TECHNICAL EVALUATION AND STANDARDIZATION OF BIOGAS PLANTS IN GHANA

By

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DECLARATION

I hereby declare that this thesis is the result of my own original research work undertaken under the supervision of the undersigned, that all works consulted have been referenced and that no part of the thesis has been presented for another degree in this University or elsewhere.

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DEDICATION

To My Lovely Mum

Rita Kensah

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ABSTRACT

Biogas plants are noted for improving sanitation, generating energy, and supplying organic fertilizer. Despite the numerous benefits derived from biogas technology, Ghana is yet to develop a major programme that will promote the dissemination of biogas plants on a large scale. This research work conducts a technical review of biogas installations in Ghana and looks into challenges facing the design, construction, and operation of biogas plants. It further proposes standardized biodigester models for use in future large-scale dissemination programmes. The study was done by surveying fifty (50) biogas plants, and conducting interviews with both plant users and service providers. Majority of the digesters were fixed-dome (82 %); water-jacket floating-drums (8 %) ranked second. From the survey, sanitation was the main motivational reason for people using biogas plants. Most sanitary plants treating blackwater from flushing toilets discharge their effluent into public drains. Of the 50 plants surveyed, 22 (44 %) were functioning satisfactorily, 10 (20 %) were functioning partially, 14 (28 %) were not functioning, 2 (4 %) were abandoned and the remaining 2 (4 %) were under construction. Reasons for non-functioning include non-availability of dung, breakdown of balloon gasholders, absence of maintenance services, lack of operational knowledge, gas leakages, and bad odour in toilet chambers of biolatrines. Design problems observed involved the wrong orientation of inlet pipes of biolatrine digesters and the faulty interconnection between tandem (series) digesters. This thesis recommends the development of a national programme focussing on three major areas – sanitation, energy, and agricultural fertilizer production. A minimum retention time of 60 days for nightsoil and slaughterhouse waste, and 30 days for livestock waste under mesophilic conditions is recommended for the design of biogas plants. Standardized household, dung-digesting plant volumes of 4, 6, 8, and 10 m^3, and nightsoil-digesting volumes of 10, 30, 50, and 60 m^3 are proposed for dissemination. The correct design layout of tandem systems is also proposed.

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ABBREVIATIONS AND ACRONYMS

BCEL	Beta Construction Engineers Limited
BCL	Biosanitation Company Limited
BEL	Biogas Engineering Limited
BTWAL	Biogas Technology West Africa Limited
B4BL	Biogas for Better Life
CDM	Clean Development Mechanism
CSIR	Council for Scientific and Industrial Research
CWSA	Community Water and Sanitation Agency
EC	Energy Commission
EPRAP	Energy for Poverty Reduction Action Plan
GES	Ghana Education Service
GHS	Ghana Health Service
GRATIS	Ghana Regional Appropriate Technology Industrial Service
GRES	Global Renewable Energy Services
GSS	Ghana Statistical Service
GTZ	German Agency for Technical Assistance
IIR	Institute of Industrial Research
KITE	Kumasi Institute of Technology and Energy
KNUST	Kwame Nkrumah University of Science and Technology
KVIP/VIP	Kumasi Ventilated Improved Pit/ Ventilated Improved Pit
MoE	Ministry of Energy
PE	Polyethylene
PVC	Polyvinyl Chloride
RT	Retention Time
REES	Renewable Energy and Environmental Systems
SNEP	Strategic National Energy Plan
SNV	Netherlands Development Organization
TIE	Technology for Improved Livelihood
WCs	Water Closets
WWCs	Water-saving Water Closets

Chapter 1 – BACKGROUND

1.1 Introduction

The success stories of biogas programmes in developing countries such as China, India and Nepal attest to the efficacy of biogas technology as a viable option in reducing environmental pollution, improving sanitation, creating employment, and promoting nutrient recycling. Even more remarkable is the cutting-edge research undertaken by institutions in these countries that have led to marked development of efficient digesters and appliances. Most African countries, however, lag behind in research, development, and promotion of biogas technology.

In Ghana, the image of biogas technology has not improved much owing, inter alia, to the absence of a coordinated national programme, the perception that biogas systems are for poor people, high cost of biogas digesters, and frequent breakdown of some plants. Despite the aforementioned challenges, biogas digesters are gradually gaining grounds especially in the treatment of nightsoil[1].

1.2 Objectives

The main objective of this thesis is to conduct a technical review of biogas plants in Ghana and to make proposals for standardization of the technology for future dissemination programmes. Specific objectives of this research work are:

- to study biogas dissemination programmes in some African and Asian countries and draw lessons from these experiences;
- to investigate engineering and environmental challenges with regards to the design, construction, and operation of biogas plants in Ghana; and

[1] A euphemism for human excreta

- to propose design parameters and standardized digester models for Ghana's biogas industry.

1.3 Approach and Methodology

1.3.1 Survey Technique

A survey was conducted to technically assess the state of biogas plants in Ghana. The survey technique used included direct observation of the various components of biogas installations, and structured and unstructured open-ended interviews with both users and experts. An interactive approach rather than a 'question and answer routine' was used for the interviews in order to enhance the quality of information collected. Most of the experts interviewed have direct experience with biogas technology dissemination in Ghana (See Appendix A for the profile of experts interviewed and Appendix B for the major questions used in the structured interviews).

1.3.2 Sampling Technique

A representative number of locations having biogas installations were visited using both stratified and convenience (purposeful) sampling techniques. According to KITE (2008), there are slightly more than 100 biogas plants installed mainly by seven biogas service providers in Ghana. Taking the total number to be 100, a sample size of 50 (50 % of 100) is representative as suggested by Nwana (1992). The total sample size of 50 plants was stratified into seven strata, with each stratum representing half of the total number of plants constructed by the seven major biogas service providers. Table 1-1 gives a list of major biogas service providers in Ghana and also shows the number of plants selected for the study.

Table 1-1: Profile of Major Biogas Service Providers and Number of Plants Sampled for the Study

Company	Date founded	Type of digester/system installed	No. of plants installed[+]	No. of plants visited
Biogas Technologies West Africa Limited (BTWAL)	2000	Fixed dome and effluent treatment plants	35	13
Biosanitation Company Limited (BCL)	1998	Fixed-dome and floating drum	28	4
RESDEM	1996	Mostly bio-latrine digesters	25	7
Global Renewable Energy Services	1996	Fixed-dome digesters	20	5
Technology for Improved Environment (TIE) / Biogas Engineering Limited (BEL)'	1994/ 2002	Fixed-dome digesters, biotoilets	18	6
Beta Construction Engineers Limited (BCEL)	2006*	Puxin Biogas Digesters	12	4
Institute of Industrial Research (IIR)	1986*	Fixed-dome digesters, biotoilets		4
UNIRECO	2001	Mostly bio-latrine digesters		2
Renewable Energy and Environmental Systems (REES)	2002	Fixed dome digesters		1
Others				4
TOTAL				**50**

Source: KITE, 2008 (Updated by author)

[+] June 2008; * Started biogas dissemination in that year

'Both TIE and BEL were founded by Dr. E. D. Aklaku; TIE became moribund in 1999

1.3.3 Analysis

Data gathered through the survey was used to study trends in Ghana's biogas industry. Four fixed-dome biogas digester models were selected for assessment based on lessons of biogas technology dissemination in Ghana. The assessment of the selected models was mainly based on the overall structural integrity, the ease of construction, operation, and maintenance. The models were then ranked based on the assessment criteria and the highest-ranked model was proposed for dissemination. Structural modifications were also proposed for this model by incorporating some good features of models that have gained widespread acceptability in other countries. Finally, proposals for design parameters including retention times for various feed materials and digester volumes were suggested leading to the design of the standardized models.

1.4 Structure of the Thesis

Chapter 1 highlights the objectives of this work as well as the methodology used to achieve them. Chapter 2 provides a general overview of biogas programmes in developing countries including Ghana, Kenya, Tanzania, China, Nepal, India, Vietnam, Brazil, and Bolivia. Also discussed is the Biogas for Better Life Initiative for Africa. Chapter 3 deals with the principles of anaerobic digestion, sizing of biogas plants, and types of biogas digesters.

In Chapter 4, problems and challenges facing Ghana's biogas industry are holistically discussed based on data gathered through field trips and information obtained through interviews with stakeholders. Chapter 5 provides arguments for the selection of the type of digester to be promoted under future dissemination programmes. It throws more light on the criteria used to select digester models for dissemination, as well as arguments used to select retention times and digester volumes for various feed materials.

Chapter 6 contains the conclusions and recommendations.

Chapter 2 – BIOGAS PROGRAMMES IN DEVELOPING COUNTRIES

2.1 Biogas Programmes in Asia

2.1.1 China

Major investment in biogas technology in China started in the 1970s (Zhenhong *et al*, 2003; Jingming, 2007). Over a million plants were constructed between 1970 and 1990 mostly in the Sichuan Province due to favourable conditions such as availability of dung and adequate temperatures (mostly between 16 and 18 ^{0}C), (GTZ, 1999a). The dissemination of biogas plants received marked patronage in areas where politicians and opinion leaders devoted themselves to the creation of awareness on biogas plants. In addition, the cooperation of the State, cooperative groups, and households created a stable atmosphere for rapid dissemination of biogas technology (GTZ, 1999a).

According to Kristoferson and Bokhalders (1991), major programmes fluctuated greatly and most plants broke down due to immature technologies and numerous nonprofessional construction teams before 1990. In 1986 alone, 350,000 digesters were built while 400,000 (includes those built before 1986) broke down (Jingming, 2007). Digesters developed and used between the 1970s and the mid 1980s included hydro-pressure digesters, RM[2]-PVC digesters, solar-heating digesters, and two-step digesters (Zhenhong *et al*, 2003). Between the mid 1980s and early 1990s, attempts were made to disseminate large and medium size biodigesters in the livestock and poultry industries; and several advanced technologies such as UASB[3] systems and anaerobic filters[4] were introduced. Stirring devices were adopted, and most digesters were built on the ground and with concrete. In addition, pretreatment

[2] Red mud
[3] Upflow Anaerobic Sludge Blanket (See section 3.5)
[4] A type of anaerobic wastewater treatment system (See section 3.5)

technologies were introduced, and thermophillic (50 - 60 ^{0}C) digestion was occasionally used (Zhenhong *et al*, 2003). Also adopted were special equipment for storage and desulphurization of biogas.

Since 1992, direct involvement of the State has reduced. Private companies have increased and obligatory standards have been introduced in the design and construction of biogas plants (Marchaim, 1993; Jingming, 2007). Moreover, intensive research in biogas technology was promoted which led to the development of efficient digester models. Technical details of most plants were scientifically investigated and standardized (GTZ, 1999a; Jingming, 2007). Additional biogas digesters such as mixing reactors, filter reactors, sludge bed reactors, and fixed bed reactors were introduced and adopted for use in treating wastewater from food processing, fermentation, and sugar refining industries, as well as swine, bovine, and poultry farms (Zhenhong *et al*, 2003).

By the end of 2000, there were 9.8 million household digesters throughout China and both gas and digested slurry were fully utilized in 55 % of the plants for agricultural activities. Standardized domestic fixed-dome plants were widely offered, with most plants having a volume of 6 m^3; plants were either concreted or built with bricks according to the availability of raw materials locally. Furthermore, large and medium plants on animal husbandry farms were built for demonstration (Jingming, 2007).

The dissemination strategy at the domestic level involved the integration of the biogas plant into productive activities of the farmer. Thus, the usage of the digested slurry was given premium attention, by using it in income generating activities such as fish farming, cultivation of edible fungi and vegetables, or as pig food (Jingming, 2007).

Jingming (2007) has described the period after 2000 as one of accelerated development of China's biogas industry; the Government in 2000 increased its investment in rural biogas dissemination under the Biohousehold programme, which culminated in the construction of 2 million household digesters each year between 2001 and 2006. Furthermore, over 200 large and medium livestock farms were financially supported to own biogas plants. The end results of the Biohousehold Programme were impressive: 18 million households adopted biogas technology, 7 billion cubic metres of gas were produced annually, and 87 million tons of animal wastes were treated by 3,556 biogas plants (Jingming, 2007). Moreover, over 300 CDM (Clean Development Movement)[5] projects involving biogas power generation have also been developed with a total capacity of over 1 GW and a total annual emission reduction of over 20 Mt of CO_2 (Schwegler, 2007).

2.1.2 India

Biogas projects in India started in 1897. In 1956, Jashbai Patel developed the floating-drum plant, famously known as the KVIC (Khadi and Village Industries Commission) design (FAO-Nepal, 1996). A massive increase in the number of biogas plants took place in the 1970s through strong government backing. By the end of 1974, more than 60,000 plants were built (Kurian, 2004), and increased to over 100,000 plants by the end of 1980 (GTZ, 1999a).

Most plants, however, did not function efficiently due to immature technologies and a dissemination strategy that failed to recognize the importance of user training and follow-up services (GTZ, 1999a). This led to the placement of all biogas dissemination programmes under the Ministry of Non-conventional Energy Sources (MNES) in 1982 (Aggarwal, 2003). MNES was responsible for developing guidelines on financial support for biogas technology, setting up frameworks for research and development into efficient digesters and appliances, and deciding on the eligibility of new digester models for aid. The dissemination strategy of MNES focused on the promotion of family-size digesters, and community and institutional

[5] The Clean Development Mechanism is an arrangement under the Kyoto Protocol allowing industrialized countries with greenhouse gas (GHG) reduction commitment to invest in projects that reduce emissions in developing countries as an alternative to more expensive emission reductions in their own countries (Wikipedia, 2009).

plants, with special attention on nightsoil-based systems. The main aim was to provide fuel for rural households, and to produce organic manure for application on agricultural fields, in order to mitigate drudgery of rural women, and reduce pressure on forest resources (Aggarwal, 2003).

Before 1987, only six digester models were approved by MNES for large-scale dissemination. They included (GTZ, 1999a):

- floating-drum plant with a cylindrical digester (KVIC model);
- fixed-dome plant with a brick reinforced, moulded dome (Janata model);
- floating-drum plant with a hemisphere digester (Pragati model);
- floating-drum plant made of angular steel and plastic foil (Ganesh model);
- floating-drum plant made of pre-fabricated reinforced concrete compound units; and
- floating-drum plant made of fibre-glass reinforced polyester.

In 1987, MNES approved the newly developed Deenbandhu model for promotion and dissemination, bringing the total number of recognised models to seven. According to Khandal (2002), the floating drum plant was the most common system used in India before 2002. This, however, did not apply to all Indian States; for instance, the Deenbandhu digester was constructed more than any other model in Orissa and Sangli States (GTZ, 1999a). Actual dissemination activities were carried out by local governments of the various Indian states, public organisations such as KVIC and countless NGOs and private companies. Specific guidelines applicable to each were also developed. For example, in Orissa state, biogas extension teams were encouraged to have at least three women whose main agenda is to motivate farmers' wives to manage and use biogas plants properly (GTZ, 1999a). The direct involvement of local governments of all Indian states was partly responsible for the success of biogas dissemination in India.

At the end of 2002, more than 3 million domestic digesters and 3,000 community and institutional plants were constructed (Aggarwal, 2003). Most plants were constructed to digest cow dung. The relatively small number of nigtsoil-based plants, according to Aggarwal (2003), was due to unavailability of sufficient quantities of nightsoil at a single location and the fact that the government of India prioritized dung-based systems.

According to Myles (2008), Deenbandhu models represented about 75 % of over 100,000 digesters disseminated annually in India since 2005. Only approved models producing a nominal gas volume of 10 m^3 per day (corresponding to a digester volume of about 30 m^3) or less qualify for subsidies paid by the central government (GTZ, 1999a; GTZ, 1999b). The extent of the subsidy was governed by the size of the plant, the social and financial status of the user, and the part of the country where the plant is located. Thus, poor farmers and farmers owning no land received higher allowances than relatively rich farmers and farmers owning parcels of land.

2.1.3 Nepal

Biogas programmes in Nepal started in 1955 but it was not until 1975 when it received a major boost as a result of the introduction of interest free loans by the Nepalese government (Silwal, 1999; CES/IOE[6], 2000). The Agricultural Development Bank of Nepal (ADB/N) assisted in financing biogas plants through a special credit framework and funded several training and dissemination programmes. ADB/N also founded the Gobar Gas Company (GGC) in 1977 to spearhead biogas digester development and dissemination (GTZ, 1999a).

Since 1988, SNV (Netherlands Development Organisation) has provided technical and financial support to GCC, specifically for research and training programmes. International agencies notably UNICEF, Save the Children Fund of US, New Era, Plan International, and

[6] Centre for Energy Studies/ Institute of Engineering

some local NGOs have also made significant contribution towards institutional growth of Nepal's biogas industry (CES/IOE, 2000).

