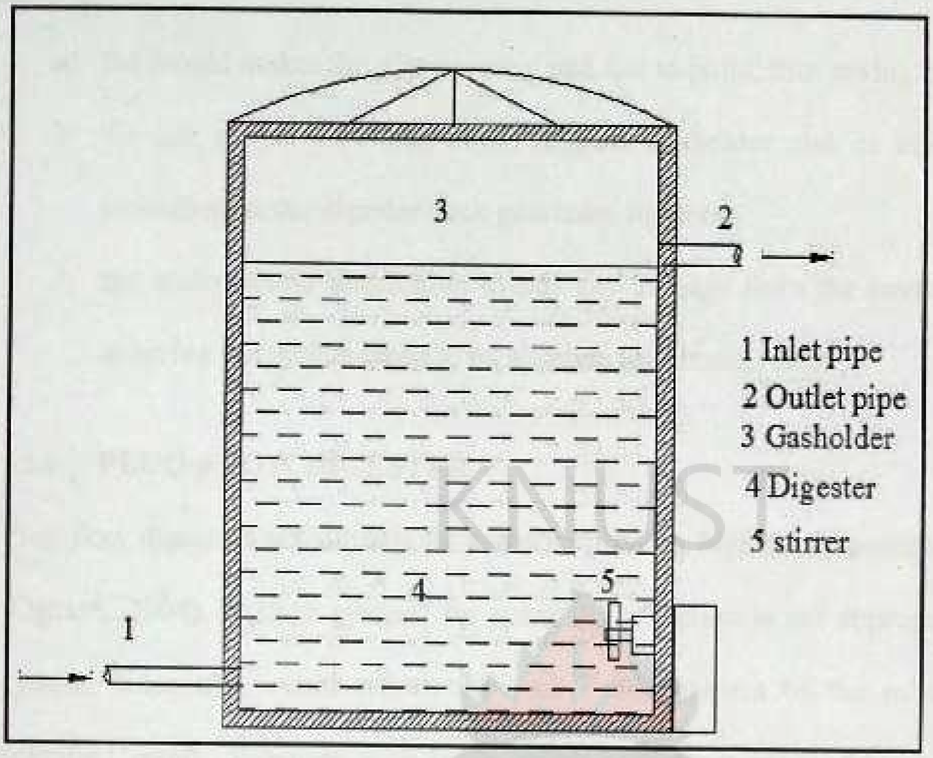

Figure 3-3: A typical vertical-mixing digester (Krieg *et al.*, 2007)

The vertical-mixing digester is a completely mixed digester usually made of reinforced concrete or steel. The substrate is continuously mixed during the digestion process in order to keep the solids in suspension and biogas accumulates at the top of the digester (Hopfner-Sixt *et al.*, 2006) as shown figure 3-3.

3.2.4 PUXIN DIGESTER

The Puxin biogas digester is a fixed dome-type which can be designed for domestic, institutional and agricultural facilities. It can also be used to digest both liquid and solid substrate. This system requires the transportation of the steel mould to the site of construction. The mould is filled with concrete and the size of a single digester can be as large as 100m^3 with a lifespan of about 40 years. It has an in-built glass fibre reinforced plastic gasholder of 1.2m^3 capacity.

The Puxin digester technology comes with a number of advantages such as;

a. the mould makes the digester easy and fast to build, thus saving money.
b. the use of the corrosion-free fibreglass gasholder and its unique way of mounting on the digester neck guarantee tightness.
c. the underground installation avoids any damage from the environment thus reducing the maintenance to an absolute minimum. ranch

3.2.5 PLUG-FLOW DIGESTER

Plug-flow digesters are suitable for substrates having high solids content of 11-13% (Ostrem, 2004). A flush system[6] for substrate collection is not appropriate for this system, since this would reduce the total solids content of the substrate below specified levels. Substrate with lower solids concentrations, solids cannot stay in solution and tend to settle to the bottom of the tank, limiting their digestion (Nelson *et al*, 2002). The substrate enters one end of the plug-flow digester, a rectangular tank, and decomposes as it moves through the digester as shown in figure 3-4.

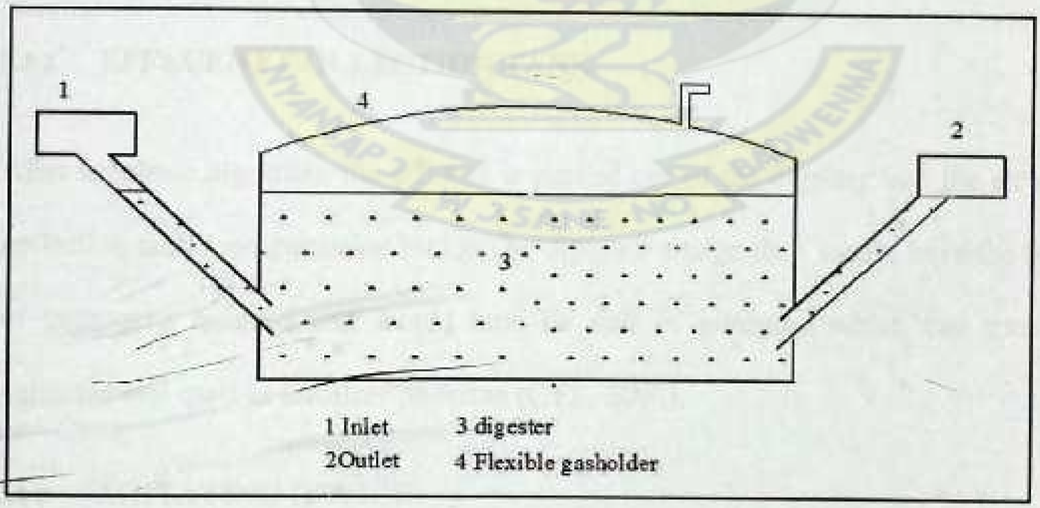

Figure 3-4: A typical plug-flow digester (EPA, 2002)

[6] A system employed in cleaning pig style, ranch, etc.

New material added to the digester tank pushes older material to the discharge end (Dennis *et al.*, 2001). Coarse solids in manure form a thick sticky material as they are digested, which limits solids separation in the digester tank. As a result, the material flows through the tank in a "plug". Anaerobic digestion of the manure slurry creates biogas as the material flows through the digester. A flexible, impermeable cover on the digester traps the biogas. Fibrous feed material is suitable for a plug-flow system (Agstar, 2002).

3.3 PLANT AUXILIARY COMPONENTS

3.3.1 INFLUENT COLLECTION TANK

In general, rectangular or square inlet tanks with one end designed to accommodate the inlet pipe are constructed. Fresh substrate is usually gathered in an influent collecting tank prior to being fed into the digester (Prakash, 2005). This influent collecting tank or mixing chamber can also be used to homogenize the various substrates and to set up the required consistency, by adding water to dilute the mixture to the required solid content before feeding into the digester (Agar *et al.*, 2006; GTZ, 2007).

3.3.2 EFFLUENT COLLECTION TANK

After substrate digestion, the effluent is pushed out of the digester into the effluent collection tank (compensation tank). The digested sludge then would have the level of pathogens reduced and would now be rich in nitrogen, which can then be collected and used as fertilizer on farms (GTZ, 2007).

3.3.3 AGITATING DEVICE

The objectives of the agitation are to maintain uniform temperature within the digester, to provide a uniform bacterial population density (Mignone, 2005), to prevent the formation of dead spaces that would reduce the effective digester volume, to avoid scum formation and sedimentation (GTZ, 2007), to mix fresh and fermenting substrate in order to inoculate the fresh substrate and to improve the activity of the bacteria through release of biogas and provision of fresh nutrients (CAEEDAC, 1999).

However, whenever a bacterial community is disrupted, the process of fermentation will remain less productive until such time when new community is formed. Typical agitation methods are electric motor driven vanes and hand driven vanes (PAES, 2007). The most widely used stirrers are the propeller mixers. They allow the most flexible application with respect to the substrate composition and the form and size of the digester. Usually slowly rotating mixers are applied with rotations as low as 15-50 rpm (Wellinger, 1999). Digesters with capacities greater than $50m^3$ should be provided with a stirring or agitation facility (Sasse, 1991).

A thorough mixing is a pre-requisite of a stable digestion process, a good degradation of the organic substrates, a high biogas yield and a good biogas quality. One mixer is recommended for biogas plants with an electric capacity under 250 kW. For biogas plants with an electric capacity over 250 kW it is appropriate to have two or three mixers installed. In digesters with a volume up to 500 m^3 only one mixer is usually installed. However, digesters with volume greater than 500 m^3 will require two or three mixers (Hopfner-Sixt *et al.*, 2006).

3.3.4 PUMPS AND PIPING SYSTEM

For the sake of standardization, it is advisable to select a single size for all pipes, valves and accessories. Biogas is 100% saturated with water vapour and contains

H_2S. Consequently, no piping, valves or accessories that contain any amounts of ferrous metals may be used for biogas piping, because they would be destroyed by corrosion within a short time (GTZ, 2007). The gas lines may consist of standard galvanized steel pipes. Also suitable (and inexpensive) is plastic tubing made of rigid PVC or rigid PE. Flexible gas pipes laid in the open must be UV-resistant (PAES, 2007).

Pumps are usually connected to the biogas plant to pump sludge from the mixing influent collecting chamber into the digester (Agar, 2006). In small plants which use the fixed-dome and floating drum the sludge flows into the digester. Pumps become necessary parts of a biogas unit, when the amounts of substrate require fast movement and when gravity cannot be used for reasons of topography or substrate characteristics. The most common types of pumps used in biogas plants are centrifugal pumps and positive-displacement pumps (reciprocating pumps).

3.3.5 GAS HOLDER AND GAS SEPARATION

The gas holder is the portion of the biogas plant where the biogas immediately generated from the sludge is collected. Depending on the design, the gas holder can be a separate unit from the digester (CAEEDAC, 1999) or is an integral part on top of the digestion chamber (PAES, 2001). The gas holder should be made of plastic or steel to prevent corrosion since the biogas contains some amount of H_2S. The presence of H_2S in the biogas is corrosive to the generator engines, compounding maintenance and shortening generator life.

a. Hydrogen Sulphide Separation

Hydrogen sulphide (H_2S) reacts endothermically with iron hydroxides [Fe $(OH)_2$] to form iron sulphide (FeS_2). A process often referred to as "iron sponge" makes use of this reaction to remove H_2S from gas. The name comes from the fact that rust-covered steel wool may be used to form the reaction bed. Steel wool, however, has a relatively small surface area, which results in low binding capacity for the sulphide. The process is highly chemical intensive, the operating costs can be high, and a continuous stream of spent waste material is accumulated. Additionally, the change-out process is labour intensive. Because of this, wood chips impregnated with iron-oxide (Fe_2O_3) have been used as preferred reaction bed material.

The Fe_2O_3 impregnated chips have a larger surface-to-volume ratio than steel wool and a lower surface-to-weight ratio due to the low density of wood. Roughly 20g of H_2S can be bound per 100g of Fe_2O_3 impregnated chips. The optimal temperature range for this reaction is between 25° C and 50° C. The Fe_2O_3 can be regenerated by passing oxygen (air) over the bed material. Typically, two reaction beds are installed, with one bed undergoing regeneration while the other is operating to remove H_2S from the biogas. For applications such as power generation requiring both H_2S and CO_2 removal and compression of the biomethane gas, the iron sponge technology using iron-impregnated wood chips appears to be the most suitable (Zicari, 2003).

b. Water Vapour Separation

Biogas from digesters is normally collected from headspace above a liquid surface or very moist substrate, the gas is usually saturated with water vapour. The amount of saturated water vapour in a gas depends on temperature and pressure. Biogas typically contains 10% water vapour by volume at 45°C, 5% by volume at 35°C, and 1% by volume at 8°C (Weast, 1958 cited by Krich *et al.*,2005, p.51). The removal of water vapour (moisture) from biogas reduces corrosion that results when the water vapour condenses within the system.

Moisture removal is especially important if the H_2S has not been removed from the biogas because the H_2S and water vapour react to form Tetraoxosulphate (VI) acid (H_2SO_4)[7], which can result in severe corrosion in pipes and other equipment that comes into contact with the biogas. Even if the H_2S has been removed, water vapour can react with CO_2 to form carbonic acid (H_2CO_3), which is also corrosive (pH near 5) (Zicari, 2003).

3.3.6 BIOGAS-FUELED ENGINES

Generating electricity is a much more efficient and economical use of biogas than using it for gas light.. In this process, the gas consumption is about 0.75 m^3 per kWh with which twenty five 40-watt lamps can be lighted for one hour, whereas the same volume of biogas can serve only seven 40-watt equivalent lamps for one hour (BRTC, 1983; cited by FAO, 1996). Most biogas contains less than 1% H_2S, so desulfurization is normally unnecessary, especially if it is to be used for operating a stationary engine (Werner *et al.*, 1989).

The ignition temperature of biogas is higher than of diesel, therefore, when biogas is used in engines, ignition spark plugs are required or partly diesel must be added to the gas (dual fuel) to run the engine. For these engines usually a second gas source must be provided for start up. Examples are natural gas, propane gas or biogas can also be used for that purpose (Krieg *et al.*, 2007).

a. Spark-Ignition(SI) Engines

Converting a spark-ignition engine for biogas fueling requires the modification of the Carburetion and Compression Ratio (Anand *et al.*, 2005).

[7] This is the IUPAC name for Sulphuric Acid

Carburetion: Carburetion modification basically involves accounting for the lower volumetric heating value of the biogas relative to the primary fuel (gasoline). Conversion of SI engine would require a complete replacement of the gasoline carburettor to a gaseous fuel carburettor sized to provide the volumetric flow necessary for maximum power output (US DoE, 1998).

Compression Ratio: The engine speed should be limited to 3000 rpm and compression ratio of 11 to 12 is suitable (GTZ, 2007). In addition, however, the mixing chamber should be equipped with a hand or automatic-operated air-side control valve for use in adjusting the air/fuel ratio (optimum value of 1.1) (US DoE, 1998). SI engine converted to run on biogas as fuel has efficiency of about 22% with a compression ratio of about 13 (Anand *et al*., 2005 and Ravikrishna *et al*., 2006).

b. Compression Ignition(CI) Engines

Diesel engine can be converted to dual fuel engine and will require the use of diesel fuel for ignition, since there is no spark and biogas has low cetane number (US DoE, 2009). In the CI engine as much as 80% of the diesel used can be replaced by biogas. (FAO, 1996 and GTZ, 2007). A diesel engine draws air and compresses it at a ratio of 17:1. The injected diesel fuel still ignites itself, while the amount injected is automatically reduced by the speed governor, depending on how much biogas is injected into the mixing chamber (GTZ, 2007).

Diesel engines can be converted to biogas fueled engines by replacing injectors with spark plugs and the injector pump with a carburettor (US DoE, 1998). The biogas supply is controlled manually or by automation and the maximum biogas intake must be kept below the point at which the engine begins to stutter. The efficiency of the biogas based CI engine is 30%-38% using a compression ratio of about 15-21 (Foss *et al*, 2005 and Sasse, 1988).

c. Biogas Engine

Biogas engine is pre-designed to use only biogas. It is based on the SI technology whose efficiency is between 24% - 29% (GTZ, 2007). It has a gaseous fuel carburettor that provides the volumetric flow necessary for maximum power output of the engine. Since biogas has very high octane number approximately 130 compared with gasoline's 90 to 94 and alcohol's 105 at best, a higher compression ratio engine can be used with biogas. Hence, cylinder head of the engine is faced so that clearance volume will be reduced for pre-designed biogas engines and compression ratio can be sufficiently increased to about 15 (Kapadia, 2006).

d. Microturbines

Micro turbines are small combustion turbines that produce between 25 kW and 500 kW of power (US DoE, 2009). Micro turbines were derived from turbocharger technologies found in large trucks or the turbines in aircraft auxiliary power units (APUs). Most micro turbines are single-stage, radial flow devices with high rotating speeds of 90,000 to 120,000 rpm (California EC, 2009) and they are composed of a compressor, a combustor, a turbine, an alternator, a recuperator, and a generator (US DoE, 2009).

However, many of the micro turbine installations are still undergoing field tests or are part of large-scale demonstrations. It can use a variety of fuels such as natural gas, hydrogen, propane, diesel and biogas[8]. It has efficiency range between 20%-

[8] Biogas as fuel is still at the testing stages

30% (unrecuperated[9]) and recuperated microturbines can have as high as 80% efficiency (US DoE, 2009). Micro turbines generally are not commercially available in large quantities.

e. Fuel Cells

Fuel cells are like electric batteries and convert chemical energy into electricity without combustion (Poliafico, 2007). There are three sections in a typical fuel cell system: (1) a fuel pre-treatment and processing section (a reformer), (2) the fuel cell stack, and (3) a DC to AC power electrical conditioning and controller section (an inverter). Fuel cells operate on hydrogen and if pure hydrogen is used as the fuel source, the sole by-product of the reaction is water (Aldrich *et al.*, 2005). Even though fuel cells are not technically classified as engines, high temperature systems can run on biogas, liquid fuels, and gaseous hydrocarbons that are first "reformed" into hydrogen (Aldrich *et al.*, 2005) Biogas generally contains 30- 45% CO_2, moisture, and up to 2,000-4,000 ppm H_2S. H_2S is the chief contaminant that makes biogas use problematic, because it is corrosive in engines and poisonous to fuel cell catalysts. Hence biogas needs to desulpherised before feeding it to a fuel cell (Shiratori *et al.*, 2008).

Current fuel cell power plants achieve fuel to electricity conversion efficiencies in the range of 35 to 55%, depending on the heating value of the fuel (Aldrich *et al.*, 2005). If the thermal energy also produced by the fuel cell can be used as well, overall efficiencies of up to 75% can be achieved (Aldrich *et al.*, 2005).