Over the years, GGC's research departments focused on the development of technical solutions and dissemination frameworks, improvement of customer service, and use of local materials (GTZ, 1999a). In order to accelerate the number of plants constructed annually, the Nepal government introduced the Biogas Support Programme (BSP) in 1991. A subsidy scheme was introduced under the BSP and was aimed at making plants affordable to rural folds. As a result of numerous interventions by the BSP, over 50 private companies were formed and over 25,000 plants were constructed annually. This necessitated the introduction of quality control measures to protect the interest of owners of biogas plants (GTZ, 1999a).

Two main types of digesters have been constructed and disseminated in Nepal – the Indian floating-drum (with an overflow at the top rim of the cylindrical digester instead of an outlet pipe) and the fixed-dome plant with a flat cement concrete floor, a brick/stone masonry cylindrical tank, a dome-shaped cement concrete roof, an inlet pipe connecting the digester with feeding tank, and rectangular outlet tank (GTZ, 1999a; CES/IOE, 2000; Panjar and Gopalan, 2006). The fixed-dome plant described above (GGC 2047) has gained wide acceptability and is currently the main digester disseminated in Nepal; it comes in sizes of 4, 6, 8, 10, 15, 20, and 50 m^3 (GGC/BSP, 1994).

Deenbandhu digesters were introduced in 1991/1992 by an NGO and more than 100 units were constructed in the Barda district of Nepal. Even though this model was accepted for mass dissemination in the SNV/BSP programme in 1994, it was not constructed due to lack of interest from the major biogas service providers; most companies claimed the savings made compared to the GGC model were marginal whereas the Deenbandhu was relatively difficult to construct (CES/IOE, 2000).

According to Silwal (1999), there has been a gradual reduction in average household digester sizes: 13.6 m^3 in 1990, 9.6 m^3 in 1994, 8.2 m^3 in 1998, and 7.49 m^3 in 1999. The adoption of smaller plant sizes has reduced investment cost considerably. Majority of plants were designed for a retention time of 65 – 70 days. At the end of 2004, over 140,000 biogas installations have been built by 62 companies, with a workforce of about 11,000 people (Bajgain and Shakya, 2005).

2.1.4 Vietnam

Biogas digesters were introduced in several provinces of Vietnam between 1964 and 1965 (Tuyen, 2008). Most plants were disseminated in small scale (up to 20 pigs) livestock farms, especially in the Mekong Delta. Beneficiary farmers relished in the use of biogas for cooking due to the savings on fuel and the convenience of using biogas compared to firewood and kerosene. However, large-scale (about 100 – 200 pigs and 1000 – 5000 chickens) farms showed low interest in using biogas plants (GTZ, 1999a).

Despite the low-level interest shown by a section of animal farmers in Vietnam, biogas technology was identified as the most suitable solution to pollution caused by the discharge of untreated waste from animal farms. According to a study, the dissemination of biogas plants could be improved among large-scale farmers if economical uses of the gas were indentified and promoted. It was observed that a farm possessing about 80 pigs or more could produce enough gas for running engines (GTZ, 1999a).

Even though, there were several setbacks during initial dissemination programmes, the government was persistent in ensuring that Vietnam achieved success with biogas technology in proportions tantamount to that of Nepal. Several biogas dissemination strategies were introduced but none achieved large-scale or long term operational success, despite favourable conditions including availability of dung and acceptance of biogas technology by the citizenry (BPO, 2006).

In 2003, the governments of Vietnam and The Netherlands signed a Memorandum of Understanding to implement large-scale construction of domestic biogas plants in 10 provinces of Vietnam, under the guidance and direction of the Biogas Project Office (BPO). This programme was aimed at, inter alia, developing a commercially viable biogas industry, building 10,000 digesters in 10 provinces, and reducing GHG (Greenhouse Gas) emissions by an equivalent of between 64,600 – 119,200 tonnes of CO_2 annually (BPO, 2006). The project reached its goal of disseminating 10,000 digesters in July, 2005.

With additional funding from the Netherlands, a total of 18,022 digesters were constructed by mid December, 2005. The success of this programme was attributed to an effective dissemination framework consisting of a wide range of activities: promotion and marketing, investment subsidies on plants, quality control, research and development, training, extension, monitoring and evaluation. Also included were institutional support and effective management by the BPO and the PBOs (Provincial Biogas Project Offices). The BPO also developed software for accurate estimation of the biogas potential of beneficiary households (BPO, 2006).

Majority of plants disseminated had volumes of 6 and 8 m^3. Two fixed-dome digester models – KT1 and KT2[7] – were approved for dissemination. Subsidies on the investment cost ranged from 25 to 30 % and most farmers used the opportunity to modernize their stables, kitchens, and latrines at the same time. BPO estimated that about 40 % of the farmers attached a toilet to their plants and about 55 % of the farmers used the bioslurry in agriculture. The total expenditure amounted to US$ 2,391,424, out of which US$ 2,321,399 was financed by the Dutch government and US$ 70,025 came from local NGOs (BOP, 2006). Furthermore, beneficiary farmers contributed an estimated US$ 2.2 – 3.3 million towards the construction of the plants. At the end of 2007, 73,000 biogas units had been installed (Tuyen,

[7] See Sub-section 3.5.1

2008). As a result of the success of the programme, a second phase is expected to be implemented with a target of 150,000 plants in five years (BPO, 2006; Tuyen, 2008). Large and advanced biodigester systems are also expected to be constructed.

2.2 Biogas Programmes in Latin America

2.2.1 Bolivia

Interest in biogas technology gained momentum in Bolivia following the cooperation between GTZ and Universidad Mayor de San Simon (UMSS) in 1986. Initial programmes were designed to tow the lines of GTZ's regional dissemination strategies until 1989 (GTZ, 1999a). Between 1990 and 1992, biogas activities were promoted under the Special Energy Programme which aimed at integrating biogas plants into the agricultural production process, in order to forestall the destruction of agricultural ecosystems. Out of 29 plants constructed in 1986, only one was functioning by the end of 1988 (GTZ, 1999a).

The Special Energy Programme was aimed at creating fundamentals for extensive dissemination of biogas plants; this was to be achieved by carrying out training workshops and building demonstration systems. Emphasis was placed on the integration of the technology into local, regional and national socio-economic structures. Farms were also fully involved. Between 1989 and 1992, most plants were built in the lowland regions falling within the tropical belt (GTZ, 1999a).

2.2.2 Brazil

In Brazil, major national programmes on anaerobic fermentation[8] technology started in the late 1970s and early 1980s (Hjort and Lorin, 2008). Most programmes targeted the dissemination of anaerobic digestion plants among pig farms as a way of reducing farmers'

[8] It seems the term *anaerobic fermentation* is prepared to *biogas technology* in Brazil

dependence on liquid petroleum gas (LPG) and chemical fertilizers. According to Hjort and Lorin (2008), many programmes failed due to lack of technological knowledge and poorly designed digesters.

In addition, the dissemination of anaerobic wastewater technology was confronted with barriers such as low training and human capability, few experts in animal waste management, lack of technology needed for large-scale anaerobic systems, equipment maintenance problems, and lack of stimulus tools such as subsidies for farmers (Lima, 2006). Biodigester models disseminated widely in Brazil include the Chinese dome and the floating-drum digesters; in addition, anaerobic lagoons were constructed in some intensive pig farms (Lima, 2006; Hjort and Lorin, 2008).

Since 2000, there have been campaigns aimed at introducing biodigesters to rural areas in order to replace the use of gasoline, woodfuel, and LPG. These programmes were also designed as part of a major CDM project with close collaboration from farmers, cooperatives, local environmental and sanitary organisations, environmental lawyers, researchers and academics, and agencies developing the CDM projects (Lima, 2006). In order to boost AD acceptability in Brazil, strategies for biogas production were formulated as part of the development of a national plan on agroenergy by EMBRAPA (Brazilian Agricultural Research Cooperation).

The strategies included (Lima, 2006):

- development of systems to compress and stock biogas;
- evaluation of the use of biofertilizer as organic manure;
- development of appliances for using biogas;
- development of equipment for the distribution of biofertilizer; and
- development of biogas purification processes.

In 2005, Brazil had about 35 and 165 million swine and bovines respectively, and huge volumes of wastewater were generated (Lima, 2006; Kunz *et al*, 2008). Even though, anaerobic digestion technologies had been widely used to treat waste from swine farms with collateral benefits of energy generation and agricultural fertilizer production, biodigesters were found incapable of removing nitrogen and phosphorus from the treated effluent. Moreover, biodigesters did not reduce the crop area needed to absorb these nutrients (Kunz *et al*, 2008).

Thus, technological innovations that allowed for greater process control and stability were introduced; advanced solid-liquid separation techniques using coagulants and flocculants and other technologies were considered for use in post-treatment of swine waste. Finally, research in the academia focused on the use of new feed materials including slaughterhouse waste and liquid waste from sugarcane cropping (Kunz *et al*, 2008).

2.3 Biogas Programmes in Africa

2.3.1 Kenya

Biogas programmes in Kenya started in 1954 but the floating-drum and the fixed-dome plants were introduced in 1970 (Laichena and Wafula, 1997). During the mid-fifties, attempts were made to promote the technology by constructing plants for treating coffee pulp. By 1984, only 150 plants had been installed and less than 25 % were in operation (O'keefe *et al*, 1984); most of these plants were sold to large-scale coffee farmers by private companies (GTZ, 1999a).

In 1983, the Kenyan Ministry of Energy with the assistance of GTZ, introduced the Special Energy Programme (SEP) to promote biogas projects. The SEP promoted the

BORDA-Sasse[9] floating-drum digester (christened Meru biogas plant) mostly in households and educational institutions usually with foreign aid. The Meru plant is a standardized floating-drum plant with digester and gasholder volumes of 9.4 and 2.4 m^3 respectively. The average retention time is 90 days if it is fed with 100 liters of slurry daily (Laichena and Wafula, 1997). The gasholder is fabricated from 3 mm thick mild steel. The guide frame is internal and is made of galvanized iron. Both inlet and outlet pipes are made of 6 in PVC pipes. The gas piping is divided into the main piping and the house piping: the main pipe consist of 1 in GI (galvanized iron) from the plant to the water trap and 1 in PVC pipe from the water trap to the house, while the house pipe is made of 1 in GI pipe.

Under SEP, several craftsmen were trained by GTZ to help promote the technology. However, it was realized that training personnel alone was not enough since there were no effective institutional structures put in place to coordinate biogas projects (GTZ, 1999a). Moreover, there were no dissemination strategy, no quality assurance, no credit system, and no operational advice to the customer; other challenges included low gas production, gas leakage and pipe defects, and non-availability of feed materials due to the free range system of cattle farming commonly practiced in Kenya (Laichena and Wafula, 1997; GTZ, 1999a; Amigun *et al*, 2006). In order to accelerate the dissemination of biogas plants, the Ministry of Energy and the Ministry of Agriculture and Livestock Development teamed up to encouraged farmers to adopt the zero-grazing (intensive system) method of animal husbandry.

Despite several interventions by the Kenya government and other stakeholders, most biogas programmes failed due to high cost of digesters, lack of capacity to disseminate large volume plants, poor maintenance, poor dissemination strategies, poor planning and

[9] BORDA (Bremen Overseas Research and Development Association) is an NGO that promotes decentralized energy and water supply interventions including biogas technology in some Asian and African countries;
Sasse is a biogas engineer who worked for GTZ as researcher and trainer in several countries including Tanzania and Kenya.

monitoring, acceptance problems, and poor design and construction that led to gas pressure problems (Shell Foundation, 2007). According to Shell Foundation (2007), a total of 2000 plants had been installed in Kenya as at October, 2007, with majority of plants constructed between 1980 and 2000.

2.3.2 Tanzania

Biogas projects in Tanzania began in 1975, and by 1984 120 floating-drum plants had been built (GTZ, 1999a). In 1982 the Centre for Agricultural Mechanization and Rural Technology (CAMARTEC) was founded to promote the dissemination of biogas technology, and together with GTZ, the Biogas Extension Service (BES) was introduced to disseminate biogas programmes. The BES initially constructed biogas plants for farmers in the areas around Arusha due to the fertile nature of the land and the high productivity of the region, and presence of large dairy farms and relatively rich farm households. Due to the large nature of the project, standardized designs of the CAMARTEC [10] fixed-dome digester and procedures were introduced by CAMARTEC to boost biogas dissemination. In 1984/85 household plants were offered with a digester volume of 8, 12 and 16 m^3. By 1990 standardized plants of sizes 12, 16, 30 and 50 m^3 for households and institutions were disseminated (GTZ, 1999a).

CAMARTEC research activities focused on the improvement of the CAMARTEC model and the development of user friendly systems; these involved livestock housings with a concrete floor and direct connection of the plant to the urine channel, and distribution channels for the slurry. In addition, CAMARTEC incorporated foot baths at the entrance of stables to wash dung on the feet of the animals and to collect urine (Marree *et al*, 2007). The research and dissemination work of CAMARTEC slumped following the gradual withdrawal

[10] See Sub-section 3.5.1

of financial and technical support by GTZ after 1990. This caused increased privatization of most activities under the BES (GTZ, 1999a).

In 2003, CAMARTEC made structural changes to its digester model by disseminating plants with one expansion chamber as opposed to the traditional expansion chambers which were either two or three per digester; this innovation, according to Marree *et al* (2007), reduced the total volume of the plant and ensured high gas production. Most of CAMARTEC's dissemination activities had slowed down considerably since 2001.

Apart from CAMARTEC, institutions such as MIGESADO[11], SURUDE (Foundation for Sustainable Rural Development), SIDO (Small Industries Development Organisation), SUDERETA (Sustainable Development and Renewable Energies in Tanzania), KAKUTE Limited, ELCT (Evangelical Lutheran Church in Tanzania), TaTEDO (Tanzanian Traditional Energy Development and Environment Organisation) and the private sector, have in diverse ways assisted in the promotion of the technology. In addition, the Ministry of Water, Energy, and Minerals has been involved in extensive dissemination programmes in the region around Dar es Salaam. Since 2001, MIGESADO has constructed an average of 110 digesters per year making it the organization with the largest number of installed digesters (Schmitz *et al*, 2007). Most digesters installed have volumes of 5 m^3 for one cow and 8 m^3 for two or more cows, and about 30 % of digesters are installed together with water storage tanks. In addition, most beneficiary farmers received subsidies (Schmitz *et al*, 2007).

ELCT has disseminated plants since 1988 but has not cooperated with other organizations such as CAMARTEC due to the use of different technologies and dissemination strategies; for example, ELCT has been disseminating Chinese fixed-dome models with a conical base while targeting farmers owning a minimum of two cattle.

[11] MIGESADO, an NGO, is the Swahili acronym for 'Gas from Cow Dung in Dodoma Region of Tanzania'.

Moreover, ELTC has been importing accessories such as lamps and stoves from India and China and are usually around half the price of those sold from CAMARTEC (GTZ, 1999a).

SURUDE and KAKUTE have promoted tubular plastic digesters in addition to fixed dome models. Both organizations, however, stopped the dissemination of plastic digesters because they claimed tubular digesters were not sustainable within the Tanzanian context (Marree *et al*, 2007; Schmitz *et al*, 2007). SIDO, a parastatal organization, disseminated a total of 120 digesters (mostly KVIC models) between 1975 and 1984, and by late 1980s, none of the plants was functioning (Mwakaje, 2007). SIDO stopped its biogas dissemination programmes in the 1980s and most of its plans were implemented by the Arusha Appropriate Technology Project (AATP). AATP focused on cheap systems such as use of oil drums as digesters; the limitations according to Marree *et al* (2007) were gas leakages and unhygienic handling of cow dung. TaTEDO's involvement in biogas dissemination is mainly confined to the provision of advisory services.

In an attempt to accelerate biogas dissemination at levels comparative to the Asian countries, a US $ 2.5 million GEF[12]-financed project was initiated in Dar-es-Salaam to utilize an estimated 23,000 m^3 of methane generated from landfills. The initiative which was to be replicated in several cities was expected to replace 10 % of electricity demand in Tanzania. According to Amigun *et al* (2006), the project ended prematurely due to cost escalation as a result of technology selection.

In summary, an estimated 4000 - 5000 digesters is believed to have been disseminated in Tanzania. Dissemination was at its highest level in the 1980s but has gone down significantly since the beginning of the millennium (Marree *et al*, 2007).

[12] Global Environmental Facility

2.3.3 Ghana

Research and development in biogas technology dates back to the late 1960s, where emphasis was placed on the provision of energy for cooking for rural households (Ahiataku-Togobo, 2008). Unfortunately, most plants disseminated failed due to immature plant designs and poor construction. In order to resuscitate the technology, a cooperative agreement between Ghana and China led to the construction of a 10 m^3 plant at the Bank of Ghana (BoG) cattle ranch in the Shai Hills and the start of the Appolonia Household Biogas Programme in 1986 (Ahiataku-Togobo, 2008; KITE, 2008).

The Appolonia Household programme focused on energy for cooking for cattle-owning households at Appolonia, a rural community in the Greater Accra region (Edjekumhene *et al*, 2001). A total of nineteen fixed-dome digesters, including six 15 m^3 and two 30 m^3 Deenbandhu[13] digesters, and eight 10 m^3 and three 15 m^3 Chinese-dome models were disseminated (Osei-Sarfo, 1998, Ahiataku-Togobo, 2008). This was followed by the construction of two household demonstration plants at Jisonayilli and Kurugu, all in the Northern Region in 1987, under the aegis of the United Nations Children Fund (UNICEF); these plants together with those under the Household programme were designed and constructed by Dr. Kwame Ampofo[14].

In June, 1992, the Ministry of Energy (MoE) commissioned the first large scale community-based biogas plant in Appolonia. The project was aimed at providing street lighting and electricity for small load appliances for all the households in that community. Cow dung and human excreta were used to feed the digesters, and the gas produced was used to run a 12.5 kVA generator which provided power for street and home lighting, while the bio-slurry was used for agriculture (Osei-Safo, 1998; KITE, 2008).

[13] See Sub-section 3.5.1

[14] A biogas expert and founder of RESDEM consultancy, a leading biogas service provider in Ghana

The Appolonia Electricity project, designed and constructed by Messrs Wisdom Ahiataku-Togobo[15] and Otoo Addo[16], experienced several setbacks and has not performed as planned due to a multiplicity of factors including feedstock problems, distance of kraals (1/2 km) from the community, maintenance problems, and uncooperative attitude of some of the inhabitants (Ahiataku-Togobo, 2008). Problems also arose in the utilization of the digested slurry as farm manure. In the initial stages, the liquid organic fertilizer from the plant was successfully used on farms even though farmers complained of the intense labour involved in carrying liquid fertilizer from the plant site to their farms. Another major problem was the drudgery involved in collecting dung from kraals situated hundreds of meters away from the community (Bensah and Brew-Hammond, 2008). Furthermore, Fulani herdsmen prevented women from collecting dung from the kraals due to superstition (Ahiataku-Togobo, 2008).

Apart from the Ministry of Energy, the Catholic Secretariat and GTZ have supported biogas dissemination in Ghana. The Catholic Secretariat financed the construction of biogas plants at the Catholic Mission at Kaleo in the Upper West Region (Ampofo, 1996), and in three Catholic hospitals – Holy Family and St. Dominic hospitals in the Eastern Region, and Battor hospital in the Volta Region – between 1994 and 1995 (KITE, 2008; Bensah and Brew-Hammond, 2008). Some biogas projects financed by GTZ were constructed to treat slaughterhouse waste at Ejura and KNUST, all in the Ashanti Region (Rockson and Aklaku, 2006; Idan, 2007).[17]

From 1993 and beyond, the direct involvement of the MoE in biogas dissemination slumped mainly due to lack of donor support and unfulfilled expectations of the Appolonia projects. Attempts were made to rekindle the involvement of the State in 1996 when the MoE

[15] A biogas expert and the director of Renewable Energy Programmes, Ministry of Energy, Ghana

[16] A biogas expert and a staff of the Institute of Industrial Research, Ghana

[17] See Appendix C for a catalogue of biogas installations in Ghana.

financed a study aimed at assessing biogas resources in Greater Accra, Volta, and the three Northern Regions (Ampofo, 1996). This study was intended to be the first step in planning and developing a national biogas programme. Ampofo (1996) estimated a potential of 88,144 m^3 of biogas a day which could generate about 193 GWh[18] of energy annually. Ampofo (1996) did not estimate the quantum of liquid fertilizer that could be generated but Bensah and Brew-Hammond (2008) have shown that an amount of 360,000 tonnes of liquid organic fertilizer could be produced yearly, which would be capable of fertilizing about 70, 000 hectares of irrigated farmland or 140, 000 hectares of dry farmland.

Intriguingly, after more than a decade since the study was completed and the report submitted to the Ministry of Energy, the Ministry has shown no interest to implement a national biogas programme. Furthermore, the Institute for Industrial Research, a parastatal organization involved in biogas digester dissemination, has not been able to influence policy makers into giving the necessary support to the biogas industry in Ghana.

Following the low involvement of biogas projects by the State, a number of private biogas companies[19] have marketed the technology on purely business grounds, and mainly based on the ability of biogas plants to improve sanitation (Amigun *et al*, 2006; Bensah and Brew-Hammond, 2008; KITE, 2008;). Households have not shown much interest in using biogas in their kitchen or the digested slurry in their farms; thus, biogas technology has been disseminated mostly in institutions such as schools, hospitals, prisons, etc where it generally gained acceptability (KITE, 2006). According to Edjekumhene *et al* (2001), major barriers that have plunged biogas dissemination in Ghana include unfavourable policies, non-availability of feed materials, poor financing arrangements, problems with social acceptance, absence of market, and lack of information.

[18] Taking the calorific value of biogas to be 6 kWh/m^3 (Sasse, 1988)

[19] See Appendix C for a list of institutions/companies at the forefront of biogas technology dissemination in Ghana.

2.4 Lessons from Biogas Programmes in Asia, Latin America, and Africa

From the experience of biogas technology dissemination in developing countries such as China, India, Nepal, Brazil, Ghana, Kenya and Tanzania, it is obvious that biogas promotion cannot be left in the hands of private companies alone. The success of biogas technology dissemination in China, India, and Nepal can be partly attributed to the direct involvement of the State through special national or parastatal bodies empowered to lead the campaign in biogas dissemination. For example, biogas plants dissemination in China was given a major boost following a declaration by Chairman Mao in 1958, that the technology be promoted in all areas of China (Jingming, 2007).

In Nepal, accelerated development of biogas technology began after the government introduced special facilities including interest-free loans to farmers and other users of biogas plants (Silwal, 1999). India's success in biogas technology promotion can also be attributed partly to active involvement of the government through the direct participation of the Ministry of Non-conventional Energy Sources (MNES) (Aggarwal, 2003). In Vietnam, a special national biogas promotion body – Biogas Project Office – with branches in all provinces was set up and empowered financially to disseminate the technology.

Apart from the active involvement of the state, other factors that have accelerated biogas plants dissemination in aforementioned Asian countries include:

- development and implementation of favourable policies and legal environments that promote biogas technology dissemination; for example, China has enacted and implemented laws, such as *Agricultural law* of 1997 and *Renewable Energy Law of 2005,* that emphasized the development of biogas technology for rural households and institutions (Jingming, 2007);
- provision of financial support such as subsidies and micro-financing schemes; for example, the Agricultural Development Bank of Nepal (ADB/N) has been financing

biogas plants through special credit frameworks since the 1970s (Bajgain and Shakya, 2005);

- development of dissemination strategies base on complete and efficient network from the national level to the grassroots level; for example, the Biogas Project Office has offices in all provinces of Nepal (BPO, 2006);
- development of effective training, education and publicizing programmes through provision of training manuals, leaflets, flyers, and TV and radio programmes; and
- promotion of research and development of new and efficient digester models and biogas appliances, through the involvement of universities, research institutes, social groups, and companies.

In Brazil, there has been active involvement of the government and state institutions including EMBRAPA in biogas technology dissemination. Research and development of large anaerobic digestion systems mainly for the treatment of wastewater from swine and bovine farms have been given attention by the Brazilian government.

In contrast, African countries have shown no/little commitment to biogas dissemination programmes leading to very low numbers of biogas plants disseminated. Even though, Tanzania and Kenya have special biogas dissemination programmes such as Biogas Extension Service in Tanzania and Special Energy Programme in Kenya, these programmes are inadequately funded, leading to poor and disjointed dissemination strategies and poor institutional structures. In addition, financial support in the form of subsidies, micro-finance schemes, and training workshops have been relatively low.

In Ghana, biogas technology has received inadequate attention by government and other relevant public institutions such as the Energy Commission[20]; for example, in the Strategic

[20] The Energy Commission (EC) is required by law to regulate, manage, and develop the utilization of energy resources in Ghana

National Energy Plan (SNEP), the potential contribution of biogas technology towards the growth of the energy sector was not captured compared to other renewable energy options such as wind and solar energy (EC, 2006). In addition, there is no national body mandated to disseminate biogas programmes. Moreover, there are no financing schemes and quality control measures. This explains why low numbers of plants have been constructed in Ghana (less than 200) relative to Kenya (about 2000) and Tanzania (between 4000 and 5000).

2.5 Biogas for Better Life (B4BL) – An African Initiative

The Biogas for Better Life (B4BL) initiative is an ambitious programme conceived by developing partners of Africa and launched in Nairobi in May 2007. The major aim is to combat poverty by providing over two million households in Africa with cleaner cooking facilities as a way of improving family health, reducing workloads for housewives and children, and creating jobs (SNV, 2007). Other objectives of the initiative include the establishment of more than 800 private biogas companies and 200 biogas appliance manufacturing workshops and the construction of one million bio-toilets[21]. Table 2-1 gives SNV's estimate of biogas potential of some African countries.

Table 2-1: Domestic biogas potential of selected African countries

Country	Potential (thousand)	Country	Potential (thousand)
Ghana	278	Guinea	255
Ethiopia	916	Nigeria	2241
Burkina Faso	876	Kenya	1259

Source: SNV, 2007

[21] A bio-toilet refers to a biogas digester directly receiving the nightsoil from any toilet facility.

According to Brew-Hammond (2007), the Research component of the B4BL initiative must be closely linked with innovation and education, with Research themes focussing on technology development including feedstocks and quality guidelines, community participation including gender, communication and marketing, delivery models including finance and cost-benefit analysis, and strategy development including policy and impact studies.

3.1 Principles of Anaerobic digestion

Anaerobic digestion is the breakdown of complex organic molecules into simpler substances by bacteria in the absence of air. This conversion of complex organic compounds into methane and carbon dioxide requires different groups of micro organisms and is carried out in sequence of four stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis (Gujer and Zehnder, 1983). During hydrolysis organic substrate is converted into smaller components; then, acidogenic bacteria use these smaller compounds and produce volatile fatty acid, ethanol, CO_2 and H_2. Acetogenic bacteria convert these fermentation products into acetic acid, CO_2 and H_2. Finally methanogenic bacteria use hydrogen and acetate to produce methane and carbon dioxide (Xing *et al.*, 1997; Horiuchi *et al.*, 2002). The diagram below summarizes the stages involved in anaerobic digestion of organic molecules.

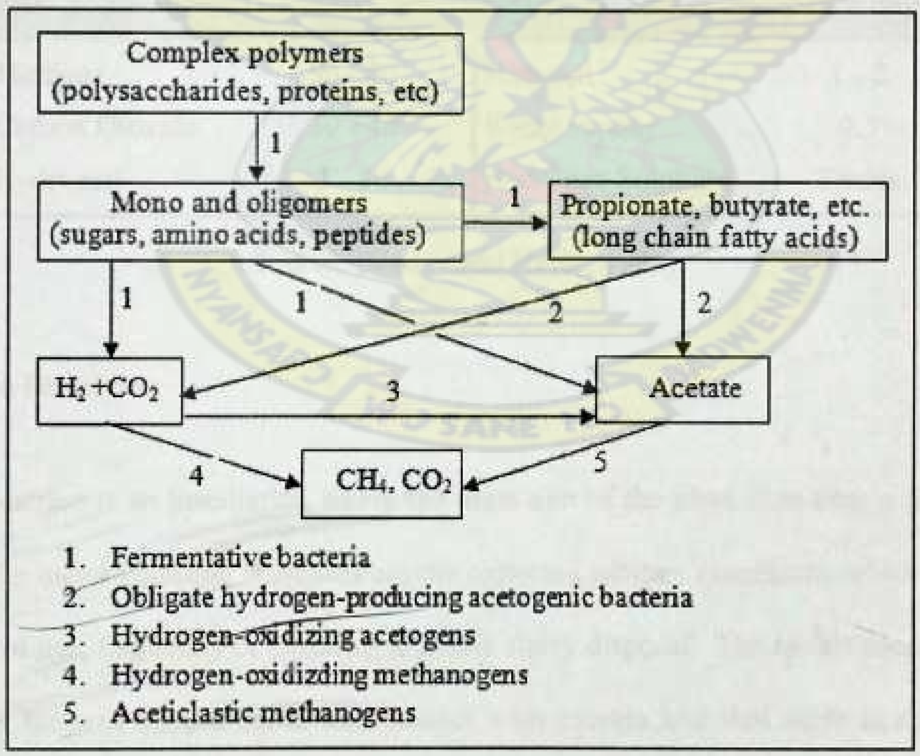

Figure 3-1: Enzymatic pathway for biogas production
Source: (Nagamani and Ramasany, 2007)

3.2 Biogas

Biogas is a by-product of anaerobic digestion and consists of a mixture of organic and inorganic gases. It is a colourless gas with a faint unpleasant smell and burns with a clear blue flame similar to that of Liquefied Petroleum Gas (Sathianathan 1975). Biogas is about 20 % lighter than air and burns with an ignition temperature in the range of 650 ^{0}C to 750 ^{0}C. It has a calorific value of 4500 – 5000 kcal/m^3 when its methane content ranges from 60 % to 70 % (Madu and Sodeinde, 2001). The domestic uses of biogas include cooking and lighting. Gas pressures of 5 – 20 cm WC (water column) are best for cooking while a pressure of 10 cm WC is good for lamps (Sasse, 1998). In agriculture, biogas is used as fuel in stationary and mobile engines, to supply motive power, pump water, drive machinery (e.g., threshers, grinders) or generate electricity. Table 3.1 gives the composition of biogas.

Table 3.1: Composition of biogas

Gas	Percentage	Gas	Percentage
Methane	50 - 70	Nitrogen	1 - 2
Carbon Dioxide	30 - 40	Water vapour	0.3
Hydrogen	5 - 10	Hydrogen Sulphide	Traces

Source: (Yadav and Hesse, 1981)

3.3 The Biolatrine

The biolatrine is an installation where the main aim of the plant is to treat nightsoil from latrines. The major planning standards are the expected sanitary conditions which depend on frequency of use, frequency of cleaning, and safe slurry disposal. The latrine must be built to ensure that humans do not come into contact with excreta and that there is no access of undigested excreta to flies. In addition, bad odour should be avoided. Slurry should be used for fertilizing trees or shrubs but not vegetables (Sasse *et al*, 1991). The slurry may also drain into a soak pit. Flushing toilets are not suitable for connection to biogas plants of less than 30 m^3 digester volume because of the danger of reducing the retention time (Sasse *et al*, 1991).

3.4 The Biogas Plant

A typical simple biogas plant consists of a slurry mixing tank, a digester, a gasholder, a compensating tank, a slurry storage tank, a slurry distribution canal, a gas piping system, and a biogas appliance. Additional components such as stables, latrines, rain water tanks, fish ponds, compost pits, and demonstration fields could as well be part of the biogas unit. The various parts of the biogas plant are discussed below. Figure 3-2 shows some of the important parts of a biogas plant.

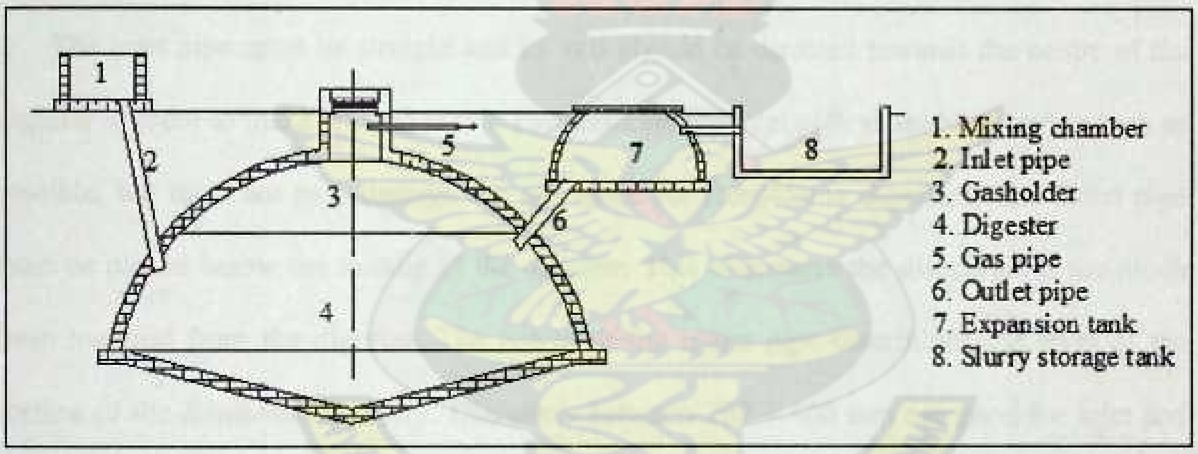

Figure 3-2: Some of the main parts of a biogas plant

3.4.1 The Mixing Tank

The feed material is mixed with water in the mixing tank. Some designs make it possible to poke the digester directly from the mixing tank. An inlet pipe links the mixing tank to the digester. The inlet pipe should be connected a few centimetres above the bottom of the mixing tank to prevent grit and sand, which have settled on the bottom, from entering the digester. A circular shape is ideal in terms of cost and operation (Sasse, 1988).