[9] Recuperated micro turbines recover heat from the exhaust gas to boost the temperature of combustion and increase the efficiency and unrecuperated (or simple cycle) micro turbines have lower efficiencies but also lower capital cost.

3.4 SLUDGE DEWATERING METHODS

After biogas is generated, the feedstock can be separated into solid and liquid residue. Dewatering may increase sewage sludge solids to 15% to 40% for organic sewage sludge and 45% or more for some inorganic sewage sludge cake (EPA, 1995). This can be achieved by using rotary drum vacuum filter or centrifuge.

a. Rotary Drum Vacuum Filter

Vacuum filtration is the simplest form of "through blow" dewatering (Peters and Timmerhaus, 1991). A pressure differential created by a vacuum applied to the inside of the filter drum causes air to flow through the filter cake thereby displacing the contained water. The solids are retained on a filter cloth and are carried to discharge point by the rotation of the drum. The goal of vacuum filter thickening is to obtain solids concentration of approximately 35% (Peters and Timmerhaus, 1991).

b. Centrifuge

Centrifugation is another method of sludge thickening. Sludge is fed at a constant feed rate into a rotating bowl and the solids are separated from the liquid by the centrifugal forces created by the rotating bowl. The solids are compacted to the bowl wall and the liquid and fine solids exit the unit through the effluent line (Kerri, 1994 cited by Governo, 2000). An internal screw conveyor removes the dewatered sludge out at one end of the bowl while water leaves the other end. The goal of centrifugal thickening is to obtain solids concentration of approximately 20% (Governo, 2000).

3.5 SAFETY ON THE BIOGAS PLANT SITE

In the operation of a biogas plant it is required that special attention is paid to the entire system in terms of safety because of the physical and chemical characteristics of biogas (GTZ, 2007). The following dangers are known:

a. Breathing in biogas in a high concentration and over longer periods of time can cause poisoning and death from suffocation (Asphyxiation). The hydrogen sulphide content of biogas is highly poisonous. Unpurified biogas has the typical smell of rotten eggs. Gas pipes and fittings should be checked regularly for their gas-tightness and be protected from damage (Prakash, 2005).

b. After emptying biogas plants for repair, they have to be sufficiently ventilated before being entered. Here the danger of fire and explosion is very high (gas/air mixture). The so-called chicken test (a chicken in a basket enters the plant before the person) guarantees sufficient ventilation (GTZ, 2007).

c. Biogas in the form of a gas-air mixture with a share of 5% to 12 % biogas and a source of ignition of 600°C or more can easily explode. Danger of fire is given if the gas-air mixture contains more than 12 % of biogas. Smoking and open fire must therefore be prohibited in and around the biogas plant (GTZ, 2007).

d. The digester of a biogas plant and the slurry storage facilities should be built in such a way that neither persons nor animals are in danger of falling into them (Sasse *et al.*, 1991).

e. Moved and movable parts should have a protective casing to avoid trapping persons or animals. The piping system can form traps on the plant site. As much as possible, pipes should be laid some 30 cm underground. Pits for water traps, gas meters, main valves or test-units should be cased by a concrete frame and covered with a heavy concrete lid (Sasse *et al.*, 1991).

4 FEEDSTOCK ANALYSIS AND PLANT DESIGN

4.1 KNUST SEWAGE TREATMENT PLANT

a. Liquid waste collection

Liquid waste generated at KNUST can be grouped into sullage and sewage. The sullage is channelled through open drains into the Wiwi river whiles the sewage is transported through pipes to the sewage treatment plant located on the campus of KNUST. Not all the facilities on campus are linked to the central sewage system. Whiles all the halls of residence, main library and faculty buildings on campus are connected as shown in figure 4-1, the same cannot be said of the residential apartment of lecturers and other staff of the university.

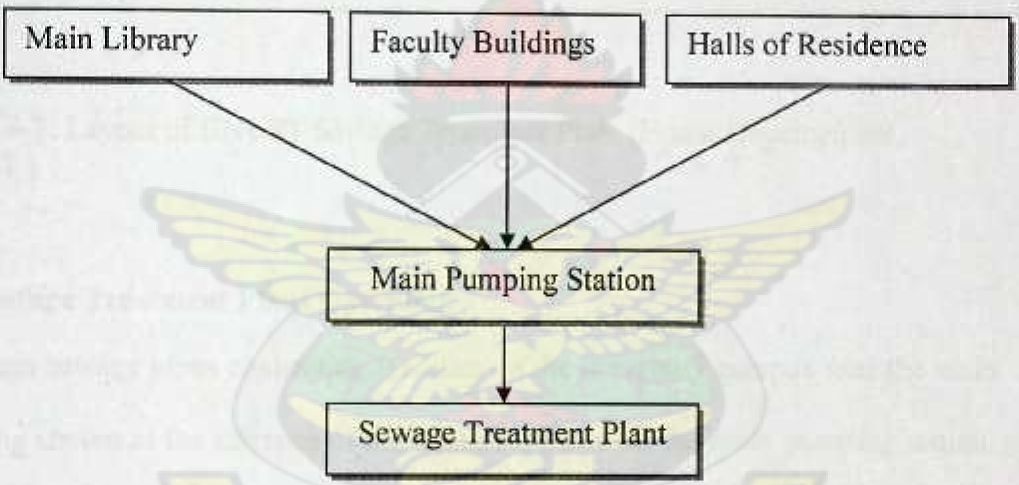

Figure 4-1: Feeds into the Sewage Treatment Plant

After the sewage enters the treatment plant, it goes through various treatment processes discussed in subsection. The flow of sewage to the treatment plant and the layout of the various treatment processes are shown in figure 4-2.

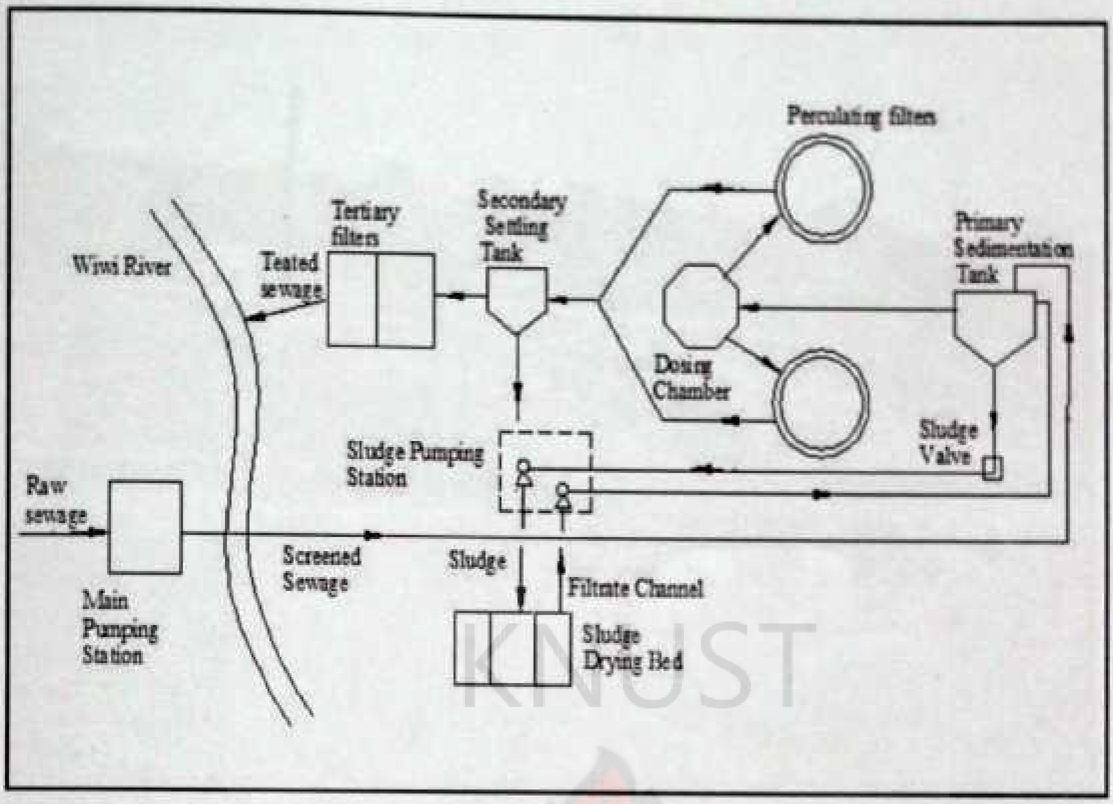

Figure 4-2: Layout of KNUST Sewage Treatment Plant (Estate Development, KNUST)

b. Sewage Treatment Plant Operation

The main sewage pipes connecting facilities on the university campus feed the main pumping station at the entrance of the treatment plant. At the main pumping station, solid materials such as papers, glass, etc are removed by a screen. The sewage is then pumped into the Primary Sedimentation Tank (PST) for dewatering (figure 4-3). The sludge (solid portion) settles at the bottom whiles the liquid remains on top. The liquid is channelled into the Dosing Chamber (DC) for chemical treatment[10]. From the DC the liquid is siphoned into the percolating filters (PF) for filtration. From the PF the liquid is channelled into a Secondary Sedimentation Tank (SST) where any sludge present in the liquid settles at the bottom.

[10] Currently it is not chemically treated. No specific reason was given but according to the manager of the plant, the university will soon resume its chemical treatment.

Figure 4-3: KNUST Sewage Treatment Plant: Primary Sedimentation Tank

The sludge present in SST is channelled to the Sludge Pumping Station (SPS) where it is pumped back into the PST for recycling whiles the liquid from the SST is pumped into Sand Filters (SF) for further filtration. From the SF, the liquid portion is discharged into the Wiwi river. The gravels in the SF and PF are occasionally removed and cleaned.

There are four penstocks (Valves) at the PST which are manually operated when the tank is observed to contain enough sludge. The sludge valves are opened to release the sludge into the sludge drying bed, where nearby farmers collect and use the sludge on their farms[11] when the sludge becomes dry. Figure 4-3 shows the PST

[11] At that stage the sludge contains high levels of pathogens which is unsafe for the environment and for the farmers to handle. They are exposed to Salmonella and E-coli found in the dry sludge which can cause typhoid fever and Gastroenteritis, respectively.

located at the sewage treatment plant where the feedstock to the biogas digesters will be taken for the biogas production.

4.2 FEEDSTOCK SAMPLING

In determining the faecal sludge quality of the sludge in the PST, samples were collected and analysed at the Environmental Quality Engineering laboratory of the Civil Engineering Department. The purpose of the analysis was to determine the quantity of Total Volatile Solids (TVS) and Total Solids (TS), which was used to estimate the quantity of degradable organic matter present in the sludge and the weight of the dry matter content respectively. The sludge from the PST will serve as feedstock for the biogas plant. The other tests such as E-coli and Samonella were carried out to determine the level of pathogens present in the sludge.

4.3 DETERMINATION OF FEEDSTOCK FLOWRATE

There was no flow meter at the PST to determine the flow rate of the sludge that is channelled into the sludge drying bed. The penstocks (valves) for sludge are released when it is visually observed that the liquid in the PST contain some sludge. According to the manager it usually occurs more frequently when the university is in session than on vacation due to the reduction in the sewage flow rate into the PST. The PST has total design capacity of about $63.65m^3$ and the volume of sludge displaced was estimated to be $17.86m^3$. In order to synchronize the operations at the treatment plant with the biogas plant operation, the sludge siphoned out of the PST will feed directly into the anaerobic digester. The flow rate of sludge was estimated to be $71.44m^3$/day (maximum) when the university is in session and $35.72m^3$/day (minimum) on vacations. The KNUST 2008/09 academic year calendar was used to determine the estimated monthly flow rate of the sludge based on the number of days when school is in session or on vacation for each month. Figure 4-4 shows the pattern of the estimated flowrate for each month of the year. The average daily flow rate of the sludge is 58.33m^3/day. The estimated flow rates are presented in Appendix A.

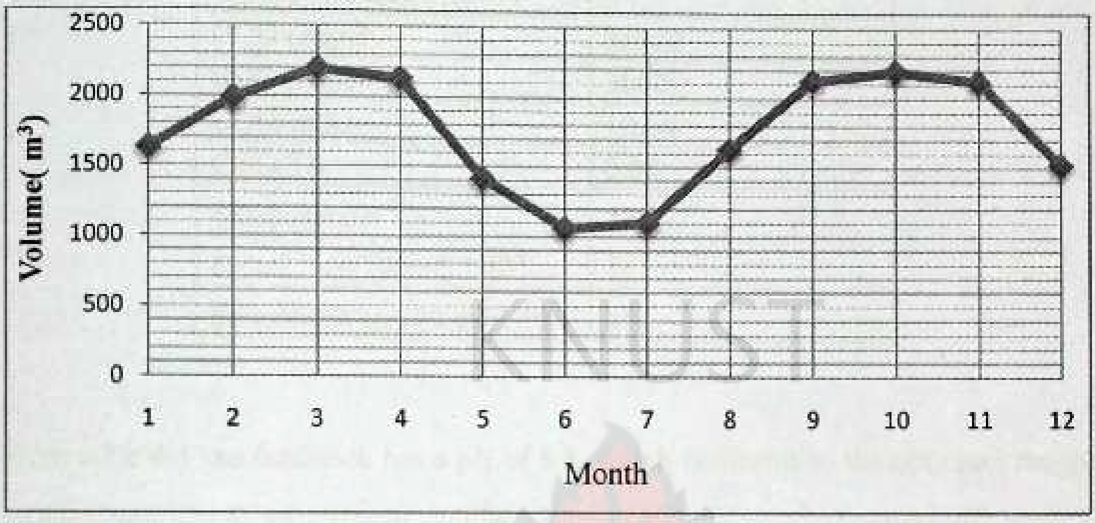

Figure 4-4: Average Monthly flowrate of feedstock

4.4 LABORATORY ANALYSIS OF FEEDSTOCK

In the determination of the biogas potential of the sewage treatment plant, analysis on the sewage was required to determine some specific parameters. These parameters include Power of Hydrogen ion concentration (pH), Total Volatile Solids (TVS), Total Solids (TS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Total Dissolved Solids (TDS). The pathogens population in the sewage was determined to establish the level of pathogens since the nearby farmers use the dried sludge on their farm as fertilisers.

Table 4-1: Quality of feedstock from the PST

Parameters	Values
pH	6.8
TS (mg/l)	89275
TVS (mg/l)	57736
TVS in TS (%)	64.7
TS in Feedstock (%)	9.1
COD (mg/l)	38320
BOD (mg/l)	3600
COD/BOD	10.64
COD/TS	0.39
Temperature(°C)	28
E-coli [12] (n/100ml) * 10^4	161
Salmonella (n/100 ml)* 10^4	863

From table 4-1 the feedstock has a pH of 6.8 which conforms to the optimum range of 6.8 to 7.2 reported by Barelli *et al* (2007) and the temperature of 28°C lies within the mesophilic range of temperatures which is between 20°C and 40°C (GTZ, 2007). The pathogens present in the sludge are very dangerous when disposed into the environment even after drying, but after digestion, the level will reduce as reported by FAO (1996).

4.5 MATERIAL BALANCE ON THE BIOGAS DIGESTERS

The material balance for each digester system was done based on the laboratory results obtained on the TS and TVS. 1m^3 of the feed is equivalent to 973.5 kg. Using daily sewage flow rate of 71.44m^3/day (69.55tonnes/day), the material balance of the feedstock was obtained as shown in table 4-2, on the digesters for the three HRTs selected for this study.

[12] This is the standard representation of the specific number of pathogens present in a 100ml sample.

Table 4-2: Material balance on biogas substrate

HRT		10 days	20 days	30 days
Component	Input (tonnes/day)	Output (tonnes/day)		
Water (% feed)	63.22(90.9)	63.22(92.2)	63.22(92.0)	63.22(91.4)
TS(% feed)	6.33(9.1)	5.37(7.8)	5.51(8.0)	5.92(8.6)
Ash[13](% TS)	2.23 (35.3)	2.23(41.5)	2.23(40.5)	2.23(37.7)
TVS(% TS)	4.10(64.7)	3.14(58.5)	3.28(59.5)	3.69(62.3)
Biogas	-	0.96[14]	0.82[15]	0.41[16]
Total	**69.55**	**69.55**	**69.55**	**69.55**

Figure 4-5 shows the direction of flow of material for the 30 day HRT system. The other two HRTs have the same flow pattern but different material balance. The sludge flows into the biogas digesters to produce biogas and the digestate.

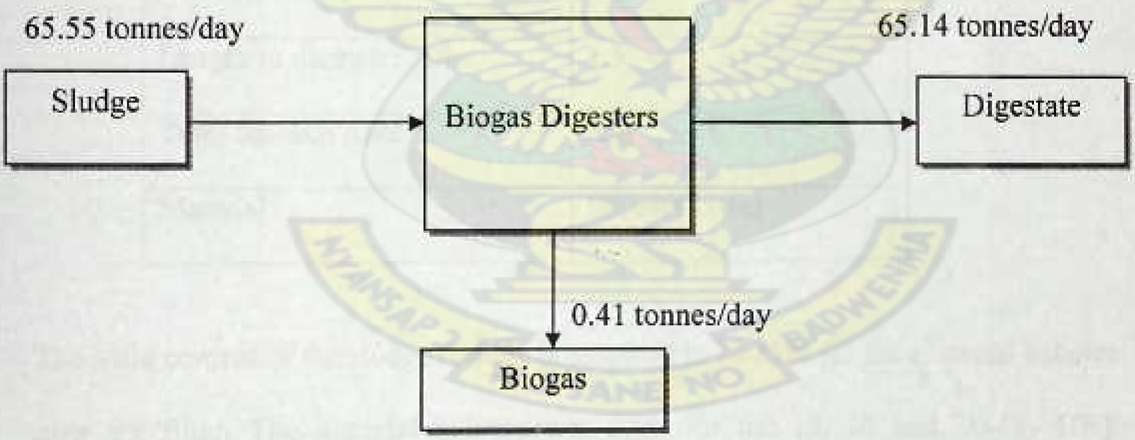

Figure 4-5: Daily mass flow for the 30 day HRT design

[13] Non-volatile organic solids

[14] 1 kg TVS is equivalent to 0.248kg biogas (ISAT and GATE, 1996) and at 40% conversion (BTC, 2007).