3.4.2 The Compensating (Expansion) Tank

The design and construction of the compensating tank (CT) should be well done. The bottom tip of the compensating tank must correspond to the zero or filling line. If the bottom of the CT is too low, some portion of the slurry is exposed to air and if too high the gas pressure rapidly becomes very high. The shape of the CT is very critical as it determines the height of the slurry surface and therefore the gas pressure. A low CT leads to low and stable gas pressures.

3.4.3 Inlet and Outlet Pipes

The inlet pipe must be straight and its axis should be directed towards the centre of the digester in order to make stirring easier. Furthermore, the inlet pipe should be fixed as high as possible, but must not pass through the gas space for fixed-dome digesters. The outlet pipe must be placed below the middle of the digester. This eliminates the discharge of too much fresh material from the digester. The height of the outlet pipe determines the level of the surface of the fermentation slurry. Diameters between 200 – 400 mm are good for inlet and outlet pipes when the feed material is fibrous while a 100 mm diameter is good for non-fibrous feed materials (Sasse, 1998). PVC pipes are ideal for use as inlet and outlet pipes.

3.4.4 The Entry Hatch

The construction of a fixed-dome entry hatch is important since poor design of the hatch can lead to gas leakage. The gas pipe should penetrate the shaft a few centimetres below the cover. The cover is sealed with screened and well-run clay and the bottom of the cover is sealed with paraffin. Weights are placed on top to keep it firmly in position and the shaft is filled with water to keep the clay gastight.

3.4.5 The Bottom Slab

The bottom slab receives the weight of the digester wall at its edge and distributes the weight over the ground. There is a risk of slab breakage if it is too weak and if the ground is of unequal uniformity. A rigid shell distributes loads better than a soft slab and a vaulted shell is the best foundation even though a conical shell is easier to excavate.

3.5 The Biogas Digester

The digester is the physical structure that provides anaerobic conditions for the generation of biogas. It must be both water- and air-tight in order to prevent seepage of water into soil and leakage of biogas into the air respectively. It must also have good insulation properties in order to ensure a stable temperature for the digestion process. Furthermore, it must be able to withstand all static and dynamic loads in addition to having a minimum surface area in order to bring down the cost of construction.

The most common types of biogas digesters include fixed-dome digesters, floating-drum digesters, bag digesters, plug flow digesters, anaerobic filter digesters, UASB (Upflow Anaerobic Sludge Blanket), earth pit digesters, lagoons, and complete mix digesters. Apart from the fixed-dome and the floating-drum types, the rest are rare in Ghana and the technologies of those plants have not been adapted to Ghana's conditions.

3.5.1 The Fixed-dome Digester

A fixed-dome digester comprises a closed, dome-shaped digester with an immovable, rigid gasholder and a displacement pit, called the expansion or compensating tank. Biogas is stored in the upper part of the digester. The accumulating gas needs room and pushes part of the substrate into the expansion tank, from where the slurry flows back into the digester as soon as gas is released. The volume of the expansion chamber is equal to the volume of gas stored. Figure 3-2 shows the various parts of the fixed-dome digester. The advantages of fixed-dome digesters include low construction cost, no moving parts, no steel parts, long life (over 20 years), and stable digestion temperature. Its disadvantages include gas pressure fluctuation, high gas pressures, development of cracks along the gasholder, and low digester temperatures (Sasse, 1988; Sasse *et al*, 1991).

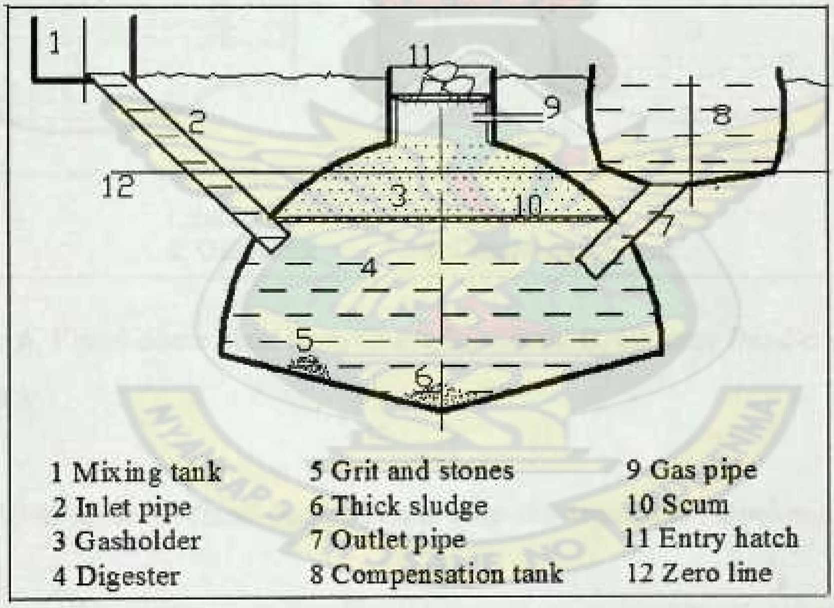

Figure 3-3: The fixed-dome digester

Source: (Hohlfeld and Sasse, 1986)

Several variations of the fixed-dome plant have been developed from the Chinese design. These variations have achieved several objectives including reduced construction cost due to a reduction in the use of building materials, improved performance, and increased durability. Some of the most notable models are briefly described below.

3.5.1.1 The Chinese Dome

This is the archetype of all fixed dome plants. The digester consists of a cylinder with a round top and a round bottom. Both inlet and outlet channels are made from PVC pipes. A modified version of this model, developed in Chengdu, has both inlet and outlet pipes made of concrete. Figure 3-3 juxtaposes the Chinese fixed-dome and the Chengdu design.

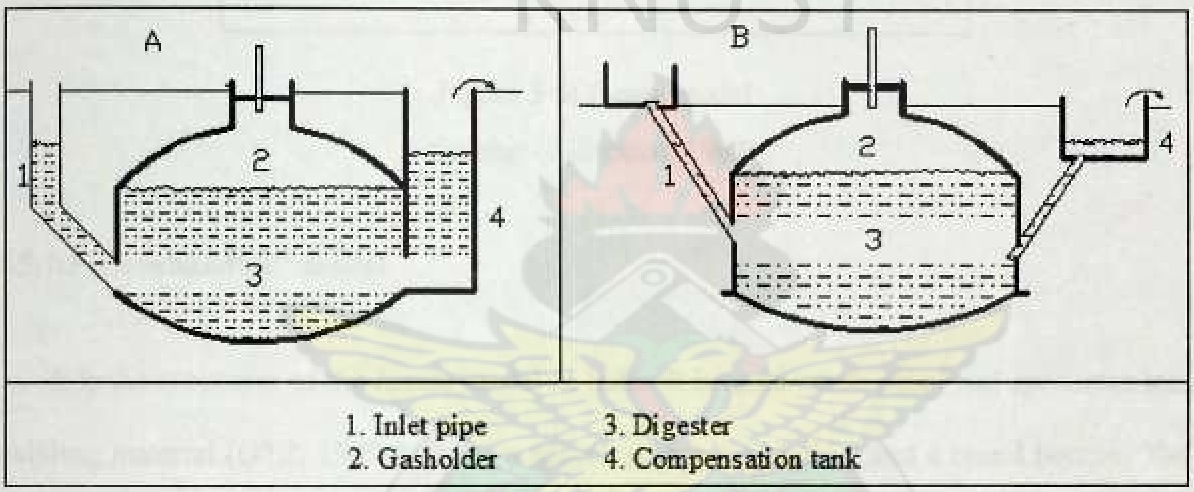

Figure 3-4: A, Fixed-dome plant from Chengdu, China; B, Chinese fixed-dome plant
Source: TBW

In Ghana, six 10 m^3 Chinese fixed-dome models were constructed at Appolonia in 1987.

3.5.1.2 Janata Model

The Janata (people's) model (Figure 3-5), developed in the late 1970s, was the first fixed-dome design in India and was built with a brick-reinforced moulded dome (Myles, 2008). It has an inlet chamber directly attached to the digester and a rectangular outlet

(Myles, 2008). It is not constructed anymore due to the leaky nature of the gasholder. It is unknown whether this model has been disseminated in Ghana.

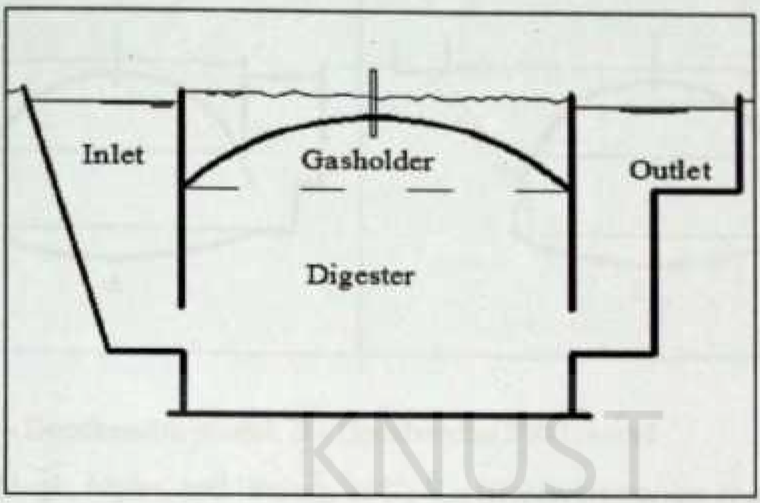

Figure 3-5: Janata model

Source: (Lichtman, 1983)

3.5.1.3 Deenbandhu[22] model

It is the successor of the Janata model in India. It is more crack-proof and consumes less building material (GTZ, 1999c). It has a spherical shape gasholder and a round bottom. The digester is constructed from ferrocement[23]. A modified form of this model, known as Deenbandhu 2000, has a dome-shaped expansion tank as opposed to the square-like shape of the earlier model. This model was developed by Action for Food Production, India. Figure 3-5 shows two variations of the Deenbandhu design. The Deebandhu model proved 30 per cent cheaper than the Janata Model and about 45 per cent cheaper than a KVIC[24] plant of comparable size in India (FAO-Nepal, 1996).

[22] Hindi word meaning friend of the poor

[23] Ferrocement is composite material containing cement, sand, water, and wire or mesh material.

[24] A type of floating-drum plant; see sub-section 3.5.2.2

Deenbandhu plants with spherical expansion tanks were built at Appolonia in Ghana as part of the Appolonia Household Programme in 1987.

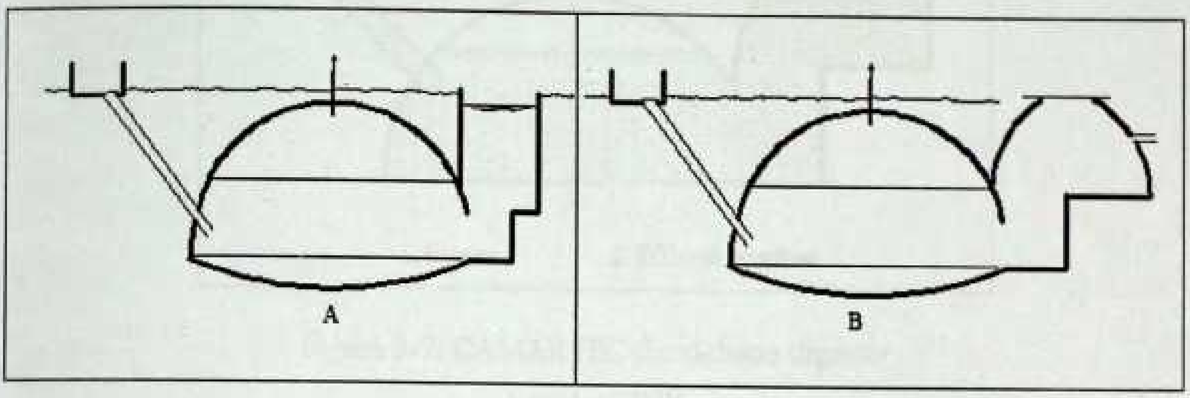

Figure 3-6: A - Deenbandhu model; B - Deenbandhu 2000 model

Source: A – (Singh, Myles, and Dhussa, 1987; B – (Balasubramanian *et al*, 2008)

Three years later, Prof. Coleman[25] and a team of engineers form the Institute of Industrial Research disseminated five household Deenbandhu digesters (variation A) at Okushibli, about 5 km from Appolonia, in the Greater Accra Region.

3.5.1.4 CAMARTEC Model

The CAMARTEC[26] model, developed in the late 80s in Tanzania, has a simplified structure of a hemispherical dome shell based on a rigid foundation ring only and a calculated joint of fraction, known as the weak / strong ring. It has a flat base and with the expansion tank directly attached to the digester. The major disadvantage is its high cost (Maree *et al*, 2007). Figure 3-7 shows a diagram of the CAMARTEC model.

[25] Biogas expert and founder of Global Renewable Energy Services, a biogas construction firm in Ghana

[26] Centre for Agricultural Mechanization and Rural Technology

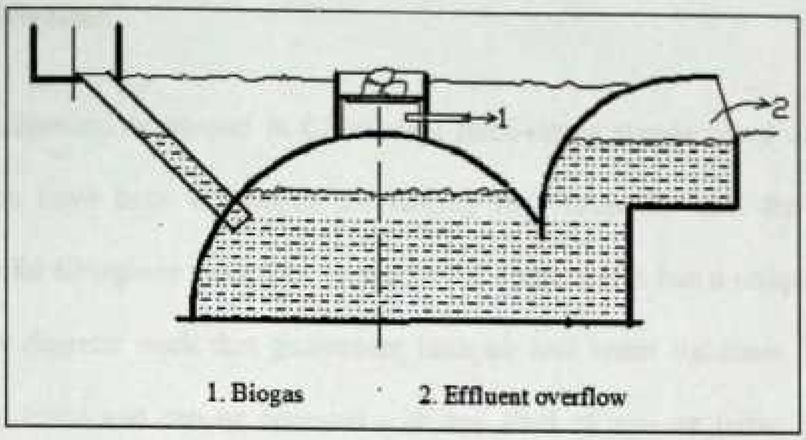

Figure 3-7: CAMARTEC fixed-dome digester
Source: TBW

This model has been constructed in Ghana mainly by Dr. Elias Aklaku, a biogas expert and founder of Biogas Engineering Limited (BEL), a major biodigester constructing company. CAMARTEC digesters with two expansion tanks have been constructed by TIE (Technology for Improved Environment) in two slaughterhouses located at KNUST and Ejura in the Ashanti Region.

3.5.1.5 Nicarao Model

This model has a cylindrical digester with a concave bottom and a dome-shaped gasholder with a manhole at the top. The expansion tank has the shape of a square. This design is schematically illustrated in Figure 3-8. This model is not known to have been built in Ghana.

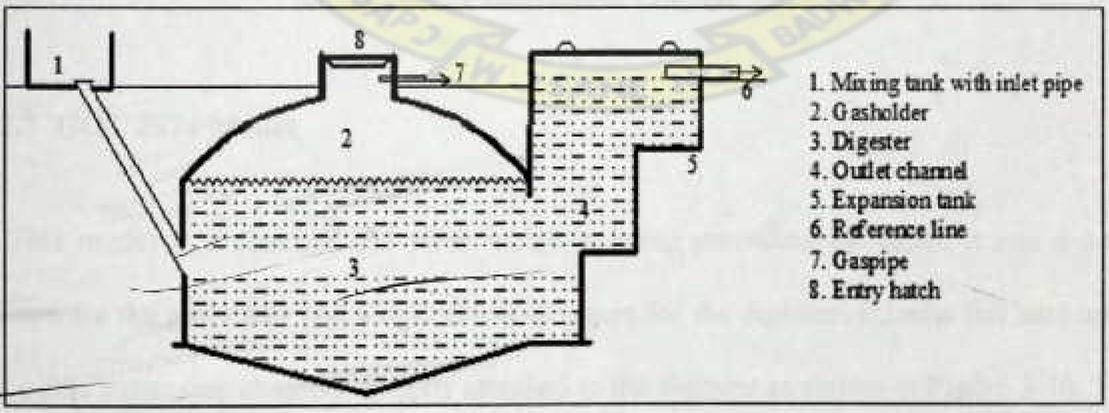

Figure 3-8: Nicarao design
Source: TBW

3.5.1.6 Puxin Digester

The Puxin digester, developed in China, is a fixed-dome standardized digester. Special concrete moulds have been developed for casting the "stomach" and the "neck" of the digester. A special fibreglass gasholder serves as the dome and it has a unique way of being mounted on the digester neck that guarantees both air and water tightness This digester is easy and fast to build and can be operated with any kind of manure (cow, pigs, etc), solid biowaste, as well as sewage (Arthur, Forthcoming). More than 20 installations have been constructed in Ghana by Beta Construction Limited since 2006. A diagram of this digester is shown in Figure 3-9.