[15] 1 kg TVS is equivalent to 0.248kg biogas (ISAT and GATE, 1996) and at 80% conversion (BTC, 2007).

[16] 1 kg TVS is equivalent to 0.248kg biogas (ISAT and GATE, 1996) and at 94 % conversion (BTC, 2007).

4.6 POTENTIAL UTILIZATION OF BIOGAS DIGESTATE

The digestate from biogas digesters will be filtered and cake sludge obtained after drying the digestate can be sold as solid organic fertilizer to farmers whiles the filtrate is channeled back into the sludge pumping station through the sludge drying bed liquid channels (ISAT) and GATE, 1996).

A Rotary Drum Vacuum Filter (RDVF) will be used to separate sludge residue from the digestate coming from the digesters. The filter specifications obtained from using equations in appendix B-2 for this design operate under the conditions shown in table 4.3.

Table 4-3: Design and operating specification of the RDVF

Efficiency	98%
Vacuum pressure	55kPa
Drum filter speed	0.2 rev/min
Drum submergence	30%
Length to diameter ratio	1.5
Total Surface Area [17]	7 m^2
Material	Stainless steel

The solid content of the sludge residue is assumed to be 35% for the material balance over the filter. The material balance was done for the 10, 20 and 30-day HRT systems. Figure 4-6 shows the material balance on the RDVF for the 30-day HRT and table 4-4 shows the summary of the material balance for the 10 and 20-day HRT systems.

[17] The procedure for the sizing RDVF is shown in Appendix B-2

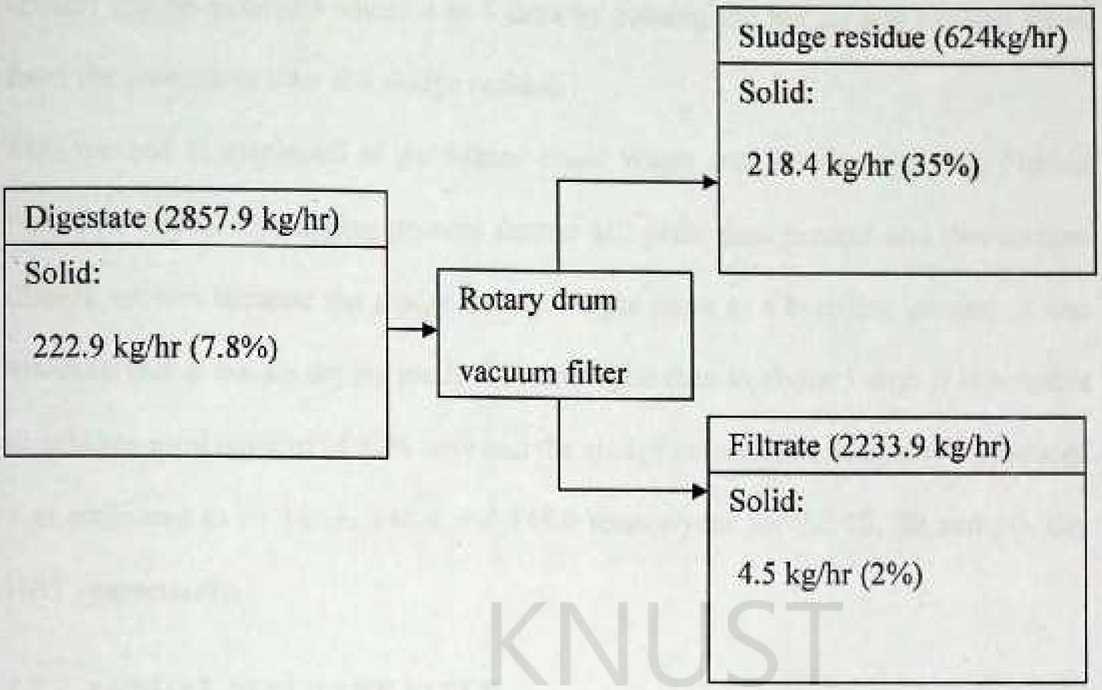

Figure 4-6: Material Balance on RDVF for 30 days HRT system

Table 4-4: Summary of material balance on the RDVF for 20 days and 10 days HRT systems

	10 days		20 days		30 days	
	Solid (kg/hr)	Liquid (kg/hr)	Solid (kg/hr)	Liquid (kg/hr)	Solid (kg/hr)	Liquid (kg/hr)
Digestate	224.7	2656.1	223.4	2640.4	222.9	2857.9
Sludge residue	220.2	408.9	218.9	406.5	218.4	624
Filtrate	4.5	2247.2	4.5	2233.9	4.5	2233.9

After separation, the sludge residue which has about 35% (solid content) is solar dried (30°C) for 30 days on a paved bed at a depth of no more than 46 cm (18 inches). Within 8 days of the start of drying, the sludge residue is turned over by labourers at least once every other day where the cake reaches a solid content of about 70%. However, this procedure can be modified and about 70% to 80% solid content can be achieved within 4 to 5 days by passing the hot air and exhaust gases from the generators over the sludge residue.

This method is employed at the Miami-Dade Water and Sewer Authority, Florida (USEPA, 1995). The drying process further kill pathogens present and discourages disease vectors because the sludge can no longer serve as a breeding ground. It was assumed that if hot air drying method is employed then in about 5 days it is possible to achieve solid content of 70% w/w and the sludge cake (Solid fertilizer)[18] produced was estimated to be 149.3, 148.4 and 148.0 tonnes/year for the 10, 20 and 30- day HRT respectively.

4.7 ANNUAL METHANE YIELD

The TVS obtained from the laboratory analysis represents the total volatile solids produced by the feedstock for digestion which formed the basis for the estimation of TVS available for each month of the year. The methane content of the biogas to be produced is assumed to about 65% (Elango *et al.*, 2006). The design of the digesters was based on feedstock maximum flowrate of 71.44m^3/day so as to accommodate all the flows throughout the year. The annual methane production was estimated on the assumption that 1kg TVS is equivalent to 0.310m^3 biogas[19]. It is assumed that there is 94%, 80% and 40 % biogas yield from sewage at 30, 20 and 10-day HRT respectively[20] (BTC, 2007).

[18] This can be sold as organic fertilizer

[19] 0.031 m^3 is the lower limit for biogas conversion from 1kg VS from sewage (ISAT and GATE, 1996 and Chae *et al.*,2007)

[20] This assumption was done based on research findings by Biogas Training Center (BTC) in China.

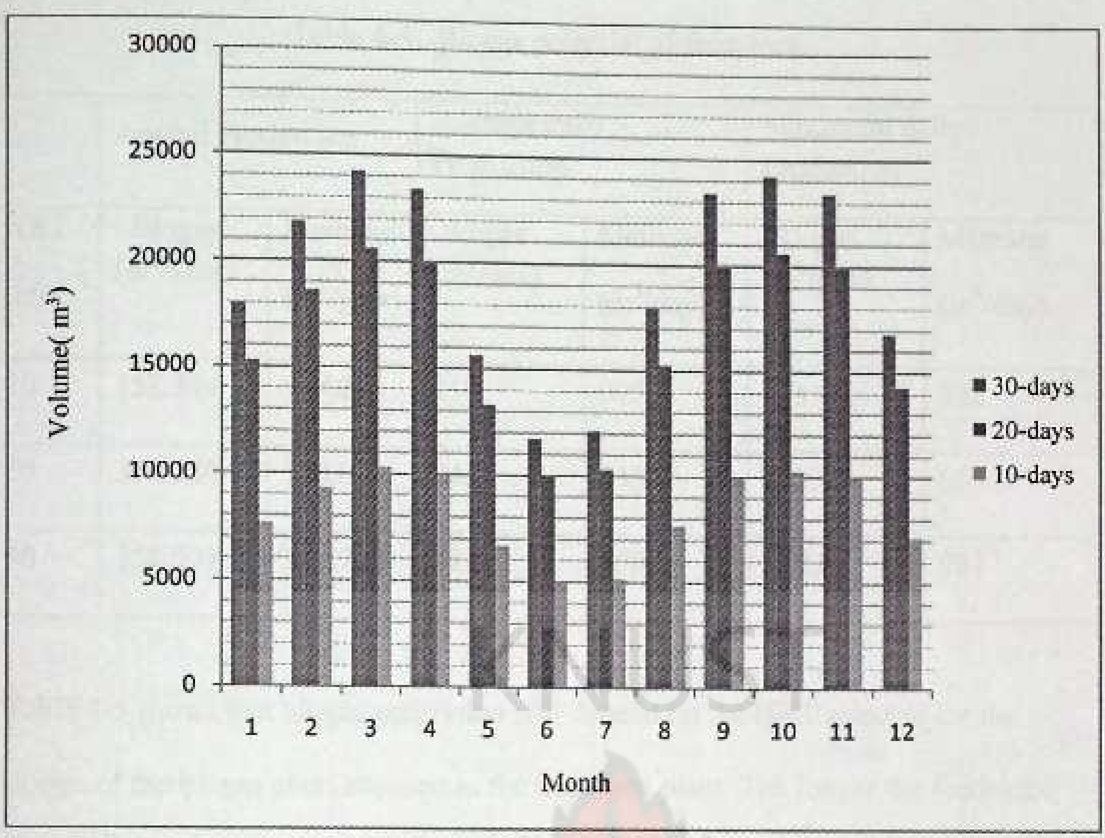

Figure 4-7: Monthly trend of methane generation

The trend of the monthly methane generation (figure 4-7) for the various HRT is an indication that the quantity of methane generated is a function of the population of the university for an academic year. Methane generation is expected to be a maximum in February, March, April, September, October and November when the university is in session and expected to be a minimum in May, June and July when the university is on long vacation. However, the maximum monthly methane generation was used in estimating the power potential of the feedstock. The daily average and maximum biogas production of the feedstock is shown in Table 4-5.

Table 4-5: Biogas potential of feedstock

	Annual Production		Average daily Production		Maximum daily Production	
HRT days	Biogas (m^3/year)	Methane (m^3/year)	Biogas (m^3/day)	Methane (m^3/day)	Biogas (m^3/day)	Methane (m^3/day)
10	152,344	99,024	417	275	511	332
20	304,689	198,049	845	543	1023	665
30	358,009	232,706	981	638	1202	781

Table 4-5 shows that biogas generation will depend on the HRT selected for the design of the biogas plant attached to the treatment plant. The longer the feedstock stays in the digesters at the same temperature of 28°C, the more biogas is produced.

4.8 BIOGAS PLANT SPECIFICATION

4.8.1 BIOGAS PLANT LAYOUT

The capacity of a single digester to take all the feedstock for a 10, 20 and 30-day retention time was estimated to be 800,1600 and 2400m^3 respectively including a design correction factor of 12%[21] . The Puxin digester system was selected for the design because it can be used to digest any solid concentration of any feedstock, the material of construction (concrete) gives it a long lifespan, durable internal gasholder (fibreglass) and the technology and expertise are readily available, experience in the field shows minimum maintenance is required and gas leakages are easily detected and repaired. The number of digesters for the 800, 1600 and 2400m^3 biogas plant capacities will require 8, 16 and 24 digesters respectively with each digester having

[21] This volume is based on the maximum daily flowrate of 71.44m^3/day.

a capacity of $100m^3$. The layout of the modified sewage treatment plant when the digesters are installed is shown in figure 4-6.The additional units attached to the treatment plant is outlined with the broken lines. It is appropriate for the digesters to be located just after the primary sedimentation tank where the sewage has high total solids suitable for the digestion process thereby reducing digester capacity.

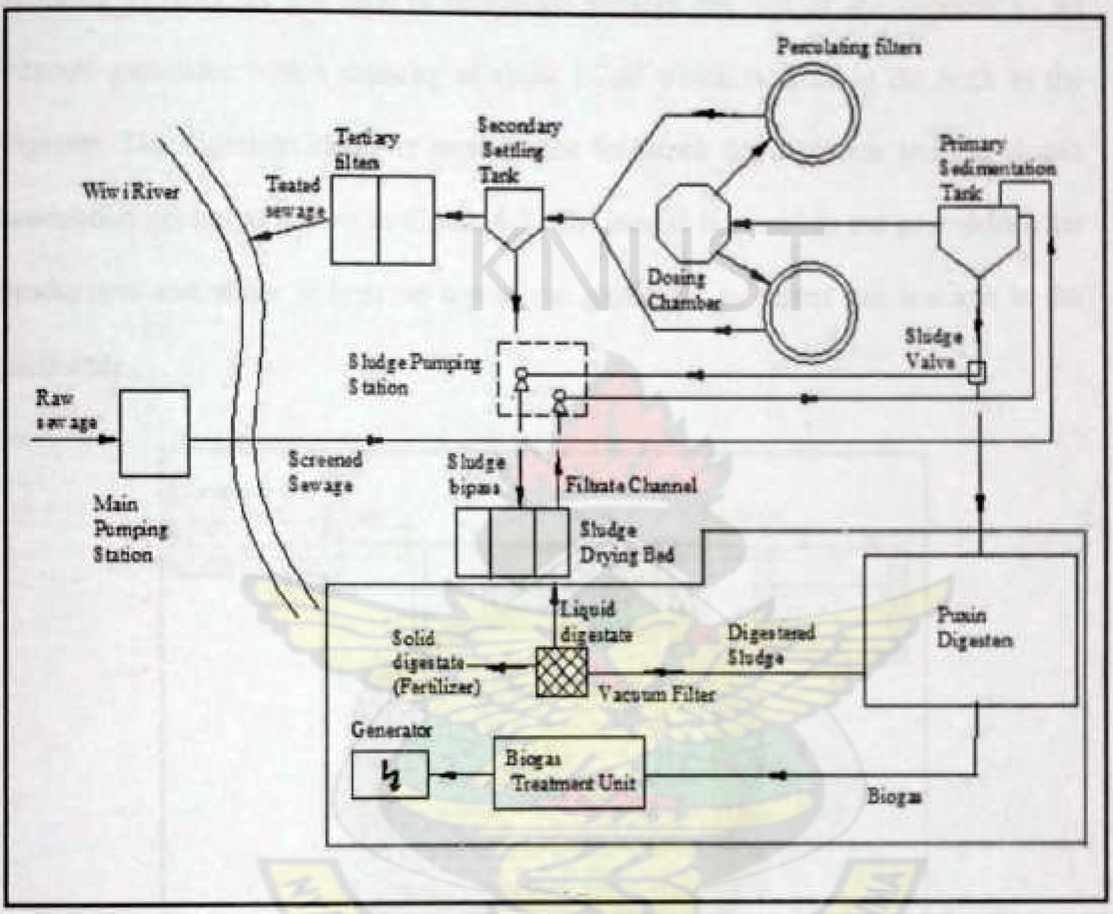

Figure 4-8: Modified Treatment Plant Layout with Puxin digesters installed

The biogas produced will go through the biogas treatment unit before it goes to the generator and the digested sludge will be sent to rotary drum vacuum filter for separation into filtrate and sludge residue. The filtrate is channelled back into the treatment process through the PST and the sludge residue is dried into cake sludge and sold as fertilizer.

4.8.2 PUXIN DIGESTER DESCRIPTION

The Puxin digester is basically designed to receive the feed through an inlet pipe and discharged through an outlet pipe. The inlet and outlet pipes are fixed such that as the feedstock enters the digester, the feedstock sets up convectional currents to ensure good mixing therefore, the Puxin digesters do not require any mixing or agitating devices. A gas pipe is connected through the top of the digester to an internal gasholder with a capacity of about 1.2m^3 which is fixed in the neck of the digester. The digestion chamber receives the feedstock for digestion and the biogas production occurs as shown in Figure 4-7. The biogas is stored in the gasholder after production and water is kept on top of the gasholder to detect gas leakage in the gasholder.

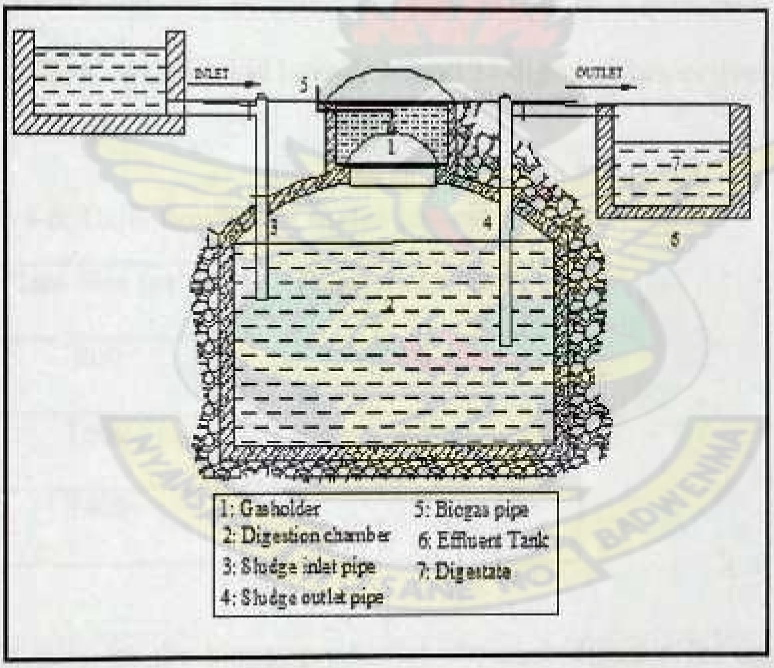

Figure 4-9: A typical Puxin digester

The auxiliary equipment for the system is gas pipes, valves, pressure gauge, gas flow meter, dehydrator, desulphurizer and pipe fittings. The processes involved in the construction of Puxin digesters are outlined as follows:

1. excavation for the main digester pit;
2. assembling of digester moulds to receive the concrete;
3. concrete pouring
4. curing concrete casting;
5. installation of the gasholder, excavation and laying of gas pipes and valves
6. installation of dehydrator, desulphurizer, flow meter and pressure gauge.

After complete installation, the system is then tested for possible gas leakages. A well constructed Puxin digester can have a lifespan of about 30 years.

The flowrate of the sewage expected to flow into each of the 100 m^3 digesters for the three systems are presented in table 4-6. This was estimated using the daily feedstock flowrate of 71.44m^3/day and the number of digesters for each plant size. The 800m^3, 1600m^3 and 2400m^3 systems will have 8, 16 and 24 digesters respectively

Table 4-6: Daily flowrate of sludge into each digester

Plant Size (m^3)	Flowrate (m^3/day)
800	9.0
1600	4.5
2400	3.0

The technical data for the biogas production for each digester for each system is shown in table 4-7.

Table 4-7:Technical data for biogas production for each Puxin digester

	HRT			
Parameters	10-day	20-day	30-day	units
Biogas production	22.0	42.6	50.1	m^3/day
Methane production	14.3	27.7	32.5	m^3/day
Biogas Production per day: Digester capacity (Specific biogas production)	0.22	0.43	0.5	$m^3/d/m^3$
Methane Production per day: Digester capacity (Specific methane production)	0.13	0.28	0.32	$m^3/d/m^3$
Biogas production[22]: m^3 Digester feed	7.3	14.2	16.7	m^3/m^3
Methane Production: m^3 Digester feed	4.7	9.2	10.8	m^3/m^3

The schematic diagram for these processes is shown in figure 4-10.

Figure 4-10: Schematic diagram of the Biogas treatment process

4.9 POTENTIAL POWER PRODUCTION

The biogas generated from the KNUST treatment plant will be used as source of fuel for an internal combustion engine to generate electricity. The estimation of the electricity potential of the biogas was made based on the assumptions in table 4-8.

[22] This is the volume (m^3) of biogas produced per unit feedstock (1 m^3) charged into each digester.

Table 4-8: Assumptions for estimating power potential of the sewage KNUST sewage treatment plant

Parameters	Values	References
Methane heating Value	37.78 MJ/m^3	Poliafico, 2007
Methane content	65%[23]	Elango *et al.*, 2006
Power engine yield (Efficiency)	29%	GTZ, 2007
Conversion factor	1 KWh= 3.6 MJ	Barelli *et al.*, 2007

4.9.1 GENSET ENGINE SELECTION

The pre-designed biogas engine operating on the principle of the SI engine was selected over other engines. Though the pre-designed SI engine can run on biogas, there should be extensive modification to the engine and its operation such as the carburetion, spark gap settings, spark timing and also its maintenance requirements. The efficiency of a modified SI engine is about 22% which is lower than that of the pre-design biogas engine of about 29%. The alterations come with maintenance problems.

Even though the efficiency of the biogas based CI engine is higher than that of the pre-designed biogas engine as a result of its high compression ratio, extensive modifications also need to be done before it can run on biogas because biogas has a low octane rating. Some of these modifications include replacement of the injector with a spark-plug, Carburetion and spark timing. It requires extensive maintenance. Air- fuel ratio adjustment system should also be fitted since biogas cannot run at high compression ratios. These alterations also come with maintenance problems. Fuel cells and micro turbines are more efficient when compared with biogas engines but they are not produced in commercial quantities at the moment, hence unlike pre-

[23] Methane content in biogas generated from human excreta (Elango *et al.*, 2006)

designed biogas engines, fuel cells and micro turbines are not readily available on the market.

4.9.2 ENGINE SPECIFICATION AND POWER ESTIMATION

Table 4-9 shows the detail specifications of the biogas generators selected for the power production.

Table 4-9: Biogas engine specifications for the biogas plants

power , (kW)	20	40	50
Requirement for Biogas	Dehydrated and should not contain oil		
	H_2S content: < 480 mg/m^3		
Starting Method	Electrical starting		
Cooling system	Forced air cooling		
Carburettor	Horizontal type, butterfly valve		
Gas Pressure (kPa)	80-160		
Compression ratio	11-14		
Rated voltage (V)	400		
Power factor	0.89		
Rated Current (A)	36	72	90
Max power (kW)	23	46	58
Rated power (kVA)	25	50	62
Dimension: Length (m) * width (m) * height (m)	1.5*0.75*1.25	2.4*0.9*1.5	2.4*0.9*1.5
Weight (kg)	552	2120	2102

The gas generation in March or October [24] was used in the estimation of the Potential power production (PPP) for the biogas plant so that throughout the year, the system

[24] Maximum methane generation occurs in March and October.

can utilise any amount of gas generated. The summary of the estimated power potential for the various HRTs are shown in the table 4-10.

Table 4-10: Potential power production of the biogas plant

HRT (days)	Biogas production (m^3/month)	Methane production (m^3/month)	PPP MWh/month (MWh/year)	PPP (at 29% engine efficiency, kW)	Total Energy production (MWh/year)
10	15851	10303	108 (1298)	40	376
20	31701	20606	216 (2595)	80	753
30	37249	24212	254 (3049)	100	884

Because of the variation in the monthly methane generation, two generators will be used for each plant. All two generators will be running during the period of maximum gas production and the single generator will run during the period of minimum gas production. The power produced will be fed into the 11 kV[25] bus bar at KNUST.

4.10 GHG EMISSION SAVINGS

4.10.1 BASE CASE EMISSION ESTIMATION

Under the UNEP-CDM baseline methodology, this project is eligible under Category III.D *Methane Recovery*[26]. The annual baseline emission was estimated on the assumption that in the absence of the biogas plant, 163,884kg[27] of methane will be released into the atmosphere annually by the sewage generated by the University.

[25] This is the standard voltage for urban high voltage distribution.
[26] A biogenic source of methane (Organic matter)
[27] This is the Methane released into the atmosphere annually by the sludge at KNUST sewage treatment plant. This was on the assumption that the Methane is not recovered.

Using the GWP of Methane of 21, then the annual CO_2 equivalent emission was estimated to be 3.44ktCO_2-e. Table 4-10 shows the equivalent monthly emissions.

Table 4-11: Monthly Base case for total emission from the sewage without a biogas Plant.

Month	Methane (kg)[28]	Base Case Emission (tCO_2/month)
January	12,648	266
February	15,396	323
March	17,051	358
April	16,497	346
May	11,001	231
June	8,252	173
July	8,522	179
August	12,648	266
September	16,497	346
October	17,051	358
November	16,497	346
December	11,824	248
Total	163,884	3,440

4.10.2 PROJECT CASE EMISSION AND REDUCTION ESTIMATION

The estimation of the emission reduction given in 4.1 was done for recoverable methane for the three HRTs used to generate electricity whereas the remaining was released into the atmosphere.

Emission reduction = baseline emission[29] - project case emission[30]……………..4.1

The total emissions and reductions for a 21 year credit period (7 years credit period and renewed twice) of the project is shown in figure 4-11.

[28] This is the total monthly Methane generated by the sludge at the treatment plant.

[29] This is the emission at treatment in the absence of the biogas plant.

[30] This emission is due to the escape of some Methane into the atmosphere even when the biogas plant is installed or the unrecoverable methane.

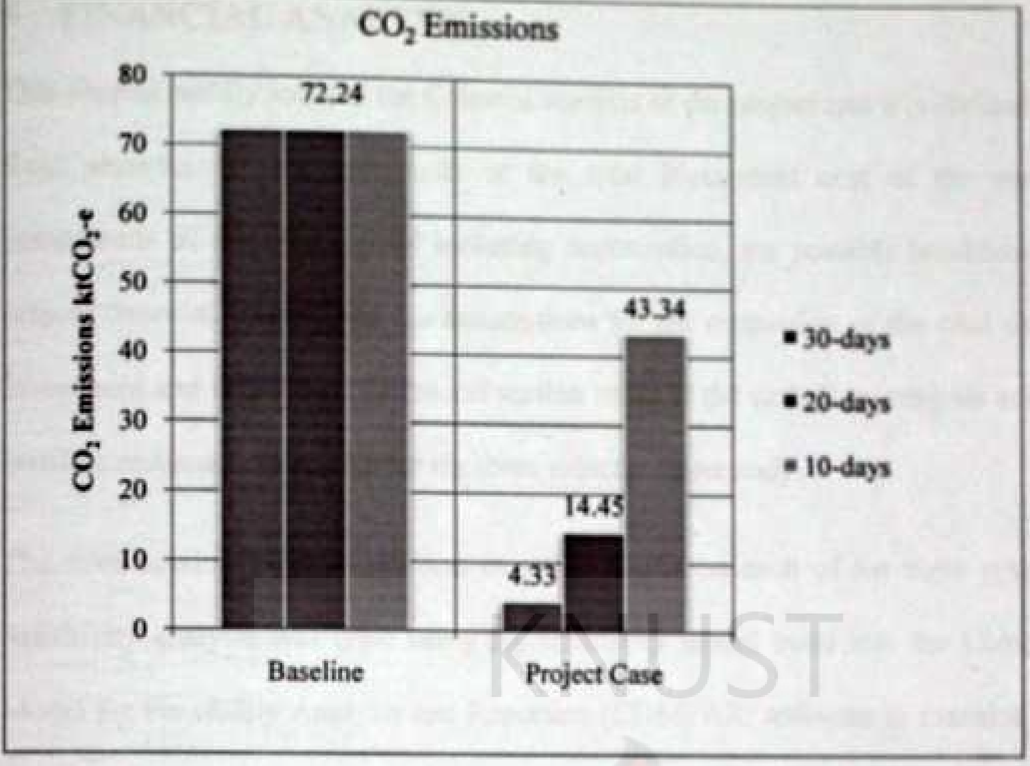

Figure 4-11: Total CO_2 emissions and reductions during 21 years credit period.

Figure 4-11 shows that the emission reduction for the 30-day HRT is higher than that of the 10-day and 20day HRT due to their low methane conversion rate. Table 4-12 shows the possible annual emission reduction that can be made from each of the biogas plants. The results in table 4-12 indicate that every 1 MWh of energy utilized corresponds to 3.66tCO_2-e saved.

Table 4-12: Potential annual CO_2 emission reduction

HRT (days)	Methane generation(kg)	Energy generation(MWh)	Emission reduction (tCO_2-e)
10	65556	376	1373
20	131109	753	2751
30	154051	884	3234

5 FINANCIAL ANALYSIS

This chapter mainly looks at the financial analysis of the project and it is divided into three sections. It first part looks at the total investment cost of the various components of the biogas plant including depreciation, the possible breakdown of project financial sources and the assumptions for the estimation of the total capital investment and taxation. The second section looks at the cash flow analysis and the possible revenues expected from the three systems understudy.

The third session looks at the cost benefit analysis on each of the three systems. Sensitivity analysis was done using the sensitivity model build into the Computer Model for Feasibility Analysis and Reporting (COMFAR) software to examine how changing the key financial variables will impact the project's overall returns. The variables considered were the selling price of electricity, fertilizer and CER credits[31]. Also, grant contribution, fixed investment cost and discount rate were also considered in the sensitivity analysis.

5.1 PROCEEDURE FOR FINACIAL ANALYSIS

The financial analysis procedure was guided by the COMFAR requirements for evaluating investment analysis. The total investment cost for the three designs were estimated[32]. The fixed investment cost comprise of site preparation and development, civil works, structure and building, plant machinery and equipment, auxiliary and service plant equipment, environment and contingency.

The pre-production expenditures comprising the cost of project management and organization and detailed engineering was estimated. The annual production cost of

[31] This was considered because of the unpredictable price quotations for CER credits on the Carbon Market.
[32] Beta construction and consultancy ltd is local company into the construction of biogas plants in Ghana.

running the plant was also estimated. The estimated revenue from the project was expected to come from the sale of power, effluent as fertilizer and carbon credits from the biogas plant.

The components of the total investment cost were fed into the COMFAR and the results generated were used to determine the cost benefit analysis of the three projects to establish which of them is financially viable. Some of the Graphic User Interfaces (GUIs) provided by COMFAR are shown appendix B-3.

5.2 INVESTMENT ANALYSIS

The analysis was based on the investments involved in the construction of three systems understudy namely; 8, 16 and 24 Puxin digester systems with each digester having a capacity of $100m^3$. The financial viability of the project was analysed based on the results generated by the Computer Model for Feasibility Analysis and Reporting (COMFAR) software. The fixed investment cost components analysed by COMFAR comprise of site preparation and development, civil works, auxiliary and service plant equipment, environment, pre-production expenditure and contingencies. The cash inflow from the project which was assumed to be generated from the sale of power generated, possible sale of digestate as fertilizer and carbon credits. The cash flows were discounted over a period of 30 years[33] at a rate of 20%[34].

5.3 TOTAL INVESTMENT COST

Total investment cost comprises fixed investment cost, pre-production expenditures and total net working capital. Pre-production expenditures component is the only one that is affected by the interest on loan repayment during the construction period.

[33] The assumed life of the project
[34] Ghana's inflation rate for January 2009 was 19.86 (Ghana Statistical Service)

5.3.1 FIXED INVESTMENT COST

The purchased equipment for the Puxin digester system includes glass fibre reinforced plastic gas holders , generators , vacuum filter, the materials for the construction of the digesters which consist of stone chippings, sand, cement, reinforcing bars. The other components of the fixed investment costs include site preparation and development, civil works, structure and building, auxiliary and service plant equipment, environmental protection, pre-production expenditure and contingency.

a. Site preparation and Development

The biogas digesters will be located on the premises of the sewage treatment plant at KNUST hence the cost for land purchase will be omitted in the plant cost estimation. The cost of site preparation consisting of site clearance and excavation were taken to be GH¢ 0.40/m^2 and GH¢9/m^3 respectively[35].

The total land area for the 24 digesters is [36]1030m^2, 16 digesters will require 680m^2 and 8 digesters will also require 442 m^2 if any of then is selected. Total area to be cleared is twice the estimated area so as to provide space for permanent and temporary structures, and excavated soil. Each digester will require an excavated man-hole of about 130m^3 for construction. The estimated cost of site preparation and development and other improvements is presented in table 5-1. Other improvements cost was estimated to be about 20% of the site clearing and excavation (Peters and Timmerhaus, 1991).

[35] This is cost at normal ground conditions including back filling, etc. However, on rocky or soft ground conditions the cost will be higher.
[36] This is made up 7m diameter for the each digester and 0.6m for average man to move around the digester.

Table 5-1: Estimated cost of site preparation and development[37]

Plant Size (m^3)	Total plant area (m^2)	Cost of land clearing (GH¢)	Excavation cost (GH¢)	Other improvements cost (GH¢)	Total Cost (GH¢)
800	442	200.00	9,400.00	2,000.00	**11,600.00**
1600	680	300.00	18,800.00	3,900.00	**23,000.00**
2400	1030	400.00	30,500.00	6,200.00	**37,100.00**

b. Civil Works, Structure and Building

The cost of civil works, structure and building for a new unit at the existing plant was estimated to be about 1% (Peters *et al.*, 1991) of the plant and equipment cost of 259,000.00, 495,000.00 and 701,000.00 for the $800m^3$, $1600m^3$ and $2400m^3$ systems respectively. This is because the inclusion of a biogas plant at the sewage treatment plant will require additional structures such as to house the generators, spare parts, etc. The cost estimated for the three systems under study are presented in table 5-2.

Table 5-2: Estimated cost for civil works, structure and building

Plant size (m^3)	Estimated Cost (GH¢)
800	2,600.00
1600	5,00.00
2400	7,000.00

[37] Beta construction company limited

c. **Plant Machinery and Equipment**

The plant machinery and equipment for this plant comprise of Puxin biogas digesters[38], biogas generators and RDVF[39]. Each of the 100 m^3 Puxin biogas digester was estimated to cost GH¢ 22,000.00[40] and the RDVF was also estimated to cost GH¢ 33,000.00[41]. The cost of the biogas generators are presented in table 5-3.

Table 5-3: Estimated cost of biogas generators

Biogas Generator (KW)	Cost (GH¢)
20	25,000.00
40	55,000.00
50	70,000.00

The 800m^3 system will require two of the 20kW generator, the 1600m^3 system will require two of the 40kW generator and the 2400m^3 system will also require two of the 50kW generator. Table 5-4 shows the total cost plant machinery and equipment for the three systems understudy.

Table 5-4: Total cost of plant machinery and equipment for the three systems

Plant Size (m^3)	800	1600	2400
Digesters (GH¢)	176,000.00	352,000.00	528,000.00
RDVF (GH¢)	33,000.00	33,000.00	33,000.00
Biogas Generator (GH¢)	50,000.00	110,000.00	140,000.00
Total Cost (GH¢)	**259,000.00**	**495,000.00**	**701,000.00**

[38] Each digester has a 1.2m^3 internal gasholder.
[39] The design and operation specifications of the RDVF are shown in table 4-3
[40] This is a quotation from Beta Construction Ltd (Local).
[41] This quotation was given by RPA Technologies (foreign) based on the specifications in table 4-3.

d. Auxiliary and service plant equipment

On the premises of the KNUST treatment plant there is a building which has an office, laboratory, store room, dressing room, toilet and shower. There are also service facilities including electricity and water supply already installed on the premises of the treatment plant. Hence the auxiliary and service plant required will comprise of the auxiliary components associated with the plant. Table 5-5 shows the unit cost of each auxiliary equipment and table 5-6 shows the number of each equipment for each system.

Table 5-5: Unit cost of auxiliary equipment

Auxiliary equipment	Unit Cost (GH¢)
Desulphurizers	750.00
Dehydrators	750.00
Gas flow meters	150.00
Pressure Regulators	150.00

The gas pipe of diameter 19mm or 25mm selected for design was estimated to cost GH¢6/lm[42].