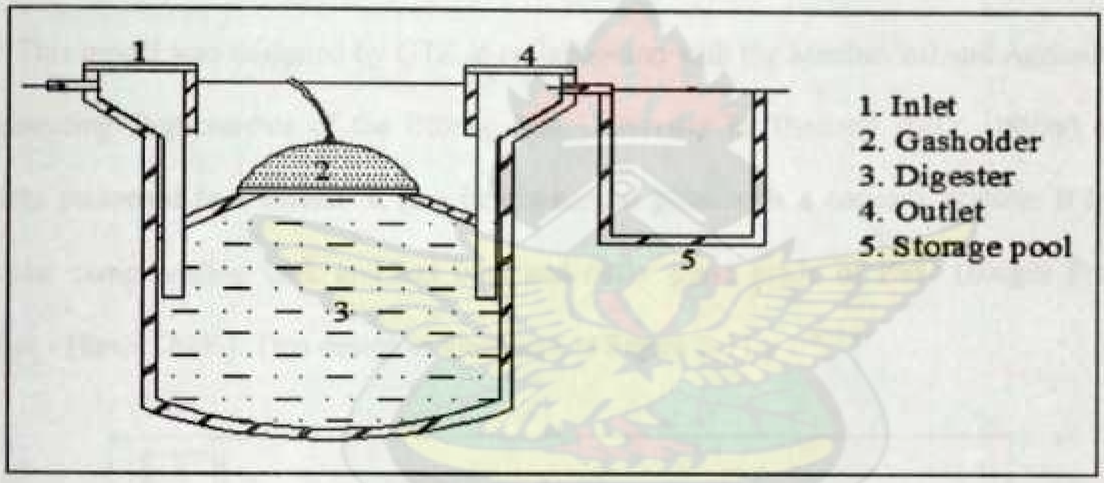

Figure 3-9: Puxin digester

Source: Beta Construction Limited, 2008

3.5.1.7 GGC 2074 Model

This model is a standardized plant which is being promoted in Nepal. It has a dome structure for the gasholder and a cylindrical structure for the digester. It has a flat base and a square-like expansion chamber directly attached to the digester as shown in Figure 3-10. This design has not been built in Ghana.

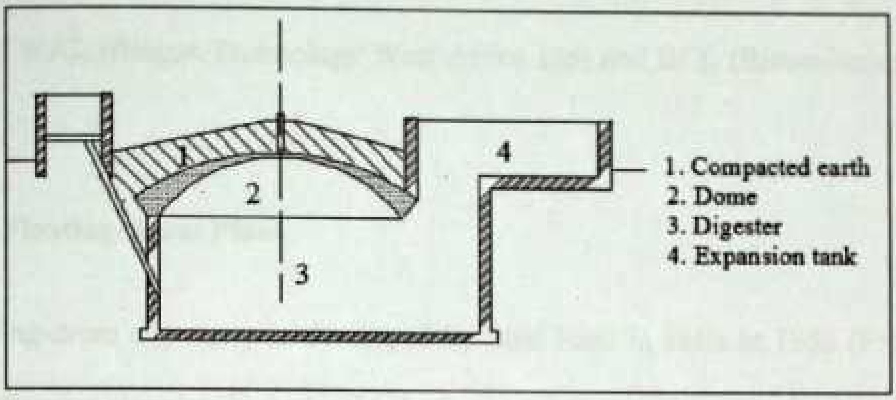

Figure 3-10: GGC fixed-dome model

Source: GGC/BSP-Nepal, 1994

3.5.1.8 KT2 Model

This model was designed by GTZ in collaboration with the Mechanical and Agricultural Engineering Departments of the Chiang Mai University in Thailand (GTZ, 1999a). It is widely promoted in Vietnam. It is a hemispherical plant with a concave bottom. It has a circular compensating tank and has inlet and outlet pipes made of PVC (Biogas Project Office - Hanoi, 2006). This design is illustrated in Figure 3-11.

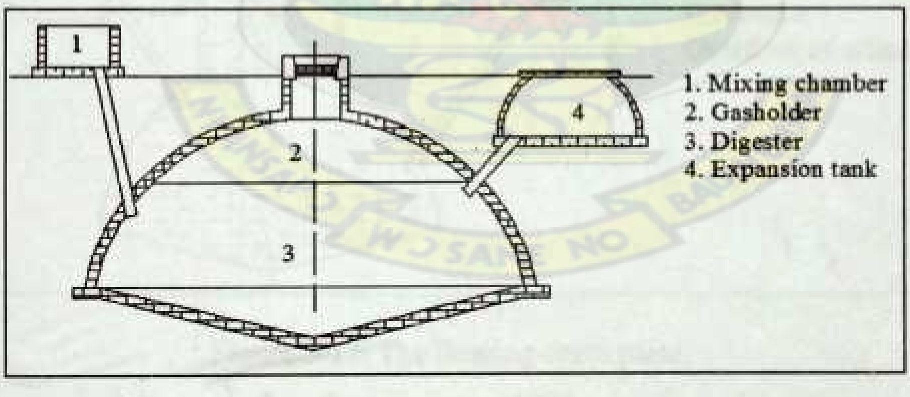

Figure 3-11: KT2 fixed-dome model

Source: BPO, 2006

Designs similar to this model have been disseminated in Ghana by biogas companies including BTWAL (Biogas Technology West Africa Ltd) and BCL (Biosanitation Company Ltd.).

3.5.2 The Floating-drum Plant

The floating-drum digester was developed by Bhai Patel in India in 1956 (FAO – Nepal, 1996). The digester chamber is made of brick masonry in cement mortar and a steel drum is placed on top of the digester to collect the gas. The gasholder (steel drum) floats either directly in the fermenting slurry or in a separate water jacket. Other materials that have been used successfully as gasholders are glass-fibre reinforced plastic, high density polyethylene, and wire-mesh-reinforced concrete (requires a gaslight, elastic internal coating) (Sasse, 1988; GTZ, 1999c). PVC drums are unsuitable because they are not resistant to UV radiation. Figure 3-11 gives the parts of the floating drum digester.

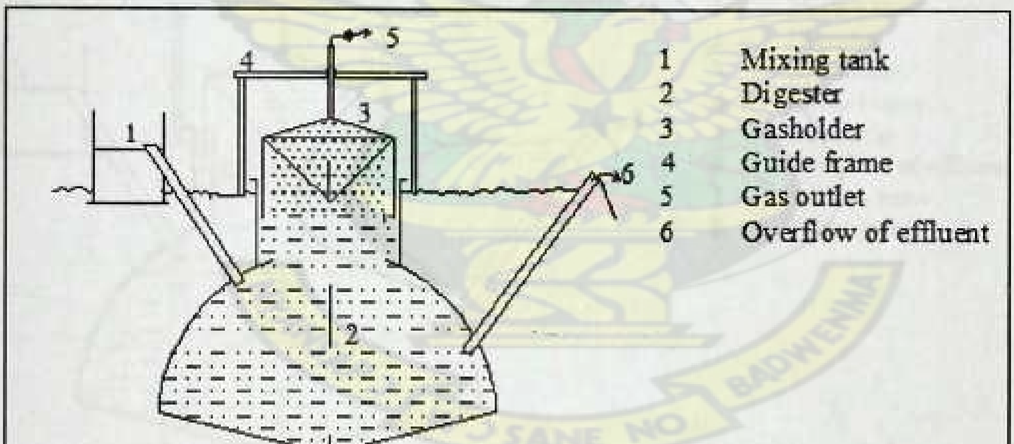

Figure 3-12: The floating-drum plant
Source: Sasse, 1988

Floating-drum plants are simple in terms of construction and operation. Gas is delivered at constant pressure and volume of gas is easily estimated. On the other hand, investment costs are on the high side compared with fixed-dome digesters of the same volume. The steel drum is expensive to fabricate and steel parts are liable to corrosion, resulting in short life of up to 15 years, and in tropical coastal regions about five years for the drum (Sasse, 1988). In spite of these disadvantages, floating-drum plants should be recommended in cases of uncertainty regarding the expertise of the designer or the construction personnel (Sasse, 1988).

3.5.2.1 Water-jacket Floating-drum Plant

In the water-jacket floating-drum plant, the drum floats in a water reservoir instead of floating directly on the slurry (Figure 3-13). They are suitable for handling feed materials with high solids content and also for treating human excrement (Sasse, 1988). The rusting of the drum is relatively slow. Blockage of drum due to scum formation is also prevented. Floating-drum plants with water-jackets are universally applicable and easy to maintain.

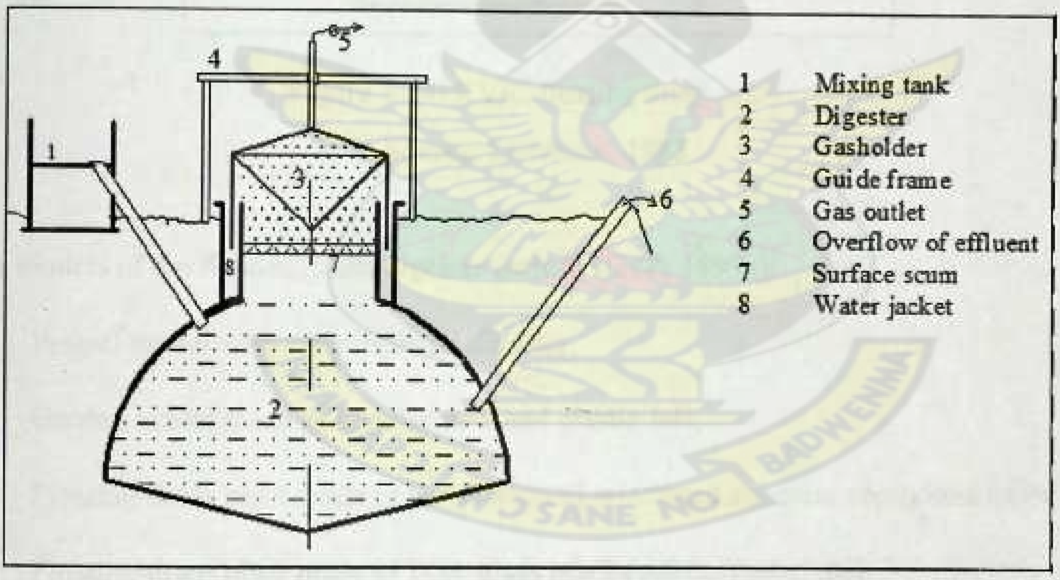

Figure 3-13: Water-jacket floating drum plant (BORDA model)

Source: Hohlfeld and Sasse, 1986

3.5.2.2 KVIC Model

The KVIC[27] design consists of a deep, well-shaped underground digester connected with inlet and outlet pipes at the bottom, just opposite to each other but are separated by a partition wall dividing the digester into two equal parts (Figure 3-14). The height of the partition walls is three-fourth of the total height of the digester (Myles, 2008).

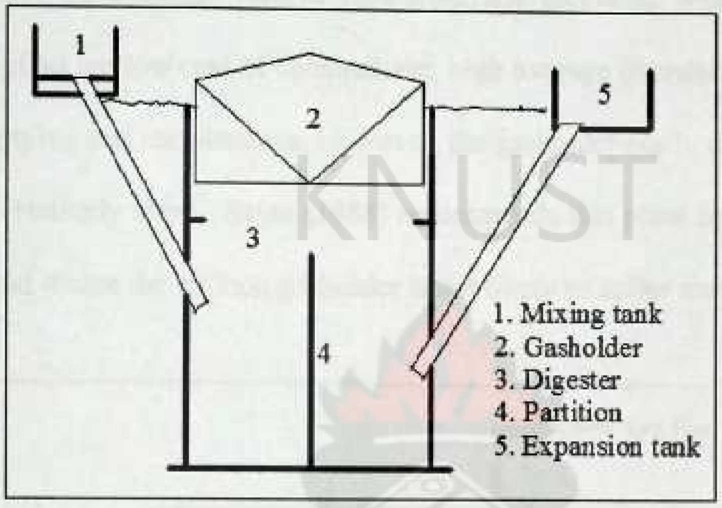

Figure 3-14: KVIC floating drum plant
Source: Lichtman, 1983

Other models of the floating-drum digester include (GTZ, 1999c):

- Pragati model with a hemispheric digester;
- Ganesh model made of angular steel and plastic foil;
- Floating-drum plant made of pre-fabricated reinforced concrete compound units;
- Floating-drum plant made of fibre-glass reinforced polyester; and
- BORDA[28] model - combines the static advantages of hemispherical digester with the process-stability of the floating-drum and the longer life span of a water jacket plant.

[27] KVIC (Khadi and Village Industries Commission) is a statutory organization which aims, inter alia, at promoting research in non-conventional energy in India.

[28] Bremen Overseas Research and Development Association

3.5.3 The Balloon Plant

A balloon plant has a rubber or plastic bag at the upper part of the plant and serves as the gasholder (Figure 3-15). The balloon material must be UV-resistant; materials that have been used successfully include RMP (Red Mud Plastic)[29] and Trevira[30]. The plant behaves like the fixed-dome plant when the gasholder is full of gas. According to Sasse (1988), balloon plants have been successful in digesting various feed materials including water hyacinths. The advantages of this plant are low cost of construction, high average digester temperatures, and uncomplicated emptying and maintenance. However, the gasholder easily deteriorates and the overall lifespan is relatively short. Sasse (1988) recommends this plant only for places with high water tables and where the balloon gasholder is not likely to suffer mechanical damage.

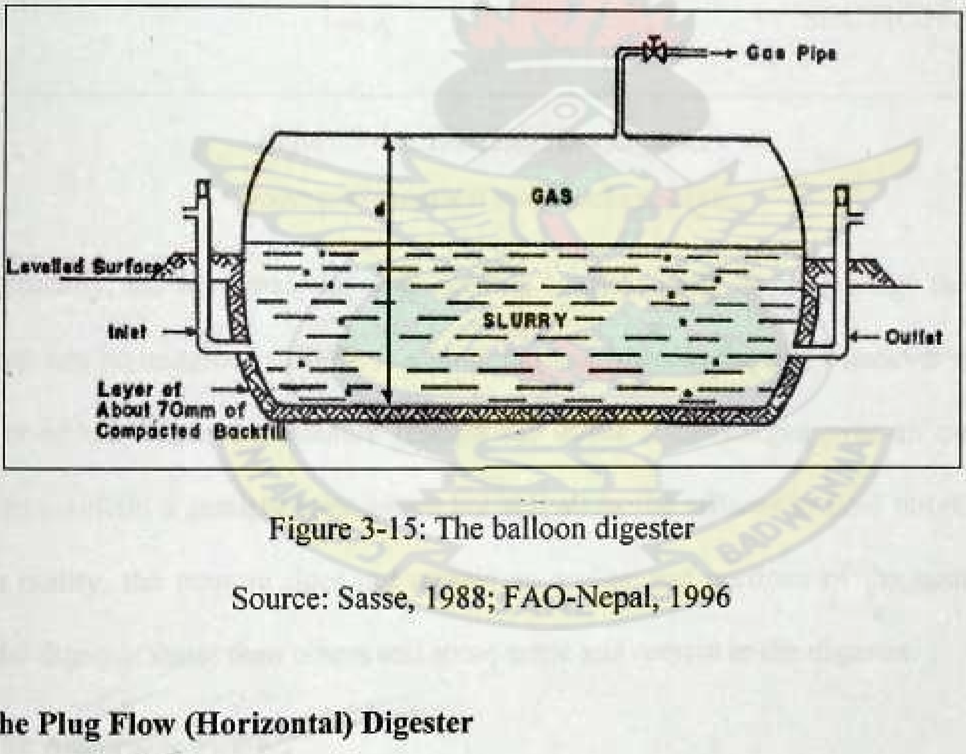

Figure 3-15: The balloon digester

Source: Sasse, 1988; FAO-Nepal, 1996

3.5.4 The Plug Flow (Horizontal) Digester

The plug flow digester was first used in South Africa in 1957 (FAO-Nepal, 1996). The digester is in the form of a long narrow (typically a 5:1 ratio; 5 times as long as the width)

[29] RMP is a composite material made from a combination of waste PVC compounds and waste red-mud.