Table 5-6: Number of auxiliary components required for each system[43]

Plant Size (m3)	800	1600	2400
Desulphurizers	4	8	12
Dehydrators	4	8	12
Gas flow meters	1	1	1
Pressure Regulators	1	1	1
Length of Pipe (m)	50	100	200
Total Cost (GH¢)	**6,600.00**	**12,900.00**	**19,500.00**

[42] lm means linear meter. This is the trade name for flexible gas pipes. However, the unit for the length of the pipe is meter (m).
[43] This was obtained from Beta Construction Ltd .

e. Environmental Protection

The anaerobic digestion is primarily a waste treatment process. However, in the process the gas generate is a source of renewable energy which can be used for heating, cooking and generation of electricity. The effluent after digestion has low amounts of pathogens and it is also a source of fertilizer. The major environmental problem associated with biogas is the fact that biogas is a fuel and can easily cause fire outbreaks. In view of this, there is a need to have a fire protection system on the biogas generation site. The total cost of fire safety equipment for the 800m^3, 1600m^3 and 2400m^3 are 4500,00, 4,600.00 and 6,300.00 respectively. The detailed number and cost for fire safety equipment required for each of the three systems under study are shown in appendix C-3.

f. Contingencies

A contingency factor is usually included in the estimation of capital investment to compensate for unpredictable events, such as storms, floods, price changes, small design changes, errors in estimation, and other unforeseen expenses. To insure that this analysis was not overly optimistic, contingency cost of 10% of the plant machinery and equipment cost was used. The contingencies for three systems are presented in table 5-7

Table 5-7: Contingencies for the three systems

Plant Size (m3)	Contingencies (GH¢)
800	25,900.00
1600	49,500.00
2400	70,100.00

The summary of the components of the fixed investment costs estimates for the biogas plant are shown in table 5-8.

Table 5-8: A summary of the Total fixed investment cost for the three systems.

Components of Fixed Investment Costs	Cost Estimates (GH¢)		
	$800m^3$	$1600m^3$	$2400m^3$
a. Site Preparation and Development (GH¢)	11,600.00	23,000.00	37,100.00
b. Civil works, structures and building (GH¢)	2,600.00	5,000.00	7,000.00
c. Plant Machinery and Equipment (GH¢)	259,000.00	495,000.00	701,000.00
d. Auxiliary and service plant equipment (GH¢)	6,600.00	12,900.00	19,500.00
e. Environmental Protection (GH¢)	4,500.00	4,600.00	6,300.00
f. Contingencies (GH¢)	25,900.00	49,500.00	70,100.00
TOTAL	**310,200.00**	**590,000.00**	**841,000.00**

5.3.2 PRE-PRODUTION EXPENDITURES

The pre-production expenditure in the project cost estimation comprise of project management and organization, detailed engineering, contracting and contingencies. The typical contractor's fee is taken to be 4%[44] of the plant machinery and equipment cost. Table 5-9 shows the summary of the pre-production expenditures for the construction of the three main plant capacities in terms of the total plant size[45].

[44] This is the lower limit in the range 4%- 8% due to the magnitude of the project

[45] These costs were estimated based on the current pre-production expenditures in consultation with Beta Construction Ltd.

Table 5-9: Pre-production expenditures (net of interest) for the three plants[46]

Components of Pre- production expenditure	Cost Estimates (GH¢)		
	$800m^3$	$1600m^3$	$2400m^3$
Project Management, Organization	9,700.00	18,400.00	25,900.00
Detailed Engineering, Contracting	12,500.00	23,500.00	32,800.00
Total	**22,200.00**	**41,900.00**	**58,700.00**

5.3.3 INVESTMENT INCENTIVES AND DEPRECIATION

Current corporate tax rate in Ghana is generally 25 percent in any sector of the economy (GIPC, 2009). This rate will drop when the appropriate incentive program listed below is applied.

a. Location Incentives (Tax Rebate)

There is a provision for an income tax rebate based on the location of a project, According to the Ghana Investment Promotion Centre Act, 1994; manufacturing industries located in regional capitals except the national capital enjoy a 25 percent tax rebate. All other manufacturing industries located outside regional capitals enjoy 50 percent tax rebate (GIPC, 2009)[47]. In this respect, locating the biogas plant in KNUST in Kumasi will attract a tax rebate of 25%. The tax rate for this project will thus be 0.75 x 25 percent = 18.75%.

b. Depreciation Rate

Linear to zero depreciation method is assumed for the lifetime of the project which is 30 years. The annual depreciation rate assumed for the assets are presented table 5-10.

[46] The details are in appendix C (Table C-1)
[47] http://www.gipc.org.gh/

Table 5-10: Depreciation rate for assets

Assets	Depreciation Rate, %
Civil works, Structures and Buildings	3
Plant Machinery and Equipment	10
Auxiliary and Service Pant Equipment	10
Fire Safety Equipment	10

(Source: Peters and Timmerhaus, 1991)

5.3.4 ANNUAL PRODUCTION COST

The production cost for the biogas to electricity generation and the fertilizer production from the biogas plant was based on annual operating cost. The details of the annual production cost are presented in appendix C-2, but the summary is presented in table 5-11.

This was used to determine the working capital for each capacity assuming the coefficient of turnover (Coto) for all the items in the working capital inventory to be 1[48] where the minimum days coverage (Mdc) equals 360 days.

[48] The Mdc is the number of days in each cycle. The cycle is the number times transactions (cash flow in and out) are done in a year. In this analysis the cycle is 1(in every normal accounting year-360 days per annum).

Table 5-11: Summary of total annual production cost for the various plant sizes

	Annual Production cost (GH¢)[49]		
Capacity	800m^3	1600m^3	2400m^3
Electricity production	7,200.00	14,700.00	21,400.00
Fertilizer production	14,020.00	14,100.00	14,100.00
Depreciation	780.00	1,975.00	2,760.00
Total	**22,000.00**	**29,035.00**	**36,160.00**

The total investment cost for each of the three systems is presented in table 5-12.

Table 5-12: Summary of total Investment cost of each project

Capacity	800m^3	1600m^3	2400m^3
Fixed Investment Cost (GH¢)	310,200.00	590,000.00	841,000.00
Pre-production Expenditures (GH¢)[50]	22,200.00	41,900.00	58,700.00
Total Net Working Capital (GH¢)[51]	62,460.00	84,460.00	104,400.00
Total Investment Cost (GH¢)	**394,860.00**	**716,360.00**	**1,004,100.00**

5.3.5 SOURCE OF FUNDING

The project will be financed by both an equity contribution of 10 % and a long-term debt of 90 %. The banks contacted for financing this size project give loans at interest rate of about 27% (Assuming a 10–year loan repayment) and charge a

[49] These values are the annual production cost excluding loan repayment and depreciation. It comprise of factory cost and operating cost.
[50] These values exclude loan repayment in the first year of production. However, the interest on Loan will increase these values.
[51] This is the difference between current assets and current liabilities.

processing fee between 1 - 3%. However, 1% is used due to large sum of money involved. The breakdown of the possible funding sources is presented in Table 5-13.

Table 5-13: Projected equity breakdown of funding

Capacity		800m^3	1600m3	2400m^3
Equity shares (GH¢)	10%	39,486.00	71,636.00	100,410.00
Long-term Loan (GH¢)	90%	355,374.00	644,724.00	903,690.00
Total Investment (GH¢)		**394,860.00**	**716,636.00**	**1,004,100.00**

5.4 CASH FLOW ANALYSIS

Though the electricity consumption and the fertilizer sale can be priced easily, the same cannot be said for the sanitation and health benefits accrued. Also, as this project meets the Small Scale CDM (SSC) project requirements, CERs credits can be sold on the global carbon market to offset part of the running costs of the project. In the financial analysis, the costs and benefits during the life of the plant were established. The economic life of the plant was taken as 30 years which is typical for biogas plants. The three systems will require different construction periods (Table 5-16) and commissioned on January 2011[52]. Thus, the plants will run from January, 2011 to December, 2040 (30 years of production).

Table 5-14: Duration of construction for the Biogas Plant

Pant Size (m^3)	Duration of construction (Months)[53]
800	4
1600	5
2400	6

[52] The COMFAR software in its planning horizon section requires specific dates for the financial analysis. However, it can always be changed to suit the current economic indicators of the country, such as the inflation rate (discount rate) to evaluate the NPV of a project.
[53] This includes mobilization of equipment and personnel, construction of digesters, testing for gas leakages, etc. This was provided by Beta Construction Ltd..

All future cash flow will be discounted at a rate of 20%[54] per annum to make them equivalent to the present value expressed as the Net Present Value (NPV). This discounted net cash flow provided a criterion for measuring the profitability of the project.

5.5 REVENUES FROM PROJECT

It is assumed that the power produced from the biogas plant will be sold to KNUST from the start of the project. KNUST is in the special load tariff (SLT), Medium voltage (MV) category of electricity power consumers in Ghana. The current PURC approved tariffs for this category effective from 1st November 2007 is presented in table 5-15.

Assuming a PF of 0.89, the maximum Real Power (RP) that can supplied to the KNUST network, is given by

$$\mathbf{AP} = \frac{\mathbf{RP}}{\mathbf{PF}} \quad \text{.................................} \quad 5.1$$

RP: Real power (kW)

AP: Apparent power (kVA)

For the 800 m^3 system, the RP is 40 kW, therefore the AP power was calculated as 45 kVA, using equation 5.1. The charge for the demand is GH¢9.00/ kVA/ month and the other charges for the electricity revenue are shown in Table 5-15. The calculation was done for the twelve (12) months. Similar calculations were done for the 1600m^3 and 2400m^3 systems.

[54] Ghana's inflation rate for January 2009 was 19.86% (Ghana Statistical Service). The inflation rate can be taken as the discount rate since it is a true reflection of time value of money.

Table 5-15: Monthly consumption charges for SLTs (MV)

Types of Charges	Unit Charge (GH¢)
Energy charge (kWh)	0.0905
Capacity charge (kVA)	9.00
Service Charge[55]	12.50

(Source: PURC,2007)

The total expected revenue the power production for three systems are presented table 5-16.

Table 5-16: Annual revenue from electricity from the three systems

Plant Size (m^3)	Annual Revenue from Electricity (GH¢)[56]
800	39, 028.80
1600	78,016.50
2400	92,248.00

The fertilizer produced from the filtered digestate can also be sold to farmers at GH¢5.00 per 25 kg[57].

The Annual global price quotations for the CER credits are unpredictable. The World Bank (2007) quoted about US\$10/tCO_2-e (with the vast majority of transactions in the range of US\$8-14 [58]or €6-11). Since it is difficult to predict the prices, US\$10/tCO_2-e was used for this analysis.

[55] This is charged irrespective of the energy consumed.
[56] This is on the assumption that all the energy produced is fed into the grid.
[57] Wienco Company Ltd, the largest fertilizer dealer quoted this price for farmers in Ghana for 2008.

5.6 COST BENEFIT ANALYSIS

The annual production and sales revenue from electricity, fertilizer and possible sale of CER credits for three systems under study are presented in table 5-17 and table 5-18 respectively.

Table 5-17: Annual production for three systems

Products	$800m^3$	$1600m^3$	$2400m^3$
Electricity (MWh)	376	753	884
Fertilizer (tonnes)	149.3	148.4	148.0
CER credits (tCO_2-e)	1317	2751	3234

Table 5-18 Annual revenue from sale of products for three systems

Products	$800m^3$	$1600m^3$	2400^3
	Annual revenue (GH¢)		
Electricity	48,786.00	78,010.80	91,759.20
Fertilizer	37,325.00	29,680.00	26,600.00
CER credits	13,761.60	20,707.50	32,354.40
Gross sales revenue	**99,872.60**	**128,398.30**	**153,713.60**
Subsidy[59]	17,259.70	26,960.20	30,377.30
Less Sale Tax	17,222.20	26,922.70	30,339.80
Annual Sales Revenue	**99,910.10**	**155,358.20**	**184,090.90**

[59] The effective ssubsidy and less sales tax were evaluated by the COMFAR software when fed with the cooperated tax incentives by virtue of the location of the plant.

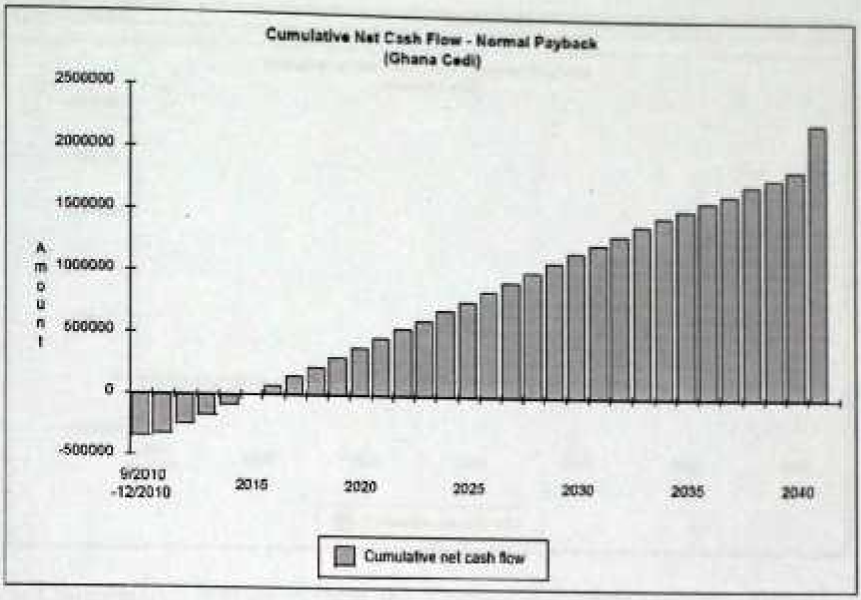

Figure 5-1: Cumulative Net cash flow for Normal Payback for the 800m^3 system

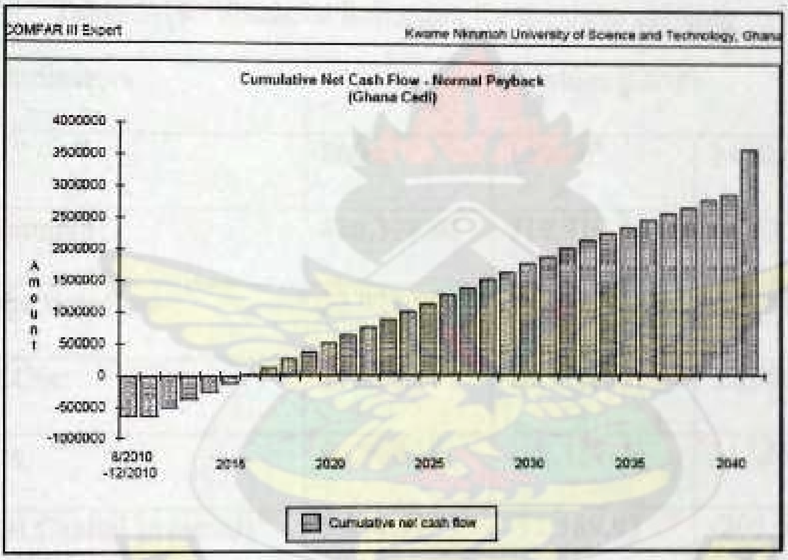

Figure 5-2: Cumulative Net cash flow for Normal Payback for the 1600m^3 system

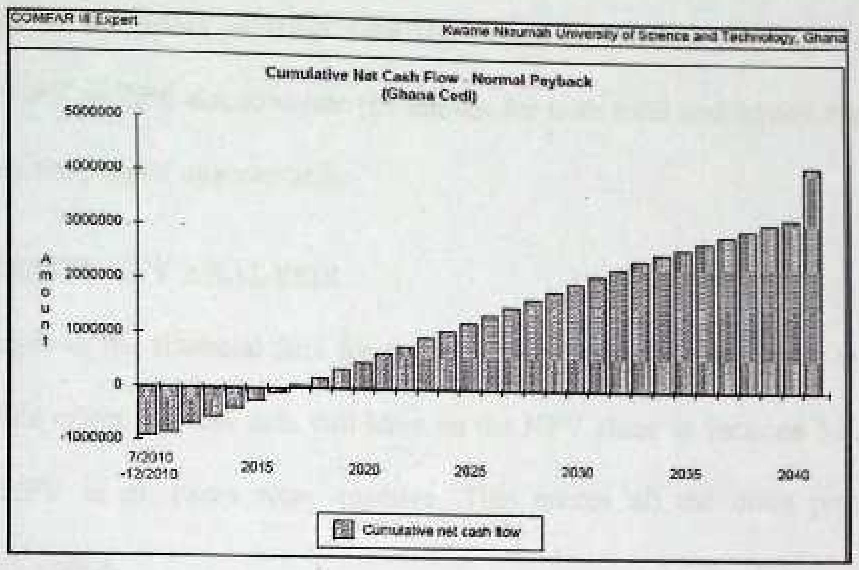

Figure 5-3: Cumulative Net cash flow for Normal Payback for the 2400m^3 system

Table 5-19: Financial Indicators for the three systems

Financial Indicators	Values (GH¢)		
	800m^3	1600m^3	2400m^3
Total Investment	430,397.40	719,910.00	1,093,262.78
Total Production Cost	32,921.97	50,182.32	66,451.38
Operating Cost	21,220.00	28,720.00	35,500.00
Net income	66,969.38	105,157.43	117,620.77
NPV (Total Capital Invested)[60]	5,076.72	-92,589.93	-205,688.85
NPV (Equity Invested)	-104,519.17	-302.904.19	-513,164.73

Normal payback for the total investment occurs after 5, 6 and 7 years for the 800m^3, 1600m^3 and 2400m^3 respectively. The cash flow is shown in figure 5-2. The financial indicators in table 5-24 show that the 20-days HRT system gives negative NPV at 20% discount rate per annum for both total and equity capital and that makes the project unacceptable.

[60] Net present values are discounted to July 2010.

The financial indicators in table 5-26 show that the 30-day HRT system gives negative NPV at 20% discount rate per annum for both total and equity capital and that makes the project unacceptable.

5.7 SENSITIVITY ANALYSIS

The changes in the financial data for the sensitivity analysis were made to analyse the possible effect the new data will have on the NPV since in sections 5.5, 5.6 and 5.7 the NPV in all cases were negative. This makes all the three projects not financially viable.

Table 5-20 shows the changes that were made to the financial data through the sensitivity model of the COMFAR software.

Table 5-20: Changes to the financial data for the Sensitivity analysis

Component	Percentage change (%)[61]
Price of Fertilizer	+20
Price of Electricity[62]	+40
Price of CER credit[63]	+10
Grant contribution	10
Discount rate[64]	+5

Figure 5-4, figure 5-5 and figure 5-6 shows the sensitivity of IRR on the some parameters of the three possible investments. However, the results in figure 5-2, figure 5-3 and figure 5-4 are only indicative. The sensitivity model was preferred as

[61] It is permissible to consider only the positive percentage change in the sensitivity analysis when the negative in the percentage change for a particular data will still give a negative NPV.
[62] The average increase in energy charge in electricity tariff from 1998 to 2007 is 40%.
[63] World Bank prices for 2007 are in the range of US$8-14. US$ 11 was chosen for scenario analysis
[64] Ghana's inflation rate increased by about 5% from January, 2008 to January, 2009.

it represented true sensitivity and provided interaction with other parameters. The effect of sensitivity of IRR on the sales revenue, increase in fixed assets and operating cost in figure 5-4 for the $800m^3$ system.

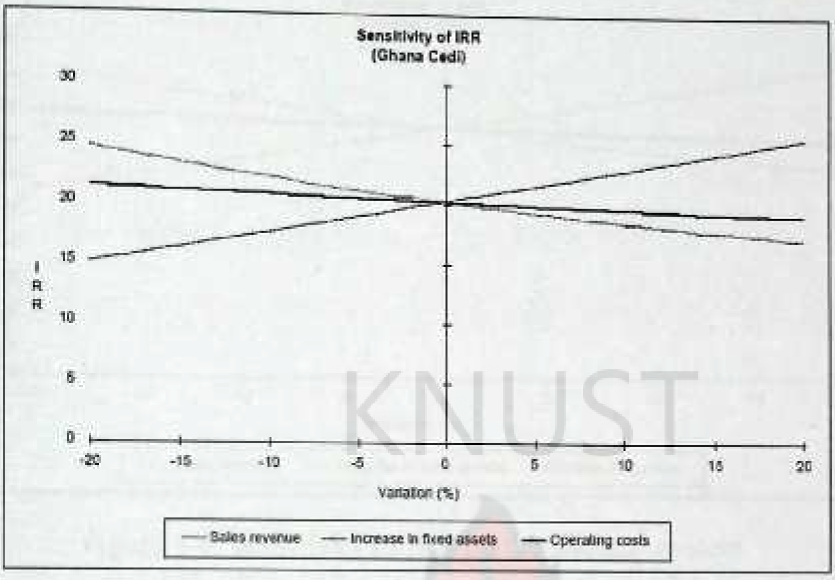

Figure 5-4: Sensitivity of IRR on the $800m^3$ system

The effect of sensitivity of IRR on the sales revenue, increase in fixed assets and operating cost in figure 5-5 for the $1600m^3$ system.

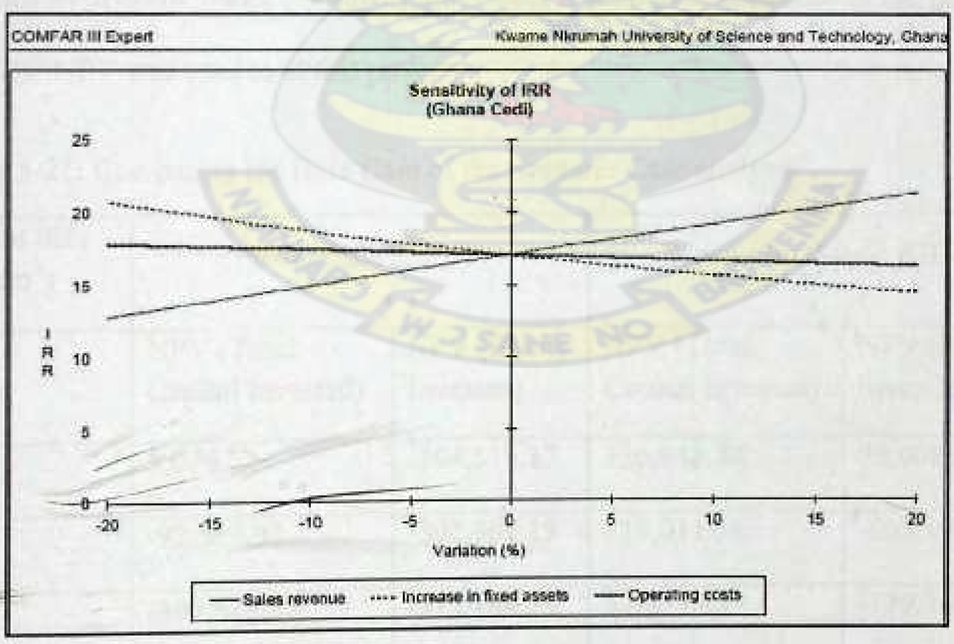

Figure 5-5: Sensitivity of IRR on the $1600m^3$ system

The effect of sensitivity of IRR on the sales revenue, increase in fixed assets and operating cost in figure 5-6 for the 2400m^3 system.

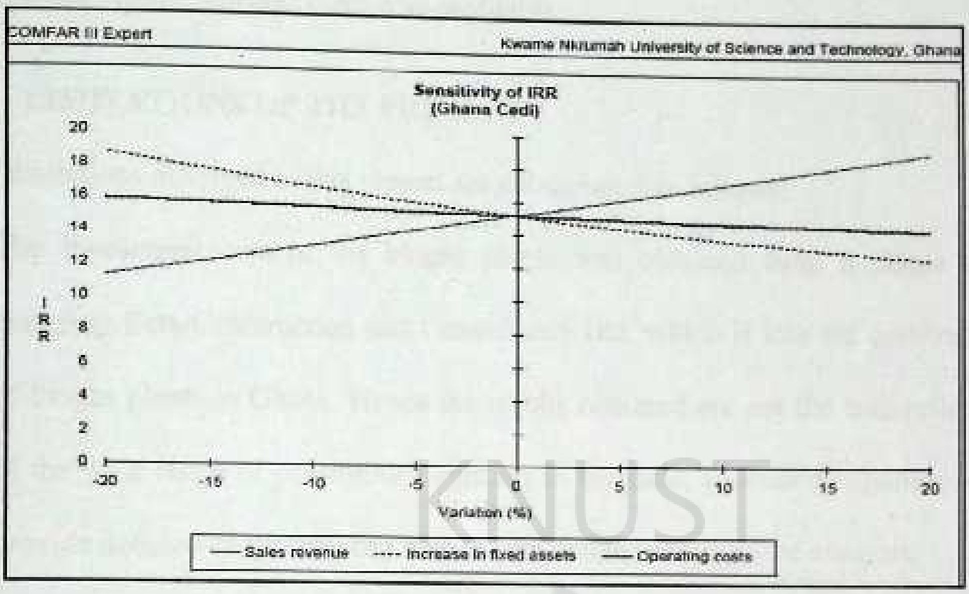

Figure 5-6: Sensitivity of IRR on the 2400m^3 system

Table 5-21 shows the results of some of the key parameters for determining the financial viability of the project after sensitivity analysis has been performed. This is because an investor wants to know if the project is profitable at the end of the project life. The NPV was used to in this project.

Table 5-21: Comparing the Base Case of the Scenario Case analysis

Plant Size (m^3)	Base Case (GH¢)		Sensitivity Case[65] (GH¢)	
	NPV (Total Capital Invested)	NPV (Equity Invested)	NPV (Total Capital Invested)	NPV (Equity Invested)
800	5,076.72	-104,519.17	136,348.84	76,008.02
1600	-92,589.93	-302.904.19	119,011.56	-663.19
2400	-205,688.85	-513,164.73	52,353.85	-129,296.67

[65] The results of the sensitivity analysis was obtained based on the assumptions presented in Table 5-20

The financial indicators for the 800m^3 clearly show that it is profitable with respect to the NPV. However, the NPV values on the equity investment for both the 1600m^3 and 2400m^3 systems makes them non-profitable.

5.8 LIMITATIONS OF THE PROJECT

The limitations observed in this project are enumerated as follows;

1. The investment cost of the biogas plants was obtained from a single local company-Beta Construction and Consultancy Ltd, which is into the construction of biogas plants in Ghana. Hence the results obtained are not the true reflection of the wide range of possibilities existing in the field. If other companies could provide detailed costs, they can help to broaden the scope of the analysis.
2. The Puxin digester was selected for this project. However, other biogas digesters such as Upflow Anaerobic Sludge Blanket (UASB) and CSTR[66] can be applied. It will be useful in future to study these types of digestors as they may provide different results.
3. A single set of parameters was selected for the sensitivity analysis. Hence the results obtained would apply if all the parameters in that set are implemented. Future analysis should explore a wider set of parameters in a more extensive sensitivity analysis.

[66] There are no local companies that are into the of design CSTR and UASB digesters.

6 CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

The implementation of any of the three biogas plants will require substantial amount of capital for the investment; the $800m^3$ will require GH¢430,397.40, the $1600m^3$ will require GH¢799,288.90 and the $2400m^3$ will also require GH¢1,093,262.78. The NPV on the total capital estimated were all negative which makes any of the projects unacceptable.

The sensitivity analysis conducted for all the plants still gave negative NPV (Equity) for all cases considered, but the $800m^3$ capacity biogas plant gave an NPV of GH¢52,816.56. On the basis of financial acceptability of the project, the three projects should not be considered unless the by-products and funding from grants are considered as assumed during the sensitivity analysis for the $800m^3$ capacity biogas plant holds.

Even though the returns on the sale of the three products from the plants were easily quantified, the same cannot be said of the impact on the environment. The sludge will be treated substantially after it is digested and usage or direct disposal into the environment will reduce the risk of exposure to pathogens. The $2400m^3$ capacity biogas plant is not financially viable but the pathogens levels will reduce drastically and the $800m^3$ capacity biogas plant is financially viable (even at the sensitivity analysis assumptions) among the three but the pathogen levels will still be substantial. Hence on the basis of environmental impact and financial viability, the $1600m^3$ capacity biogas plant should be considered and could meet both criteria and therefore can be implemented.

6.2 RECOMMENDATIONS

In the estimation of the biogas potential of the feedstock from the KNUST sewage treatment plant, the TVS values determined in the laboratory was used based on an equivalent volume of biogas from such a system found in literature. Even though it is from a reliable source, there maybe some unknown factors so it is however recommended that any future study should include a construction of a miniature digester to generate the biogas and subsequently measure the volume generated. At the same time the population of pathogens should be measured daily to ascertain the levels in the digestate.

This study looked at the Puxin digester technology for the biogas plant at the sewage treatment plant. However, it is recommended that other technologies based on other parameters apart from availability of expertise and technology should also be considered. Example of such a parameter is the available space for the biogas plant. A typical digester to be considered is the vertical mixing digester which takes very little space. It is also recommended that the choice of 12 and 15-day HRT should also be considered in future studies as they are also used by biogas companies in Ghana to size either domestic or institutional digesters.

When the biogas plant is constructed, the filtrate from the RDVF should be tested. If it meets the EPA standards, it should be channelled into the Wiwi river without going back into the treatment plant.

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APPENDIX A- Biogas Generation

Table A- 1 Average monthly flow rate of feedstock (2008/09 Academic year)

Month	Days(University in-session)	Days (On vacation)	Average Flow (m^3/month)
January	15	15	1630.1
February	28	0	1984.4
March	31	0	2197
April	30	0	2126.1
May	9	22	1417.5
June	0	30	1063.2
July	0	30	1098.6
August	15	16	1630.1
September	30	0	2126.1
October	30	0	2197
November	30	0	2126.1
December	12	19	1523.8

Table A- 2: Estimation of monthly methane generation for each system

	30 days			20 days			10 days		
Month	[67]Biogas (m^3)	Methane (m^3)	methane kg)	[68]Biogas (m^3)	Methane (m^3)	methane (kg)	[69]Biogas (m^3)	Methane (m^3)	methane (kg)
January	27630	17960	11890	23515	15285	10119	11757	7642	5059
February	33633	21861	14472	28624	18606	12317	14312	9303	6159
March	37249	24212	16028	31701	20606	13641	15851	10303	6821
April	36038	23425	15507	30671	19936	13198	15335	9968	6599
May	24031	15620	10340	20452	13294	8801	10226	6647	4400
June	18027	11718	7757	15342	9972	6601	7671	4986	3301
July	18616	12100	8010	15843	10298	6817	7922	5149	3409
August	27630	17960	11890	23515	15285	10119	11757	7642	5059
September	36038	23425	15507	30671	19936	13198	15335	9968	6599
October	37249	24212	16028	31701	20606	13641	15851	10303	6821
November	36038	23425	15507	30671	19936	13198	15335	9968	6599

[67] 94 % biogas recovery at 30-day HRT, temperature of 28°C, 1kgVS is equivalent to 0.310m^3 of biogas.
[68] 80 % biogas recovery at 20-day HRT
[69] 40% biogas recovery at 10-day HRT

December	25830	16790	11115	21983	14289	9459	10992	7145	4730
Total	**358009**	**232708**	**154051**	**304689**	**198049**	**131109**	**152344**	**99024**	**65556**

Table A- 3: Monthly Emission Reduction for each project Case

Month	Potential Methane Generated (kg)	Total Base Case Emissions (tCO_2/month)	Emissions for 30-days HRT (tCO_2/month)		Emissions for 20-days HRT (tCO_2/month)		Emissions for 10-days HRT (tCO_2/month)	
			Project Case	Reduction	Project Case	Reduction	Project Case	Reduction
January	12648	266	16	250	53	213	160	106
February	15396	323	19	304	65	258	194	129
March	17051	358	21	337	72	286	215	143
April	16497	346	21	325	69	277	208	138
May	11001	231	14	217	46	185	139	92
June	8252	173	10	163	35	138	104	69
July	8522	179	11	168	36	143	107	72
August	12648	266	16	250	53	213	160	106
September	16497	346	21	325	69	277	208	138
October	17051	358	21	337	72	286	215	143
November	16497	346	21	325	69	277	208	138
December	11824	248	15	233	50	198	149	99
Total	**163884**	**3443**	**206**	**3234**	**689**	**2751**	**2067**	**1373**

Table A- 3: Electricity Tariffs in Ghana Effective November 1, 2007

CATEGORY	RATES (GH¢)	CATEGORY	RATES (GH¢)
RESIDENTIAL		**SLT-LV**	
0-50(Exclusive charge)	0.0950	Capacity Charge (kVA/Month)	1.0000
1-300[70]	0.1200	Energy Charge(/ kWh)	0.1600
301-600	0.1600	Service Charge (/Month)	7.5000
600+	0.1900	**SLT-MV**	
Service Charge (/Month)	0.5000	Capacity Charge (kVA/Month)	9.0000
NON-RESIENTIAL		Energy Charge(/ kWh)	0.0905
0-300	0.1400	Service Charge (/Month)	12.500
301-600	0.1700	**SLT-HV**	
600+	0.1950	Capacity Charge (kVA/Month)	9.0000
Service Charge(/month)	2.5000	Energy Charge(/ kWh)	0.0805
		Service Charge (/Month)	12.500

[70] Residential customers who consume from 51 up to 150 units shall be subsidized at a rate of GH¢0.0413 per kWh only

Table A- 4: Monthly energy utilization at KNUST for 2008

Month	Energy Utilised (MWh)	Accumulated Apparent Power (MVA)	Max Demand (kVA)
January	545.84	583.705	1691
February	964.564	1000.416	2936
March	1118.847	1171.232	3198
April	1225.318	1369.226	3386
May	1301.512	1450.132	3422
June	732.032	856.812	2616
July	646.624	756.702	1839
August	1004.885	1115.5005	3031.5
September	1045.206	1200.9085	3162.5
October	1346.067	1521.245	3224
November	1166.904	1312.47	3315
December	1045.206	1230.585	3127

APPENDIX B- 1: CDM Calculation Procedure

Category III.D: CDM Baseline Methodology Guide book

Renewable Energy Project (Methane Recovery)

This category includes projects that prevent release of methane emissions into the atmosphere from coal mines, agro-industries, landfills, wastewater treatment facilities and other sources through measures to recover the emitted methane. This category includes projects that process organic components of municipal solid waste prior to its disposal in a landfill site and reduces the potential for methane emissions. But projects that use the organic component of municipal solid waste for incineration to avoid methane emissions are not covered in this category.

If the methane captured is from a non-biogenic source (methane captured in coal mines) then the CO_2 emission from the combustion of captured methane is counted in project emissions.

(Shrestha *et al*, 2005)

Baseline Emission (BE)

The emission baseline is defined as the amount of methane that would be emitted to the atmosphere in the absence of the proposed project activity. In the case where certain proportion of methane in the baseline is captured and flared, then it is also accounted for. It should be noted that in the case of landfill gas, waste gas, waste water treatment and agro-industries projects, if recovered methane is used for electricity generation, the proposed project activity is also eligible under Category I.D of CDM-Baseline methodology. If in a project, methane recovered is used for heat generation, the project is also eligible under Category I.C. In such cases, project participants may submit one single project design document for all of the components of the proposed project activity.