[30] Trevira is a thermoplastic polymer with good air and water resistant properties (Wikipedia, 2009).

insulated tank made of reinforced concrete, steel, fiberglass, or any impermeable membrane. The digester is covered with either a flexible polymer such as EPDM[31], concrete or galvanized iron. It is best suited for dairy manure that has solids concentration of 11-14 % (EPA, 1997). Swine manure has not been successfully digested in plug flow digesters because of the low fibre content. Figure 3-16 shows a sketch of the plug flow reactor.

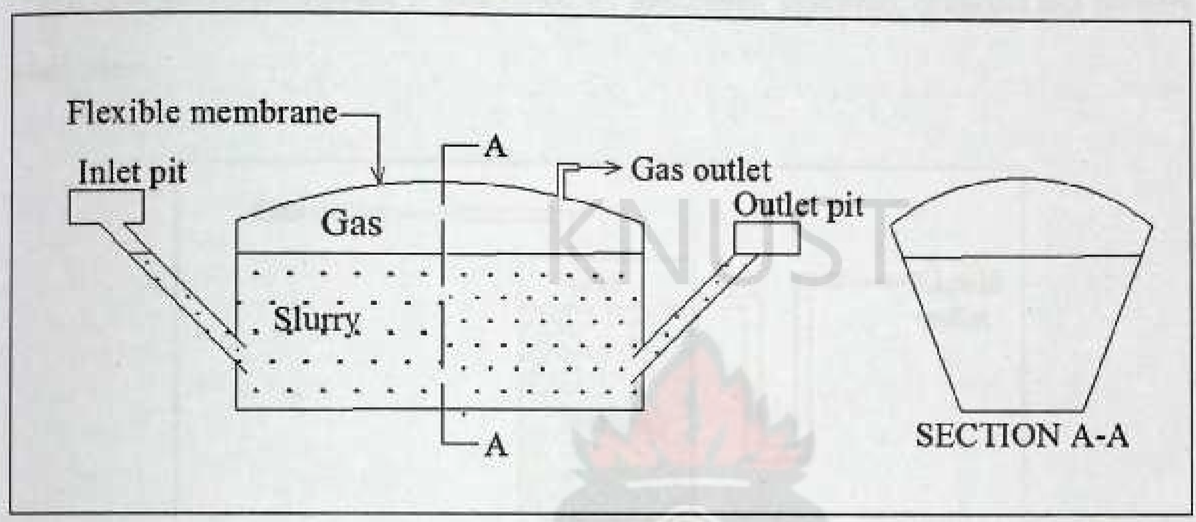

Figure 3-16: The plug flow digester
Source: Gunnerson and Stuckey, 1986

Theoritically, the feed material does not mix longitudinally on its passage through the digester but can be imagined to flow as a plug, moving towards the exit whenever fresh feed material is added. When the manure reaches the outlet it discharges over an outlet weir arranged to maintain a gastight atmosphere but still allow the effluent to flow out (Converse, 2002). In reality, the manure does not remain as a plug and portions of the manure flow through the digester faster than others and some settle and remain in the digester.

3.5.5 The Anaerobic Filter

This digester was developed for the treatment of dilute and soluble waste water with low level of suspended solids (FAO-Nepal, 1996). The digester has in its column a non-

[31] EPDM (ethylene propylene diene M-class rubber) is an elastomer used for applications such as vehicular weather seals, waterproof roofing, and pond lining (Wikipedia; December, 2008).

biodegradable packing medium (Figure 3-17). Materials that have been successfully used as packing medium include stones, plastic, coral, mussel shells, reeds, and bamboo rings.

The large surface area of the packing materials provides a micro-climate for the growth of methanogens. Since the methanogens are retained in the digester and not carried away in the effluent, this digester is often christened fixed-film or retained-film digester (USAID, 1984). The anaerobic digester is best suited for fermenting industrial, chemical and brewery wastewater.

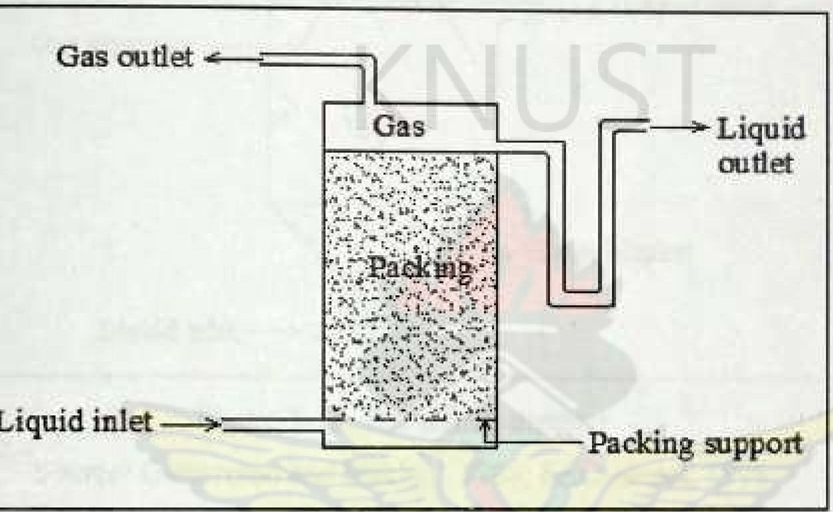

Figure 3-17: The anaerobic filter
Source: Gunnerson and Stuckey, 1986

3.5.6 Upflow Anaerobic Sludge Blanket (UASB)

This digester was developed in Holland in 1980 and is very common in Europe. Similar to the anaerobic filter, it has in its column a large concentration of immobilized bacteria including methanogens. However, unlike the anaerobic filter, the UASB contains no packing materials; instead, the bacteria are found in dense granules of sludge blanket covering the lower part of the digester. The feed material (wastewater) enters the digester via the bottom and organic materials are anaerobically fermented as the liquid feed material flows up through the sludge blanket (Figure 3-18).

The UASB digester is ideal for treating dilute wastewater from breweries, sugar beet processing factories, etc. In Ghana, a UASB digester can be found at Guinness Ghana Breweries Limited in Kumasi (see Appendix D for details).

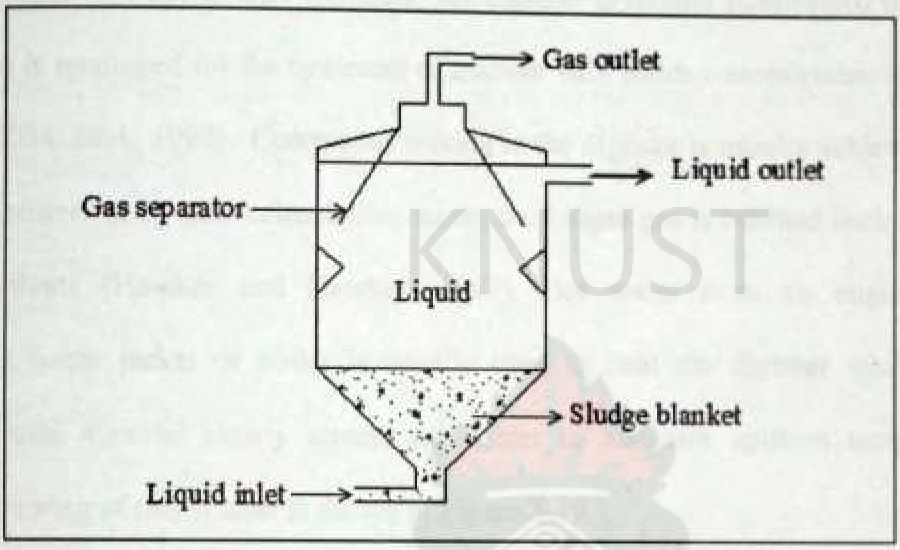

Figure 3-18: The UASB digester
Source: Gunnerson and Stuckey, 1986; FAO-Nepal, 1996

3.5.7 The Covered Lagoon Digester

The Lagoon digester is simple to design and construct and is usually suited for bovine or dairy operations. It usually consists of an anaerobic combined storage and treatment lagoon, an impermeable flexible plastic cover serving as the gasholder, an evaporative pond for the digester effluent, and a gas treatment and/or energy conversion system. The Covered Lagoon digester typically has a hydraulic retention time (HRT) of 40 to 60 days and is used for feed materials containing less than 2 % solids (EPA, 1997). A collection pipe leading from the digester carries the biogas to either a gas treatment system such as a combustion flare, or to an engine/generator or boiler that uses the biogas to produce electricity and heat. After treatment, the digester effluent is transferred to an evaporative pond or to a storage lagoon prior to land application.

3.5.8 The Complete Mix Plant (Continuous Stirred Tank Reactor, CSTR)

This plant consists of a mixing tank, a complete mix digester (reactor) and a secondary storage or evaporative pond. The complete mix digester is usually constructed from steel or concrete and is employed for the treatment of manure with solids concentration of 3 to 10 % (Parawira, 2004; EPA, 1997). Continuous mixing in the digester is usually achieved by using mechanical stirrers or by gas recirculation, where the biogas gas is bubbled back through the digester contents (Hawkes and Hawkes, 1987). Hot water from an engine/generator cogeneration water jacket or boiler is usually used to heat the digester whiles a pump circulates waste material slowly around the heater to maintain uniform temperature. A schematic drawing of this system is shown in Figure 3-19.

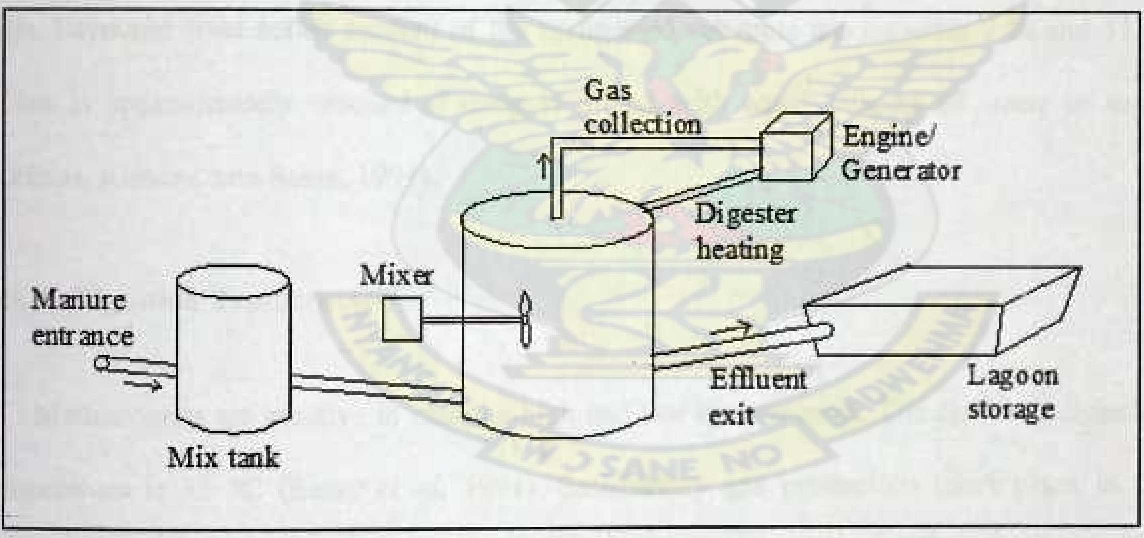

Figure 3-19: Complete mix digester
Source: EPA, 1997

3.6 Design Parameters of a Biogas Plant

The metabolic activity involved in microbiological methanation is dependent on the following factors:

3.6.1 Digester Loading Rate

The digester loading indicates how much organic material per day is supplied to the digester. It is calculated in kilograms of organic dry matter (ODM) per cubic metre of digester volume per day (kg ODM/m³/day). Low digester loadings lead to long retention times. The pH falls if the digester loading is too high.

3.6.2 Dilution and Consistency of Inputs

Slurry separates less if the feed material is homogeneous and the total solids content is high. Favoured total solids content of the undigested substrate are between 7 % and 11 % which is approximately reached if dung is mixed with equal volume of water or urine (Kellner, Kimaro, and Sasse, 1991).

3.6.3 Digestion Temperature

Methanogens are inactive in extreme high and low temperatures. The optimum digestion temperature is 35 °C (Sasse *et al*, 1991). Satisfactory gas production takes place in the mesophilic range, between 25 and 35 °C. When the ambient temperature is 30 °C or less, the average temperature within the dome remains about 4 ^{0}C above the ambient temperature (Lund, Andersen and Tony-Smith, 1996).

3.6.4 Retention time

The retention time is the average period that a given quantity of input remains in the digester. It is appreciably shorter than the total time required for complete digestion of the feed material. It is a function of the digestion temperature. Optimum retention times for the various digestion temperatures are: psychrophilic (10 – 21 ^{0}C, over 100 days), mosophilic (20 – 35 ^{0}C, over 20 days), and thermophilic (50 – 60 ^{0}C, over 8 days), (Sasse, 1988).

Longer retention times save energy and ensure that the effluent is safe and that harmful pathogens are destroyed (FAO-Nepal, 1996). Harmful micro-organisms such as typhoid, para-typhoid, vibro-cholerae, and dysentery bacteria are destroyed in 14 days, while hookworm and bilharzia take 21; tapeworm and roundworm die only when the fermented slurry is sun dried (Sasse, 1988). Therefore, Sasse (1988) recommends retention times of at least 30 days for plants digesting dung at a mean temperature of 28 ^{0}C.

Experiences from Ghana, Tanzania, Kenya, China, India, and Nepal show the importance of choosing correct retention times especially for the digestion of human excreta. In Nepal, digesters are designed using a retention time of 50 - 60 days for dung only, and 70 – 80 days for nightsoil (FAO-Nepal, 1996); GGC standardized models are designed with a retention time of 70 days (GGC/BSP, 1994). In Punjab State of India, Singh and Sooch (2004) has reported of standardized Deenbandhu plants designed with a retention time of 40 days for the treatment of dung at an average temperature of 25 ^{0}C.

In Kenya, the average retention time of the Meru plant is 90 days if the digester is fed with the designed feeding rate of 100 litres of slurry daily (Laichena and Wafula, 1997). In Ghana, majority of biogas plants treat nightsoil; see Section 4.8 for retention time used by biogas service providers.

3.6.5 Substrate pH

The optimum biogas production is achieved when the pH value of input mixture is about 7 (Sasse *et al*, 1991). The pH in a biogas digester is also a function of the retention time and it is favoured by long retention times. Methanogenic bacteria are very sensitive to pH and do not thrive below a value of 6.5 or above 8.5. When the methane production level is stabilized, the pH range remains buffered within 7.2 to 8.2 (FAO – Nepal, 1996). A healthy digestion process shows a pH of 7.0 (Sasse *et al*, 1991).

3.6.6 Carbon/Nitrogen (C/N) ratio

The C/N ratio indicates the relative amounts of carbon and nitrogen in organic materials. A C/N ratio ranging from 20 to 30 is considered optimum for anaerobic digestion (Sasse, 1988). If the C/N ratio is very high, the nitrogen will be consumed rapidly by methanogens and will no longer react on the left over carbon content of the material. On the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of ammonia (NH_3) which will lead to high pH values. Materials with high C/N ratio could be mixed with those of low C/N ratio to bring the average ratio of the composite input to a desirable level (FAO –Nepal, 1996; Idan, 2007). C/N ratio of some of the commonly used materials is presented in Table 3-1.

Table 3-1: C/N ratio of commonly used feedstock

Organic material	C/N ratio	Organic material	C/N ratio
Cow dung	24	Goat manure	12
Human excreta	8	Pig manure	18
Chicken droppings	10	Water hyacinth	25
Straw (maize)	60	Straw (rice)	70

Source: Karki and Dixit, 1984

3.7 Sizing Parameters

3.7.1 Retention Time (RT)

The retention time is a determining factor of the size of the digester and hence the cost of the plant. It also depends on economic circumstance of the user assuming the user pays for the entire cost of the plant. It has a direct bearing on the size (volume) of the digester.

A biogas plant designer must choose a retention time based on several considerations, notably, the digestion temperature, the type feed material, the end use of the digested slurry, and the economic capability of the biogas user. If the plant is to treat nightsoil, then priority must be given to retention times that result in reduction of pathogens to acceptable levels for safe disposal. For plants handling cow dung with a focus on energy, long retention times are worthwhile even though investment costs are higher. In summary, the designer must conform to guidelines that recommend parameters such as the minimum retention time for a specified feed material at a specified digestion temperature.