BE (tCO_2-e) = Methane (kg) * 21[71]

[71] Global warming potential of Methane

APPENDIX B- 2: Design of the RDVF

The surface area required for the filtration process was estimated using the equations below:

Equation B-1 was used to estimate the correction of the slurry concentration for the cake moisture.

$$C_{corrected} = \left(\frac{1}{c} - \frac{1}{\rho_s} - \frac{m-1}{\rho}\right)^{-1} \text{ ....B-1}$$

Where

C= concentration of feed (kg/m^3)

ρ_S = solid density (kg/m^3)

ρ= liquid density (kg/m^3)

m= wet/dry cake mass ratio

Equation B-2 was used to estimate the surface area of the RDVF

$$\frac{t}{V} = \frac{\alpha\mu c}{2A^2\Delta p} \text{ ....B-2}$$

This is on the assuming that the resistance of the filter medium is negligible.

Where

t= filtration time (s)

V= Filtrate volume (m^3)

α= Specific cake resistance (m/kg)

μ= liquid viscosity (Ns/m^2)

A= surface area (m^2)

Δp = vacuum pressure (N/m^2)

$C_{corrected}$= Slurry concentration correction for cake moisture (Kg/m^3)

APPENDIX B- 3: Description of COMFAR *III Expert* software

a. Purpose of the program

The Computer Model for Feasibility Analysis and Reporting (COMFAR *III Expert*) is intended as an aid in the analysis of investment projects. The main model of the program accepts financial and economic data, produces financial and economic statements and graphical displays and calculates measures of performance. Supplementary modules assist in the analytical process. This makes the software suitable for this project.

Cost-benefit and value-added methods of economic analysis developed by UNIDO are included in the program and the methods of major international development institutions are accommodated.

The program is applicable for the analysis of investment in new projects and expansion of rehabilitation of exiting enterprises as, e.g., in the case of reprivatisation projects. For joint ventures, the financial perspective of each partner of class of shareholder can be developed. Analysis can be performed under a variety of assumption concerning inflation, currency revaluation and rice escalations.

b. General Description of the Model

The program communicates with the user through a graphical user interface (GUI) to facilitate data entry. Data are entered into pre-defined annotated windows selected from a browser, a special window that graphically depicts the structure of the project data. Another browser permits the user to select, calculate and display or print numerical of graphical reports.

COMFAR *III Expert* provides flexibility with regards to the structure of project data. The system presents standard input data structures depending on the type of project and level of analysis which can be expanded beyond the minimum structure at the discretion of the user within practical limits. The planning horizon can be expanded to up to 10 years of construction and up to 50 years of production (operational phase). During the construction and ser\tup phase, the user may specify, with some restrictions, planning units from a minimum of one month to a maximum of one year. A variety of standardised reports for display or print in the form of numerical data or graphical output can be selected. The formats of financial reports conform generally to the schedules in the UNIDO Industrial Feasibility Studies Manual. Non-standard reports can be generated by exporting data into an external program.

I. Financial and Economic Model

The *financial and economic model*, which is the main model, accepts data concerning the description and definition of the project. For financial (Commercial) analysis, data concerning investment and operating costs, capital structure, project financing and taxation are entered. Inflation and price escalation data can be included. Cost items can be assigned to standard or user-defined cost centres for analysis of the project's costs structure. Analysis of products profitability is also possible by allocating indirect costs among products, although it is recommended to allocate costs to products via cost centres. For joint-venture projects the level of equity participation by the partners and the distribution of profits are defined. Financial reports can generated for each joint-venture partner.

The model facilitates the analysis of expansion or rehabilitation projects by permitting the entry of data concerning the assets of an existing enterprise in the form of starting balance. Assistance in the selection of items in the financial analysis requiring adjustments for economic analysis is provided by the model that ranks items by significance. Items can also be assigned for adjustment directly. Selected items form a data structure in the economic section of the browser. Adjustment factors relating economic prices to market prices for the selected items are defined the user.

II. Sensitivity Model

One way to assess the impact the changes of a project parameter have on the financial and economic feasibility of a project is to enter the alternative assumptions using the financial data input. Another way is to use the sensitivity model of the COMFAR *III Expert*, which serves to analyze the impact of parameter variations for critical variables without going into the input system.

c. Graphical User Interfaces (GUIs) in COMFAR *III Expert*

I. *Project Definition*

A project is defined by project **Type** and a **Level of analysis** in the NEW PROJECT modal window as shown in Figure B-1. The choice of project type determines the minimum structure provided by the system for the entry of the data and display in the input browser and browser overview panel.

The level of analysis feature serves to determine the initial configuration of the structure of the input items. The **Feasibility study** level offers a detailed structure; **Opportunity study** level offers a more aggregated (minimum) structure.

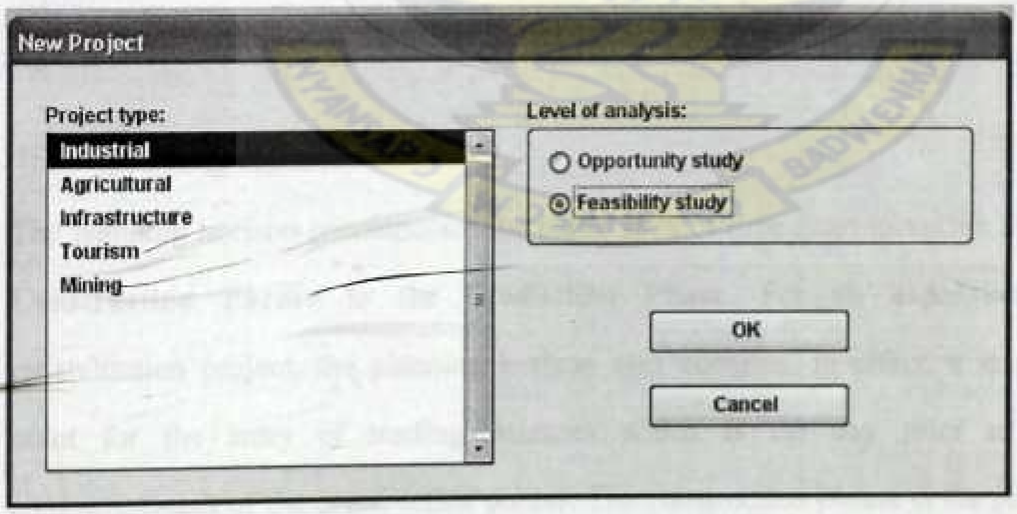

Figure B-- 7: New project modal window

II. *Project Identification*

The project is identified by the parameters fed into the interface. The parameters include the **Project Title**, **Project Description**, **Date** and **Time**, **Project Classification** and depth of analysis as shown in figure B-2.

Figure B- 8: Project identification window

III. *Planning Horizon*

The planning horizon encompasses the entire span of time from inception of the **Construction Phrase** to the **Production Phase.** For an expansion or rehabilitation project, the planning horizon also contains, in effect, a starting point for the entry of starting balances which is the day prior to the commencement of the construction phrase. The construction phrase is the period from the start of construction to the earliest date of production as shown in figure B-3.

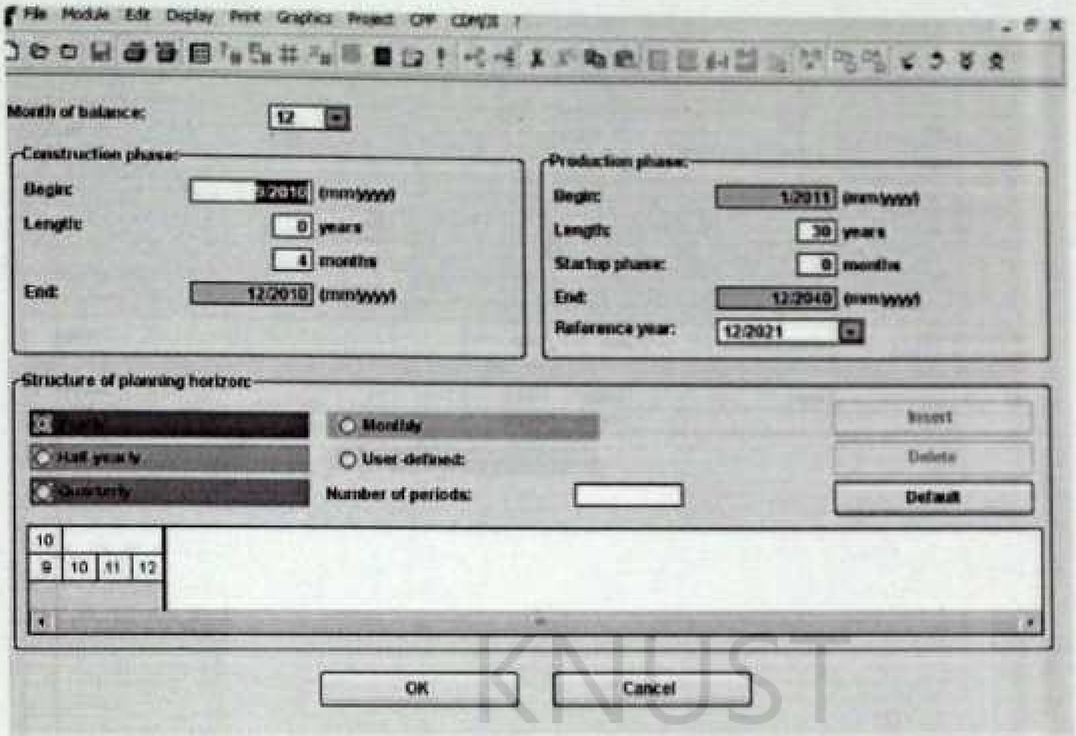

Figure B- 9: Planning horizon window

IV. *Product Definition*

Products are defined with their production time intervals and nominal capacities which should correspond to the standard production costs. The nominal capacity and standard cost are defined for the projected sales (in a full year) rather than the projected level of production. The variable costs for any period are interpolated or extrapolated based on the relation between the projected level of production and respective sales in the period and the nominal capacity. The actual start of production and the actual end of production are required in the window as shown in figure B-4.

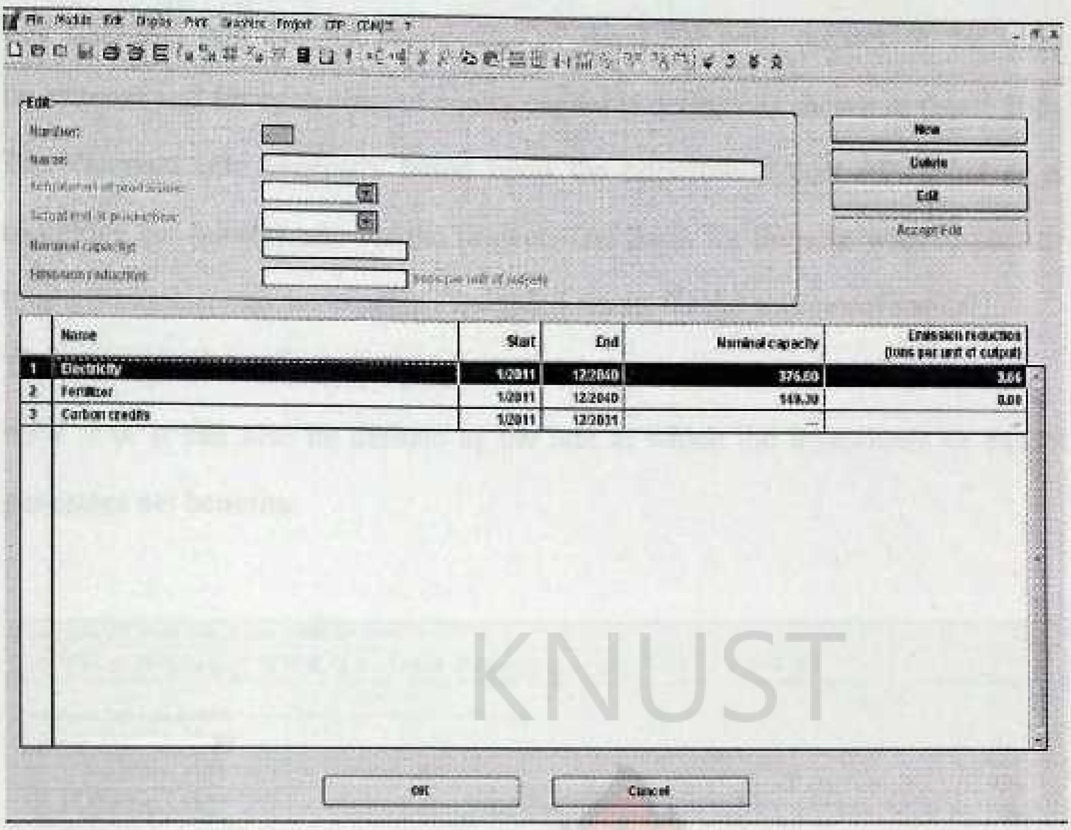

Figure B- 10: Product definition window

V. *Discounting*

The time value for money taken into account in determining the present value (discounted) or future value (compounded) of amount (flow of funds or resources) occurring at different point in time.

The NPV is defined as the sum of the present (discounted) values of amounts in a series of periods. It is a method of aggregated amounts occurring in different periods of time in a common measuring unit, present value.

$$\text{NPV} = \sum_{j=1}^{n} \frac{A_j}{(1+R)^j}$$

A_j Net of all positive and negative flows, period j
R Discounted rate
n Number of periods in the planning horizon
j A particular period

The discount rate for the calculation of the NPV with respect to the total investment and for each class of equity capital is defined as shown in figure B-5. The discount rate generally based upon the opportunity cost of capital as a challenge (or hurdle) rate for the project. The basis for the rate with respect to total investment may be expected weighted return for the sources of capital.

The Internal Rate of Return (IRR) is defined as the discount rate at which NPV = 0. It can also be defined as the rate at which the investment or equity generates net benefits.

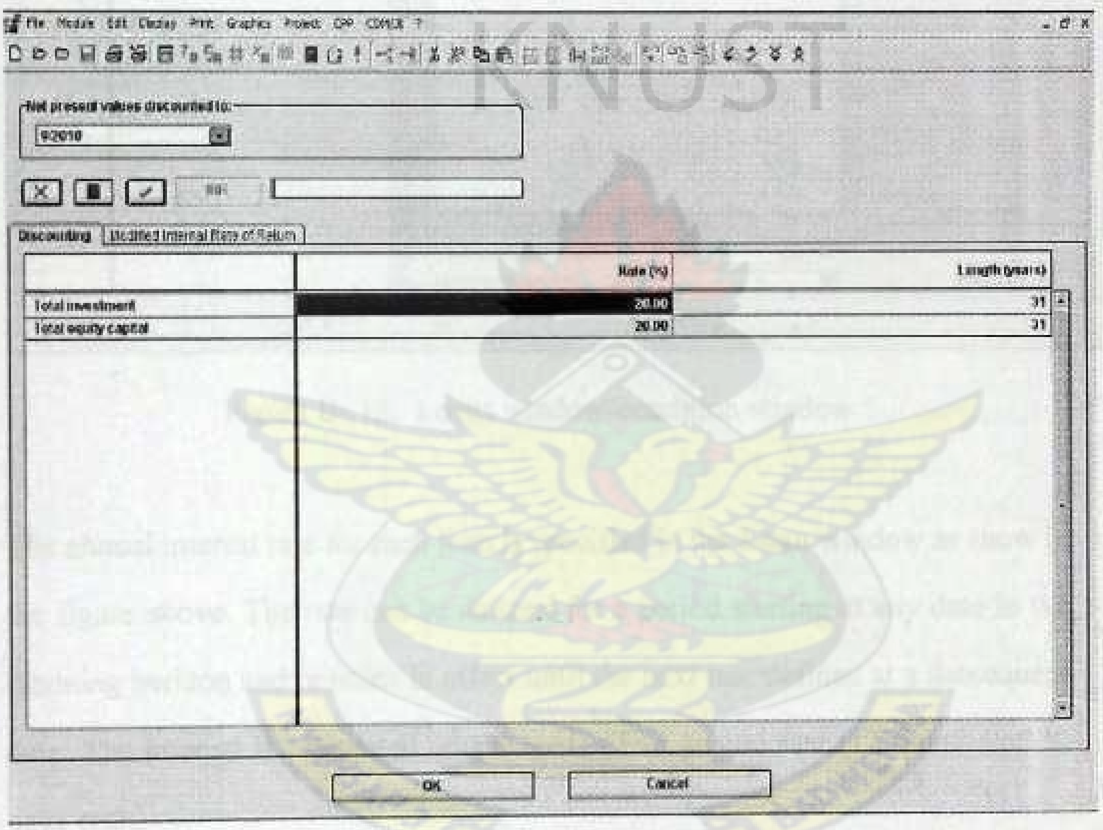

Figure B- 11: Currencies window

VI. *Sources of finance*

Equity capital is classified as ordinary or preference capital. Preference capital is identified by the assignment of preferred dividends are defined is assumed to be preference capital. Equity capital can be classified as paid in or paid out.

Long- term-loans and short-term-loan fed into the program with repayment options offered being constant principal, annuity or profile as shown in B-6.

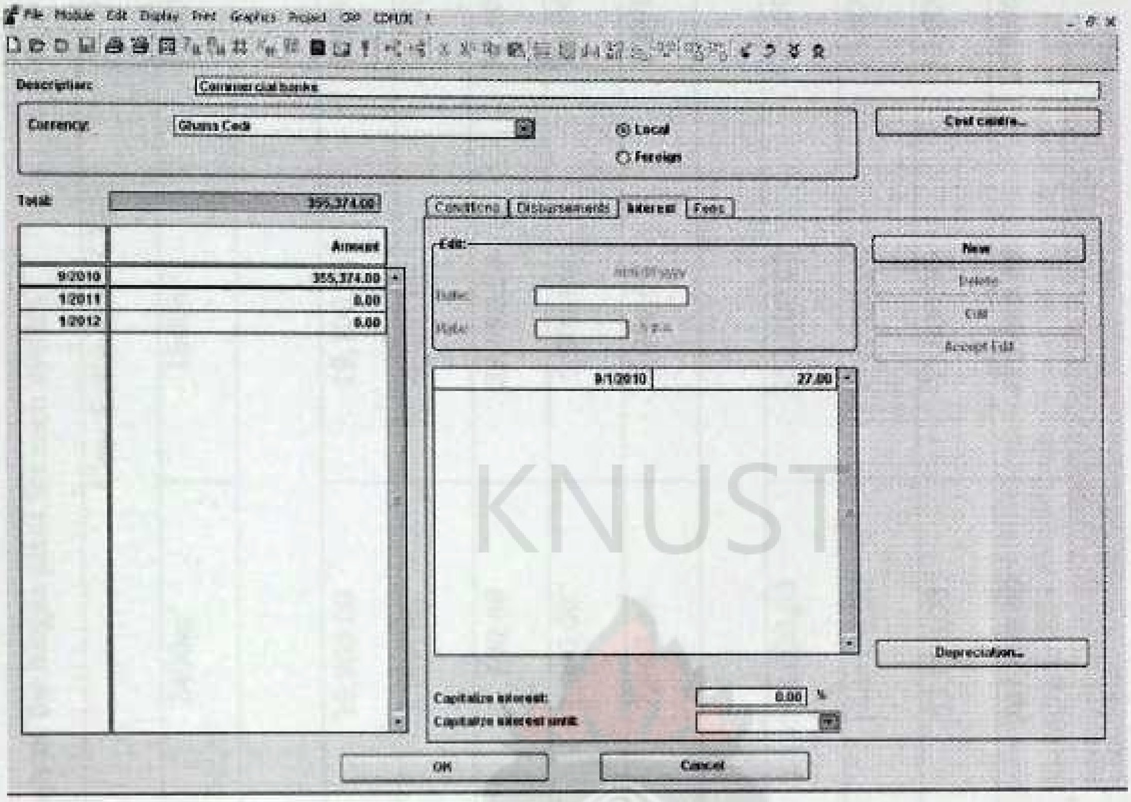

Figure B- 12: Loans window-condition window

The annual interest rate for each loan is specified in the **Loan** window as show in the figure above. The rate can be defined for a period starting at any date in the planning horizon and remains in effect until the next rate defined at a subsequent date. The interest is calculated on the basis of an annual rate (12 months of 30 days each)

APPENDIX C – FINANCIAL ANALYSIS

Table C- 1: Projected fixed investment costs of the biogas plant for each system

Cost components	Cost Estimates (GH¢)		
	$2400m^3$	$1600m^3$	$800m^3$
Site preparation and development (Yard Improvement)			
Site clearing ad Excavation	30,900.00	19,100.00	9,600.00
Other improvements	6,200.00	3,900.00	2,000.00
Subtotal	***37,100.00***	***23,000.00***	***11,600.00***
Civil works, structures and building	7,000.00	5,000.00	2,600.00
Subtotal	***7,000.00***	***5,000.00***	***2,600.00***
Plant machinery and equipment			
Digesters	528,000.00	352,000.00	176,000.00
Generators	140,000.00	110,000.00	50,000.00
Rotary drum vacuum filter	33,000.00	33,000.00	33,000.00
Subtotal	***701,000.00***	***495,000.00***	***259,000.00***

Auxiliary and service plant equipment			
Gas pipe	1,500.00	600.00	300.00
Gas flow meter	150.00	150.00	150.00
Gas Purification Devices	18,000	12,000.00	6,000.00
Pressure Regulator	150.00	150.00	150.00
Subtotal	***19,500.00***	***12,900.00***	***6,600.00***
Environmental protection			
Fire Safety protection	6,300.00	4,600.00	4,500
Subtotal	***6,300.00***	***4,600.00***	***4,500***
Pre production expenditure			
Project management, organization			
Temporary construction and operation	7,000.00	5,000.00	2,600.00
Construction tools and rentals	14,000.00	9,900.00	5,200.00
Travel and living	1,400.00	1,000.00	600.00
Other construction overhead	3,500.00	2,500.00	1,300.00

Detailed engineering and supervision			
Construction design and Engineering	1,100.00	800.00	400.00
Purchasing	2,800.00	2,000.00	1,100.00
Reproductions and communications	900.00	900.00	900.00
Contractor's fee	28,000	19,800.00	10,100.00
Subtotal	***58,700.00***	***41,900.00***	***22,200.00***
Contingencies	70,100.00	49,500.00	25,900.0
Subtotal	***70,100.00***	***49,500.00***	***25,900.00***
TOTAL	**841,000.00**	**590,000.00**	**310,200.00**

Table C- 2: Summary of the Annual production cost for the production of Electricity and fertilizer

		Projected Cost (GH¢)								
	Component of Production Cost	30-day HRT system			20-day HRT system			10-day HRT system		
		Electricity	Fertilizer	Total	Electricity	Fertilizer	Total	Electricity	Fertilizer	Total
Factory Cost (GH¢)	Spare parts consumed	1,400.00	700.00	**2,100.00**	1,000.00	660.00	**1,660.00**	500.00	660.00	**1,160.00**
		Work in Progress								
	Repair, Maintenance and Materials	1,400.00	700.00	**2,100.00**	1,000.00	660.00	**1,660.00**	500.00	660.00	**1,160.00**
	Labour: Skilled	10,000.00	4,800.00	**14,800.00**	7,000.00	4,800.00	**11,800.00**	3,400.00	4,800.00	**8,200.00**
	Labour: Unskilled	7,200.00	7,200.00	**14,400.00**	4,700.00	7,200.00	**11,900.00**	2,300.00	7,200.00	**9,500.00**

Operating Cost (GH¢)	Administrative Cost	1,400.00	700.00	**2,100.00**	1,000.00	700.00	**1,700.00**	500.00	700.00	**1,200.00**
Depreciation (GH¢)				**2,760.00**			**1,975.00**			**780.00**
Total (GH¢)	Finished Product	21,400.00	14,100.00	**36,160.00**	14,700.00	14,100.00	**29,035.00**	7200.00	14,100.00	**22,000.00**

Table C- 3: Detail cost estimates for fire safety equipment for the biogas plant

Description	Estimated Cost (GH¢)		
Biogas plant capacity	2400m^3	1600m^3	800m^3
Trolley Fire extinguishers			
Carbon dioxide(CO_2)-25kg	2,800.00	2,100.00	2,100.00
Carbon dioxide(CO_2)-50kg	3,000.00	2,000.00	2,000.00
Dry Chemical powder-6Kg	75.00	75.00	75.00
Accessories			
Smoke detectors	90.00	90.00	90.00
Fire alarm sounder	110.00	110.00	110.00
Call points	105.00	105.00	70.00
Fire notices and signs[72]	120.00	120.00	55.00
Total	**6,300.00**	**4,600.00**	**4,500.00**

[72] This comprise of Assembly point, "no smoking", Fire instructional notices and Exit signs.

Table C- 4: Summary Sheet of the Financial Analysis for the $800m^3$ capacity biogas Plant

COMFAR III Expert — Kwame Nkrumah University of Science and Technology, Ghana

SUMMARY SHEET

Project title:	Institutional Biogas Plant At KNUST
Project description:	This project looks at the Financial viability of a 10-day HRT(800m3 capacity) Biogas Plant at KNUST using himan effluent at the Sewage treatment plant.
Date and time:	
Project classification:	New project
Construction phase:	9/2010 - 12/2010
Length:	4 months
Production phase:	1/2011 - 12/2040
Length:	30 years
Accounting currency:	Ghana Cedi (GHc)
Units:	Absolute
Local currency:	Ghana Cedi (GHc)

INVESTMENT COSTS

	Total construction	Total production	Total investment
Total fixed investment costs	310,200.00	0.00	310,200.00
Total pre-production expenditures	57,737.40	0.00	67,737.40
Pre-production expenditures (net of interest)	*22,200.00*	*0.00*	*22,200.00*
Interest	*35,537.40*	*0.00*	*35,537.40*
Increase in net working capital	0.00	62,460.00	62,460.00
TOTAL INVESTMENT COSTS	367,937.40	62,460.00	430,397.40

SOURCES OF FINANCE

	Total construction	Total production	Total inflow
Total equity capital	39,486.00	0.00	39,486.00
Foreign	*0.00*	*0.00*	*0.00*
Local	*39,436.00*	*0.00*	*39,486.00*
Total long-term loans	355,374.00	0.00	355,374.00
Foreign	*0.00*	*0.00*	*0.00*
Local	*355,374.00*	*0.00*	*355,374.00*
Total short-term loans	0.00	0.00	0.00
Foreign	*0.00*	*0.00*	*0.00*
Local	*0.00*	*0.00*	*0.00*
Accounts payable	0.00	22,380.00	22,380.00
TOTAL SOURCES OF FINANCE	394,860.00	22,380.00	417,240.00

INCOME AND COSTS, OPERATIONS

	First year 2011	Reference year 2021	Last year 2040
SALES REVENUE	96,440.50	99,910.10	86,148.50
Factory costs	20,020.00	20,020.00	20,020.00
Administrative overhead costs	1,200.00	1,200.00	1,200.00
OPERATING COSTS	21,220.00	21,220.00	21,220.00
Depreciation	2,556.87	2,106.87	0.00
Financial costs	95,950.98	9,595.10	0.00
TOTAL PRODUCTION COSTS	119,727.85	32,921.97	21,220.00
Marketing costs	0.00	0.00	0.00
COSTS OF PRODUCTS	119,727.85	32,921.97	21,220.00
Interest on short-term deposits	0.00	0.00	0.00
GROSS PROFIT FROM OPERATIONS	-23,278.35	66,988.13	64,928.50
Extraordinary income	0.00	0.00	0.00
Extraordinary loss	0.00	0.00	0.00

E108 - Production - Automatic overdraft generated due to lack of funds!

SUMMARY SHEET

Depreciation allowances	0.00	0.00	0.00
GROSS PROFIT	-23,071.55	67,246.63	65,187.00
Investment allowances	0.00	0.00	0.00
TAXABLE PROFIT	0.00	67,246.63	65,187.00
Income (corporate) tax	18.75	18.75	18.75
NET PROFIT	-23,090.30	67,227.88	65,168.25

RATIOS

Net Present Value of Total Capital Invested	at 20.00%	6,247.34
Internal rate of return on investment (IRR)	20.35%	
Modified IRR on investment	6.86%	
Net Present Value of Total Equity Capital Invested	at 20.00%	-103,348.55
Internal rate of return on equity (IRRE)	11.80%	
Modified IRRE on equity	7.13%	
Net present values discounted to	9/2010	

E108 - Production - Automatic overdraft generated due to lack of funds!

Table C- 5: Summary Sheet of the Financial Analysis for the 1600m^3 capacity biogas Plant

SUMMARY SHEET

Project title:	Institutional Biogas Plant At KNUST
Project description:	This project looks at the Financial viability of a 20-day HRT(1600m3 capacity) Biogas Plant at KNUST using himan effluent at the Sewage treatment plant.
Date and time:	
Project classification:	New project
Construction phase:	8/2010 - 12/2010
Length:	5 months
Production phase:	1/2011 - 12/2040
Length:	30 years
Accounting currency:	Ghana Cedi (GHc)
Units:	Absolute
Local currency:	Ghana Cedi (GHc)

INVESTMENT COSTS

	Total construction	Total production	Total investment
Total fixed investment costs	593,550.00	0.00	593,550.00
Total pre-production expenditures	121,278.90	0.00	121,278.90
Pre-production expenditures (net of interest)	*41,900.00*	*0.00*	*41,900.00*
Interest	*79,378.90*	*0.00*	*79,378.90*
Increase in net working capital	0.00	84,460.00	84,460.00
TOTAL INVESTMENT COSTS	714,828.90	84,460.00	799,288.90

SOURCES OF FINANCE

	Total construction	Total production	Total inflow
Total equity capital	71,991.00	0.00	71,991.00
Foreign	*0.00*	*0.00*	*0.00*
Local	*71,991.00*	*0.00*	*71,991.00*
Total long-term loans	647,991.00	0.00	647,991.00
Foreign	*0.00*	*0.00*	*0.00*
Local	*647,991.00*	*0.00*	*647,991.00*
Total short-term loans	0.00	0.00	0.00
Foreign	*0.00*	*0.00*	*0.00*
Local	*0.00*	*0.00*	*0.00*
Accounts payable	0.00	30,380.00	30,380.00
TOTAL SOURCES OF FINANCE	719,982.00	30,380.00	750,362.00

INCOME AND COSTS, OPERATIONS

	First year 2011	Reference year 2021	Last year 2040
SALES REVENUE	119,167.90	155,358.80	134,651.00
Factory costs	27,020.00	27,020.00	27,020.00
Administrative overhead costs	1,700.00	1,700.00	1,700.00
OPERATING COSTS	28,720.00	28,720.00	28,720.00
Depreciation	5,943.94	3,968.94	0.00
Financial costs	174,957.57	17,495.76	0.00
TOTAL PRODUCTION COSTS	209,621.51	50,184.70	28,720.00
Marketing costs	0.00	0.00	0.00
COSTS OF PRODUCTS	209,621.51	50,184.70	28,720.00
Interest on short-term deposits	0.00	0.00	0.00
GROSS PROFIT FROM OPERATIONS	-90,453.61	105,173.80	105,931.00
Extraordinary income	0.00	0.00	0.00
Extraordinary loss	0.00	0.00	0.00

E108 - Production - Automatic overdraft generated due to lack of funds!

SUMMARY SHEET

Depreciation allowances	0.00	0.00	0.00
GROSS PROFIT	-90,453.61	105,173.80	105,931.00
Investment allowances	0.00	0.00	0.00
TAXABLE PROFIT	0.00	105,173.80	105,931.00
Income (corporate) tax	18.75	18.75	18.75
NET PROFIT	-90,472.36	105,155.05	105,912.25

RATIOS

Net Present Value of Total Capital Invested	at 20.00%	-92,589.83
Internal rate of return on investment (IRR)	17.18%	
Modified IRR on investment	15.45%	
Net Present Value of Total Equity Capital Invested	at 20.00%	-302,927.56
Internal rate of return on equity (IRRE)	8.81%	
Modified IRRE on equity	11.25%	
Net present values discounted to	6/2010	

E106 - Production - Automatic overdraft generated due to lack of funds!

Table C- 6: Summary Sheet of the Financial Analysis for the 2400m^3 capacity biogas Plant

SUMMARY SHEET

Project title: Institutional Biogas Plant At KNUST

Project description: This project looks at the Financial viability of a 30-day HRT(2400m3 capacity) Biogas Plant at KNUST using himan effluent at the Sewage treatment plant.

Date and time:

Project classification: New project

Construction phase: 7/2010 - 12/2010
Length: 6 months
Production phase: 1/2011 - 12/2040
Length: 30 years

Accounting currency: Ghana Cedi (GHc)
Units: Absolute
Local currency: Ghana Cedi (GHc)

INVESTMENT COSTS

	Total construction	Total production	Total investment
Total fixed investment costs	842,800.00	0.00	842,800.00
Total pre-production expenditures	189,735.05	0.00	189,735.05
Pre-production expenditures (net of interest)	*58,700.00*	*0.00*	*58,700.00*
Interest	*131,035.05*	*0.00*	*131,035.05*
Increase in net working capital	0.00	104,400.00	104,400.00
TOTAL INVESTMENT COSTS	1,032,535.05	104,400.00	1,136,935.05

SOURCES OF FINANCE

	Total construction	Total production	Total inflow
Total equity capital	128,845.05	0.00	128,845.05
Foreign	*0.00*	*0.00*	*0.00*
Local	*128,845.05*	*0.00*	*128,845.05*
Total long-term loans	903,690.00	0.00	903,690.00
Foreign	*0.00*	*0.00*	*0.00*
Local	*903,690.00*	*0.00*	*903,690.00*
Total short-term loans	0.00	0.00	0.00
Foreign	*0.00*	*0.00*	*0.00*
Local	*0.00*	*0.00*	*0.00*
Accounts payable	0.00	37,600.00	37,600.00
TOTAL SOURCES OF FINANCE	1,032,535.05	37,600.00	1,070,135.05

INCOME AND COSTS, OPERATIONS

	First year 2011	Reference year 2021	Last year 2040
SALES REVENUE	209,045.30	184,090.90	151,738.50
Factory costs	33,400.00	33,400.00	33,400.00
Administrative overhead costs	2,100.00	2,100.00	2,100.00
OPERATING COSTS	35,500.00	35,500.00	35,500.00
Depreciation	9,311.75	6,551.75	0.00
Financial costs	243,996.30	24,399.63	0.00
TOTAL PRODUCTION COSTS	288,808.05	66,451.38	35,500.00
Marketing costs	0.00	0.00	0.00
COSTS OF PRODUCTS	288,808.05	66,451.38	35,500.00
Interest on short-term deposits	0.00	0.00	0.00
GROSS PROFIT FROM OPERATIONS	-79,762.75	117,639.52	116,238.50

E107 - Construction - Automatic equity generated due to lack of funds!
E106 - Production - Automatic overdraft generated due to lack of funds!

SUMMARY SHEET

Extraordinary income	0.00	0.00	0.00
Extraordinary loss	0.00	0.00	0.00
Depreciation allowances	0.00	0.00	0.00
GROSS PROFIT	-110,929.70	103,805.05	101,042.75
Investment allowances	0.00	0.00	0.00
TAXABLE PROFIT	0.00	103,805.05	101,042.75
Income (corporate) tax	18.75	18.75	18.75
NET PROFIT	-110,948.45	103,786.30	101,024.00

RATIOS

Net Present Value of Total Capital Invested	at 20.00%	-274,717.03
Internal rate of return on investment (IRR)	13.63%	
Modified IRR on investment	14.75%	
Net Present Value of Total Equity Capital Invested	at 20.00%	-561,002.45
Internal rate of return on equity (IRRE)	5.73%	
Modified IRRE on equity	10.59%	
Net present values discounted to	7/2010	

E107 - Construction - Automatic equity generated due to lack of funds!

E108 - Production - Automatic overdraft generated due to lack of funds!