3.7.2 Digester Size

The volume of the digester in cubic meters, V_D, is determined by:

$$V_D = S_D \times R_T \quad \text{...... 3-1}$$

Where S_D= daily supply of fermentation slurry in cubic meters; and

R_T= retention time, in days.

3.7.3 Gasholder size

The gasholder volume (V_G) depends on the daily gas production and the pattern in which the biogas is used. The rate of gas production, in turn, is dependent on the type of feed material, the digestion temperature, the retention time, frequency of stirring, and the type of digester. Long retention times, thorough mixing of fermentation slurry, and uniform temperatures favour gas production. In tropical regions such as Ghana, gas production should be estimated, at the design level, by using a temperature range of 26 – 28 ^{0}C (Sasse, 1998).

As a rule of thumb, the designer must choose a gasholder volume that is capable of accepting the volume of gas produced at a time, capable of accepting gas produced between periods of gas consumption, and capable of compensating for daily fluctutions (75 – 125 % of calculated gas production) (Sasse, 1988).

3.7.4 Gasholder Capacity

The ratio of gasholder volume to daily gas production is called the gasholder capacity; this is expressed mathematically as

$$C_G = \frac{V_G}{D_G} \quad \text{..........3-2}$$

where V_G = gasholder volume

D_G = daily gas production

The gasholder capacity measures the capacity of the biogas plant to store gas for longer periods; the larger the gasholder capacity, the larger the amount of gas that can be stored in the gasholder. Small capacities lead to gas losses whiles large capacities lead to high construction costs even though plant operation is convenient. Sasse (1988) recommends a gasholder capacity of 50 – 60 % for domestic plants in developing countries.

3.7.5 Digester/Gasholder Ratio

This ratio is a major determinant of the shape and design of a biogas plant and it affects the economics of the plant (Sasse, 1988). A ratio of 6 or more will make a spherical shell far more economical than a cylindrical shape. For floating-drum plants with a low digester/

gasholder ratio (1:1 to 3:1), the best shape for the digester is a cylinder (Sasse, 1998). If the ratio is larger, shell and vault structures are worthwhile (Sasse, 1988).

Chapter 4 – ANALYSIS OF BIOGAS PLANTS IN GHANA

4.1 Overview of Field Reports

In order to ascertain the true state of biogas plants disseminated by the various service providers, it was necessary to conduct an independent survey of a number of plants constructed. The survey was also necessary because biogas service providers do not have up-to-date information on the performance of most plants constructed. Field visits were mainly conducted between 2nd and 25th June, 11th and 18th September, 29th November and 16th December, all in 2008; additional field visits were conducted between 2nd and 13th February, 2009. Fifty (50) installations were visited, representing about 50 % of known biogas plants in Ghana[32].

The study was initially aimed at finding out the state of all plants built in Ghana but was not possible due to the inability to secure funding and the failure of most biogas service providers in providing complete data on the locations of plants disseminated. Other challenges faced include:

- withholding of some vital information by some service providers on business grounds;
- difficulty in locating biogas plants in cities, towns and villages where they have been disseminated. This was due to the fact that most inhabitants have no idea concerning the exact locations of plants located in their communities; and
- absence of a national body that keeps track of developments in the industry

All the aforementioned challenges affected the smooth gathering of data and information. Nevertheless, the depth of data gathered was enough to make generalizations on biogas

[32] See Appendix C for a list of known biogas installations in Ghana

technology dissemination in Ghana. From data gathered, most plants were located in major cities and towns, where basic amenities and utilities exist. Majority of plants had been disseminated mainly in Greater Accra and Ashanti. Table 4-1 and Figure 4-1 give the location and regional distribution of surveyed plants, respectively. In Obuasi, Anglogold Ashanti Limited has adopted biosanitation technology in treating sewage from her estates and other facilities including the company's hospital.

Table 4-1: Location of surveyed plants[33]

City/town	No. of plants	City/town	No. of plants
Appolonia (GR)	7	Abeman/Oshiuman (GR)	1
Accra (GR)	6	Tepa (AR)	1
Okushibli (GR)	5	Ejura (AR)	1
Kumasi (AR)	4	Mankranso (AR)	1
Obuasi (AR)	4	Prampram (GR)	1
Tema (GR)	2	Oyibi (GR)	1
Koforidua (ER)	2	Tetrem (AR)	1
Tamale (NR)	2	New Tafo (ER)	1
Kotoku (GR)	1	Nkawkaw (ER)	1
Hebron (GR)	1	Akwatia (ER)	1
Miotso (GR)	1	Nsawam (ER)	1
Jisonayilli (NR)	1	Battor (VR)	1
Gambaga (NR)	1	Ankarful (CR)	1

[33] GR – Greater Accra Region; NR – Northern Region; AR – Ashanti Region; VR – Volta Region; CR – Central Region

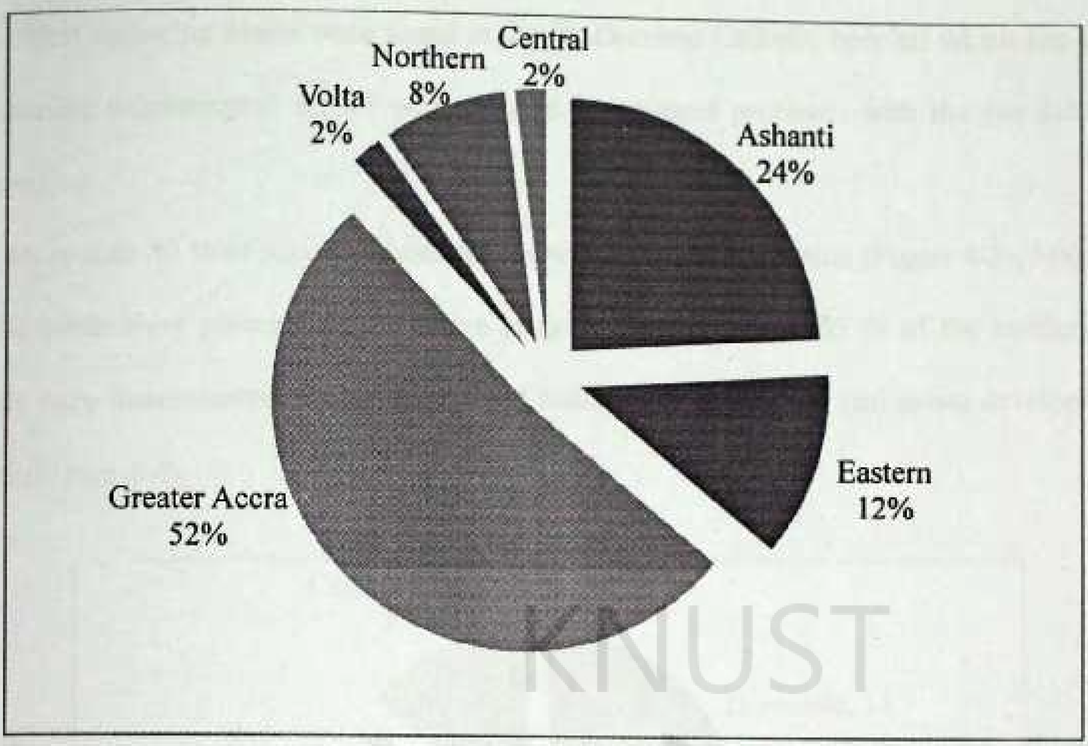

Figure 4-1: Regional distribution of surveyed plants

Of the 50 plants surveyed, 22 were in good condition, 10 were functioning even though some defects (including deteriorated gasholders, gas pipelines and appliance) were observed, 14 were not functioning, 2 were abandoned and 2 were under construction. This observation is shown in Figure 4-2.

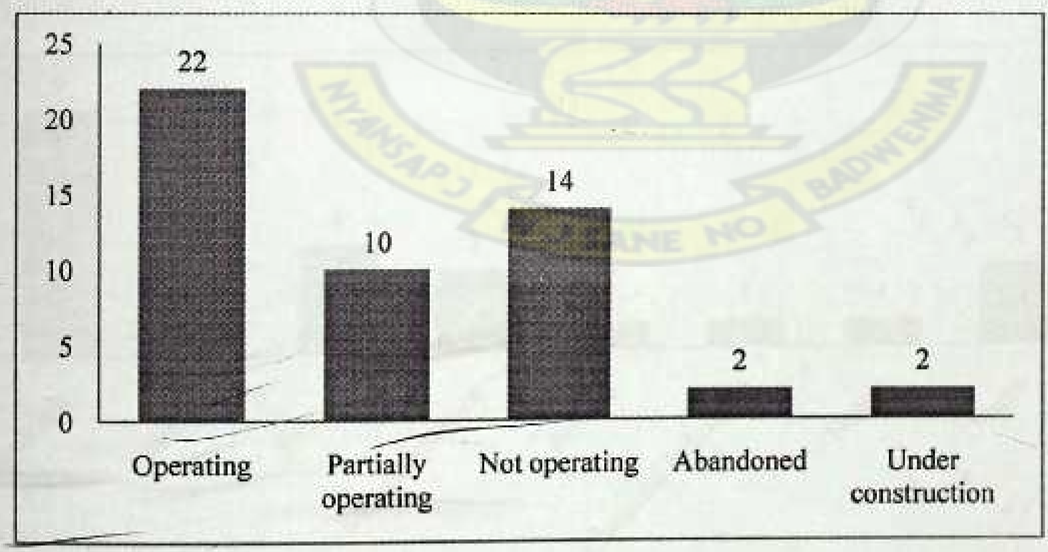

Figure 4-2: Functional status of plant at the time of visit

The oldest operating plants were found at the St. Dominic Catholic hospital which has been functioning uninterrupted for 15 years despite intermittent problems with the gas delivery systems.

More than 50 % of surveyed installations were institutional plants (Figure 4-3). Majority of the community plants were biolatrine projects and more than 65 % of the institutional plants were disseminated in educational and health institutions, and real estate development areas (Figure 4-4).

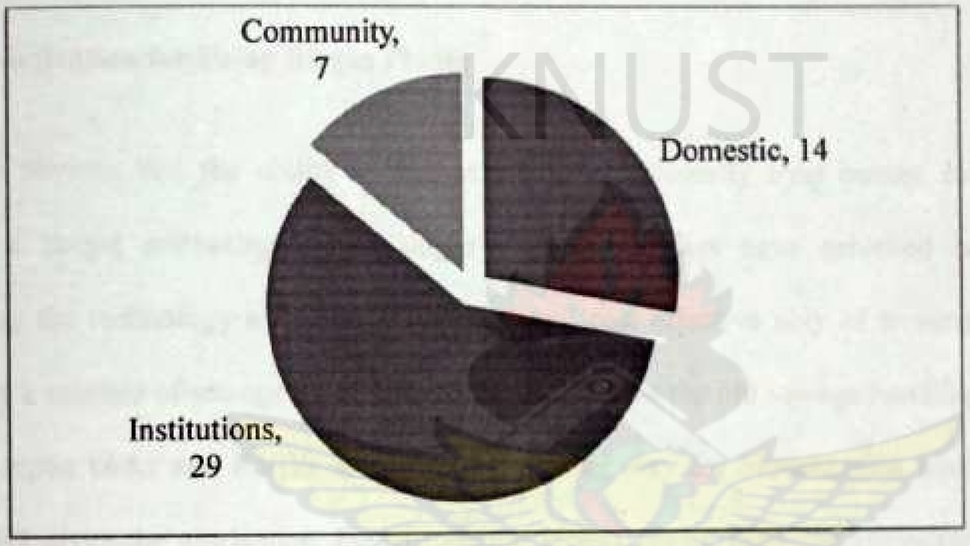

Figure 4-3: Surveyed installations grouped into institutional, community, and domestic plants

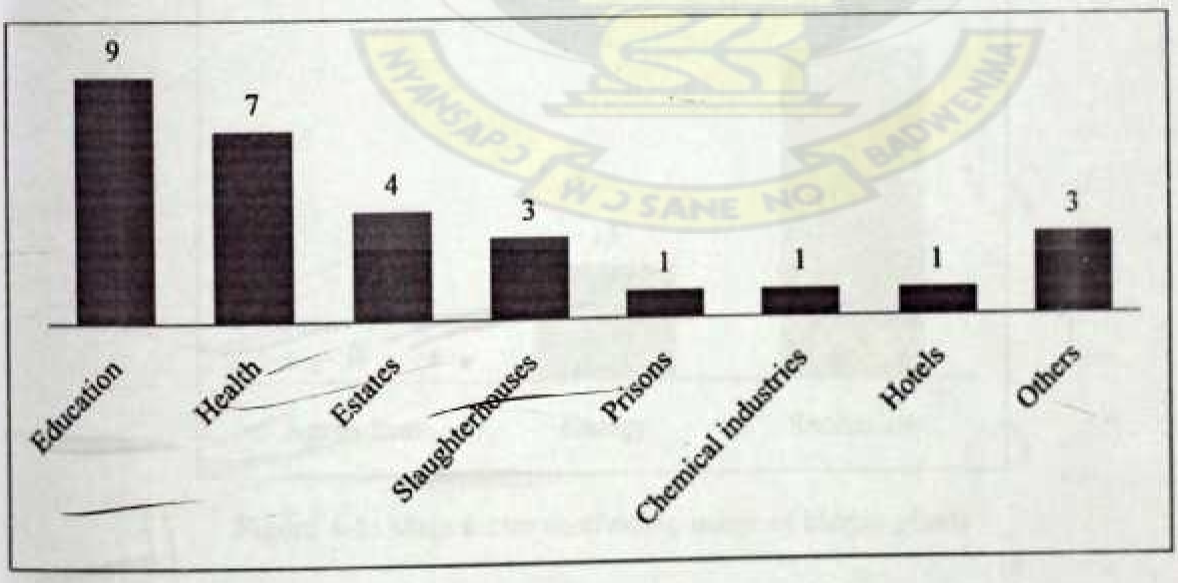

Figure 4-4: Institutions using biogas systems

The domestic installations surveyed include 6 plants built in 1987 at Appolonia and 5 plants disseminated at Okushibli in 1990. Most of these installations broke down between 1996 and 2001 due to several challenges including non-availability of cow dung (see Appendix D). After the Appolonia Electrification programme in 1992, no community installation digesting cow dung has been constructed due to the high cost of biodigesters and the absence of specific programmes designed to promote community digesters in cattle-rearing areas in Ghana.

4.2 Motivation for Using Biogas Plants

It is obvious that the ability of biogas plants to efficiently treat human excreta has become a strong marketing force. Biogas service providers have achieved success in promoting the technology as the most efficient and cost effective way of treating sewage. There are a number of sewage rehabilitation projects where the old sewage handling systems such as septic tanks and KVIPs are gradually making way for biosanitation interventions. Figure 4-3 gives the motivation for patronizing biogas plants from the perspective of the biogas user.

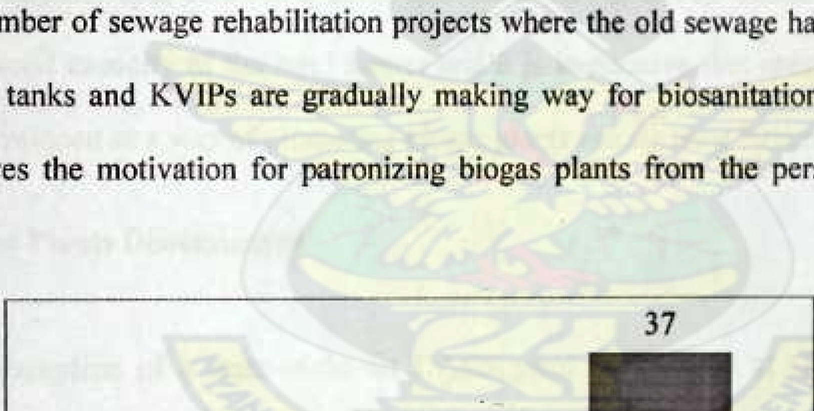

Figure 4-5: Main factor motivating usage of biogas plants

Apart from improving sanitation, biogas plants are also known for generating energy and organic fertilizer. It appears that the ability of biogas plants to produce organic fertilizer for agriculture has not been given any priority by the service providers in Ghana. Most users of biogas systems are content with the performance of the plant as long as the plant treats their sewage without any problem. The low level of interest to disseminate biogas plants focussing on energy and agriculture can be attributed to the lack of a concerted programme targeting the dissemination of biogas plants among livestock farmers in Ghana, majority of them living in rural communities and with limited/no access to agricultural inputs and modern energy services. These are people who will value the products of the biogas plant and therefore make use of both the gas and the fertilizer. The major problem, however, lies with the inability of rural cattle farmers to afford the full cost of biogas plants which are very expensive in Ghana. For example, in 2008 the investment cost of a 6 m^3 digester ranged from $1,200 to 2600 while a 10 m^3 digester cost between $ 2,400 and 4000 (KITE, 2008). These figures are far above the financial capacity of the rural farmer and it is imperative that special microcredit schemes are developed as a way of promoting biogas plants among poor farmers.

4.3 Types of Plants Disseminated

With the exception of a state-of-the-art UASB plant constructed at Guinness Ghana Limited in Kumasi, most of the plants surveyed are either floating-drum or fixed-dome digesters. All the floating-drum digesters are of the water-jacket type with a spherical digester. KVIC models (floating-drum plants with cylindrical digesters) are nonexistent. All floating-drum gasholders are made of mild steel with the exception of two glass-fibre gasholders at Tepa slaughterhouse and Holy Family hospital, Nkawkaw, and a high density polythene gasholder at GIMPA. Despite the merits of the floating-drum digester, the fixed-dome digester has found favour among most biogas service providers in Ghana, accounting for more than 80 % of installations sampled. Figure 4-4 highlights the main types of biodigesters found in the survey.

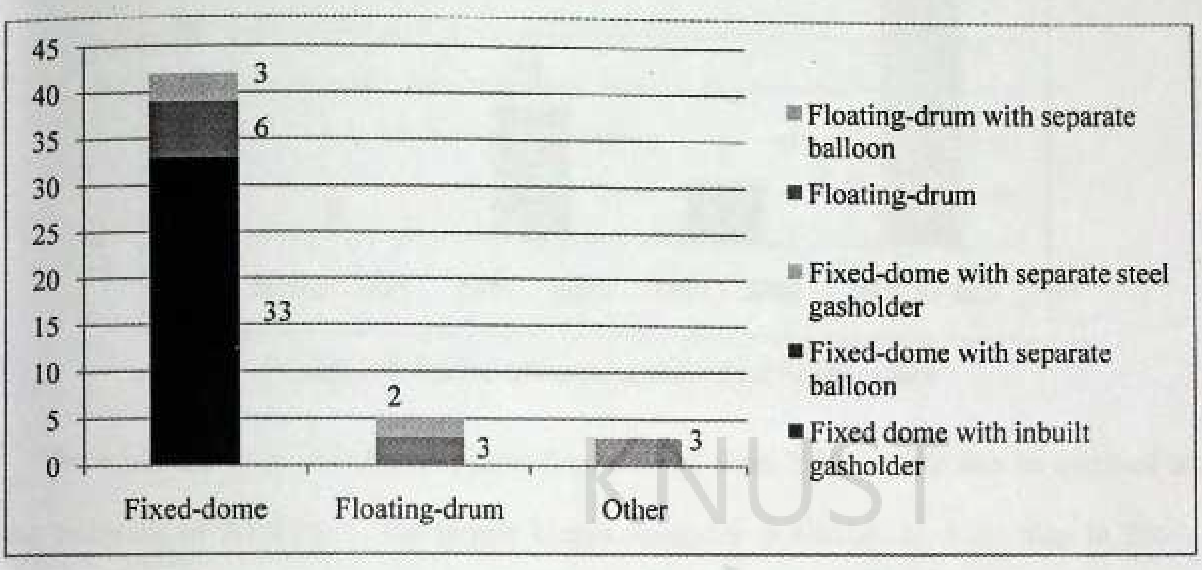

Figure 4-6: Variation of biodigesters disseminated in Ghana

Fixed-dome plants are less expensive compared to floating-drum digesters. Fixed-dome models disseminated by the various companies are the CAMARTEC model, the Deenbandhu model, the Chinese dome model, and lately the Puxin digester. It should, however, be emphasized that most of the biogas companies have also disseminated designs with slight variations from the aforementioned models just to suit the topographic conditions of a particular area.

Figure 4-7 shows the number of installations built over the last three decades. The 1981 – 1990 period saw the implementation of the domestic biogas programmes at Appolonia and Okushibli – two major cattle-rearing communities in Greater Accra Region. In 1992, the Appolonia Electricity programme was commissioned; in addition, biogas plants were built in three hospitals at Battor, Nkawkaw, and Akwatia.

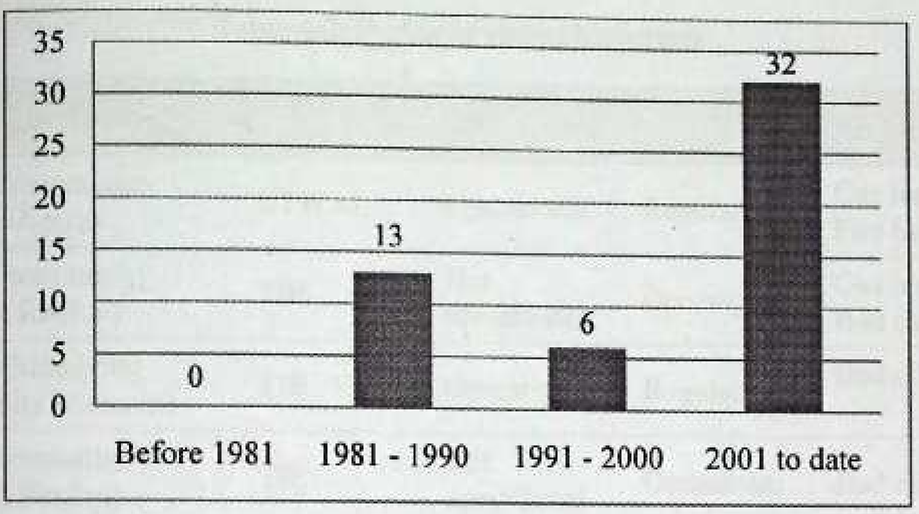

Figure 4-7: Period of construction of surveyed plants

The relatively large number of plants disseminated from 2001 to date can be ascribed to the founding of BTWAL[34], the largest biogas company in Ghana, by John Idan in 2000. Some of the biogas installations disseminated by BTWAL can be found at the palatial Golden Jubilee House in Accra, Central University College – Miotso campus, and Tamale Teaching hospital (Idan, 2006). Another major factor was the decision by Beta Construction – a civil engineering company – to disseminate biogas plants; the company has constructed over 20 Puxin digesters in Ghana and a few in Nigeria since 1995.

Apart from the aforementioned companies, the other biogas service providers (see Appendix C) have not been very active; for instance, IIR (Institute of Industrial Research) has disseminated a few biotoilets at various locations in Ghana, between 2004 and 2006, in addition to the ongoing 200 m^3 plant at Ankarful prison in Central Region.

4.4 Biolatrine Systems

A total of 9 biolatrines were visited. All the biolatrines had even-numbered seats ranging from six to twelve, with men and women having equal numbers of seats, and were attached to fixed-dome digesters. Table 4-1 profiles the biolatrines surveyed.

[34] Biogas Technology West Africa Limited

Table 4-2: Profile of visited biolatrines

Location of biolatrine	Service provider	Status	Water usage	Problem
1. Abeman community (Greater Accra)	BTWAL	Operational	Regular	Gas leakage Fire hazard
2. Parkoso community (Ashanti Region)	TIE	Not operational	Occasional	Gas leakage Bad odour
3. Asokore Mampong community (Ashanti)	TIE	Operational	Regular	Bad odour
4. Kaase community (Ashanti Region)	TIE	Not operational	Occasional	Bad odour
5. Tamale West Hospital (Northern Region)	BTWAL	Operational	Regular	Gas leakage
6. St. Martins SHS (Eastern Region)	-	Operational	Regular	Choked inlet pipe
7. Gambaga community (Northern Region)	IIR	Not operational	Occasional	Bad odour Gas leakage
8. Mankraso community (Ashanti Region)	IIR	Not operational	Occasional	Digester choked
9. Kotoku community (Greater Accra)	IIR	Operational	Occasional	Gas leakage

Of the 9 biolatrines visited, four were not functioning due to some design and operational challenges. The major problem with the design of biolatrines pertains to the connection between the toilet seat and the inlet pipe of the digester. If faeces get stuck to the inlet pipe, aerobic digestion takes place and extremely bad smell is produced.

Aklaku[35] has admitted that the collapse of the Kaase and Parkoso community biolatrines (see Appendix D) was caused by challenges in the design of the inlet pipe and the mode of operation of the plant. Even though, experience from the Kaase and Parkoso project have led to improved designs, there are still problems with gas leakage through the inlet pipe into the toilet house, as observed in the biolatrines at the twin city of Abeman and Oshiuman, Asokore-Mampong, Kotoku, and Tamale West hospital.

[35] Founder of the defunct, Technology for Improved Environment (TIE)

The other major problem concerns the mode of operation of the biolatrine. Even though, biolatrine systems are designed to handle as effectively as possible human faeces with little or no water, they rather perform efficiently if water is frequently used to flush the faeces. Thus, most biolatrines having water reservoirs enable users to flush the toilet with some water after use. The use of water regularly avoids the occurrence of aerobic decomposition of faeces entrained in the inlet pipe of the digester. It was also found that odour problems were prevalent in plants where water is scarcely used.

From the survey, two biolatrines (Figures 4-8) were found to have been disseminated within the vicinity of rubbish dumps.

Figure 4-8: Biotoilets engulfed in garbage at Mankranso (left) and Asokore-Mampong (right)

Caretakers of these biotoilets attributed the low patronage of the biotoilets to the unbearable stench from the dump that persistently engulfed the entire toilet chamber. It was also observed that community benefiting from biolatrine projects were not involved in the planning and implementation of the plants. The absence of interaction between community members and service providers on the functions of biolatrines has created ignorance among communities on the importance of biolatrines in improving sanitation and health.

4.5 Tandem (Series) Digesters

Tandem plants have two or more digesters working in series such that the effluent of one digester becomes the feed material for the second digester and so on. They may comprise two or more of the same type of digester or different digesters working together as one unit. In a two-digester tandem system or two-phase digestion, the first digester may be for liquefaction (hydrolysis) and acidification and the second digester for methanation (Ghosh and Poland, 1974). The main advantages of tandem digesters (two-stage systems) over one-stage systems include higher biomass conversion efficiency, higher methane concentration in the gas, better process reliability and stability, and high quality organic fertilizer (Anderson *et al.*, 1994; Ghosh *et al.*, 2000). Despite the aforementioned merits, tandem systems are not widely disseminated worldwide because they are expensive and difficult to engineer, construct and operate (Sasse, 1988; Lettinga, 1995; Gunaseelan, 1997).

In Ghana, Tandem plants have been constructed to treat sewage by BTWAL, BCEL, IIR, and BCL. Most common tandem digesters found in Ghana consist of two series digesters except the systems at Pope John's Seminary in Koforidua and Hebron Prayer camp at Hebron (near Amasaman), where BCEL has constructed systems comprising four 10 m^3 Puxin digesters. The main problem with tandem digester designs used by service providers in Ghana pertains to the inappropriate way of connecting adjacent digesters via a horizontal pipe near the base of the digesters. This arrangement leads to inefficient digestion since the second digester merely serves as an expansion chamber of the first digester rather than serving as a digester on its own. Moreover, digestion in the first digester will also be inefficient as slurry flows freely into the second digester. Figure 4-4 shows the layout of tandem digesters as used by biogas service providers as opposed to the recommended layout.

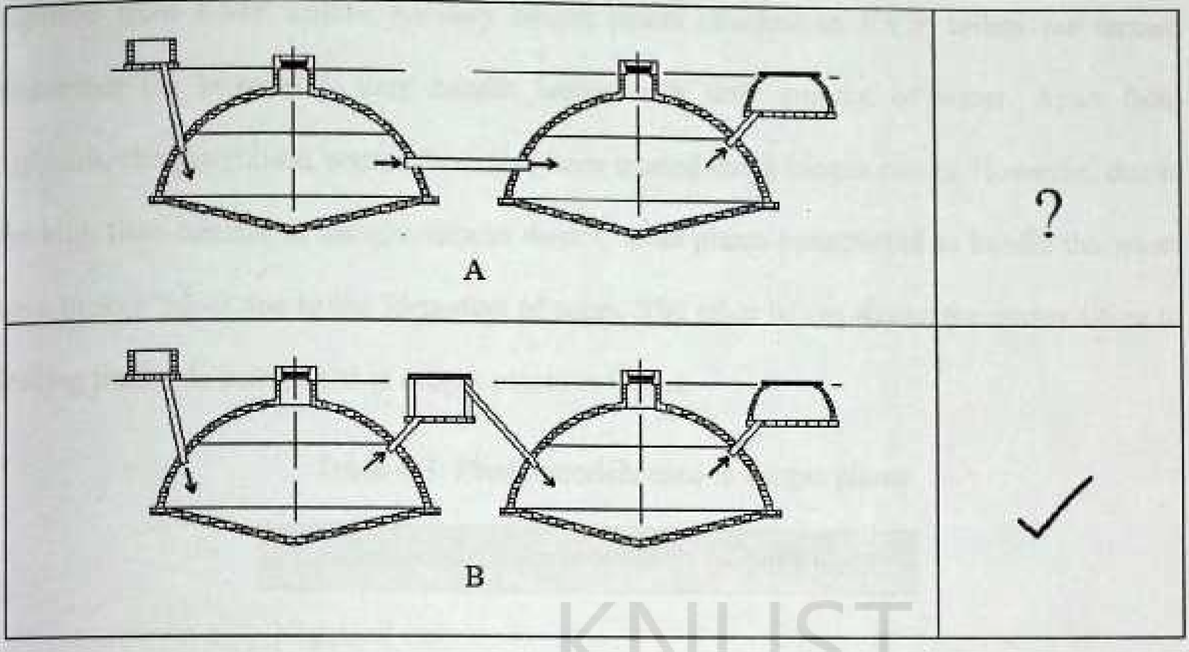

Figure 4-9: A – Tandem-digester layout used by BTWAL, BCEL, and BCL; B – Appropriate and recommended layout

Tandem plants require a lot of calculations before designing them. The designs with horizontal pipes connecting adjacent digesters can work efficiently only if valves are placed at vital points to control the feed materials moving from one digester to another and also the flow of effluent from the last digester. However, such an arrangement will be labour intensive in terms of operation and will also require skilled attendants. The correct arrangement of tandem plants, as seen in Figure 4-4B, is to connect a pipe near the base of the first digester to an expansion chamber which empties into the next digester (Sasse, 1988). This arrangement ensures that both plants function as fixed-dome systems, thus ensuring that the effluent from the last digester undergoes thorough digestion.

4.6 Feed Material

In Section 4.2, it was seen that the majority of households and institutions patronize biogas plants mainly as waste (nightsoil) treatment systems and as replacement for septic tanks. Most sanitary plants are either designed to treat nightsoil from flushing toilets or nightsoil from KVIP toilets. Sanitary biogas plants attached to KVIP toilets are termed biolatrines (or biotoilets); they handle faeces with little amount of water. Apart from nightsoil, slaughterhouse wastes have also been treated using biogas plants. However, due to the high fibre content of slaughterhouse wastes, most plants constructed to handle the waste have broken down due to the formation of scum. The table below shows the composition of feeding materials being used in biogas plants in Ghana.

Table 4-3: Feed materials used in biogas plants

Feed material	No. of plants
Nightsoil only	31
Nightsoil and kitchen waste	2
Nightsoil and dung	1
Dung only	12
Slaughterhouse waste	3
Industrial waste	1
Total	**50**

4.7 Plants Treating Slaughterhouse Waste

Out of the 50 plants studied, three of them were constructed to treat slaughterhouse waste at Tepa, Ejisu, and KNUST, all in the Ashanti region. Aside the Tepa slaughterhouse plant which has been abandoned due to misunderstanding between butchers and the Assembly regarding the location of the slaughterhouse, the other two plants have broken down. The failure of plants built to treat slaughterhouse waste can be attributed to designs that fail to deal with the formation of scum. Scum is formed when fibrous feed materials accumulate at the top of the slurry, thicken and harden, thus obstructing the flow of gas into the gasholder.

The gas is then forced to escape into the atmosphere via the inlet and outlet pipes of the digester.

4.8 Digester Size and Retention Time

The volumes of surveyed plants (digester and gasholder as one unit) range from 10 to 100 m^3. Table 4-3 gives the details of digester sizes constructed by the biogas service providers.

Table 4-4: Digester size of surveyed installations[36]

Digester size, m^3	No. of digesters	Digester size, m^3	No. of digesters
10	29	60	11
16	4	100	4
30	7	800	1
40	2	Unknown	7
50	28	Total	93

Biogas service providers disseminate mostly 10 m^3 digesters at the household level and 50 m^3 in institutions. Series digesters involving 10 m^3 plants have also been constructed by Beta Construction Ltd. The most important criterion in sizing the digester is to be able to meet the minimum retention time; this is very important if the plant is to treat human excreta. Before the designer settles on the digester volume to use, he needs to consider the design factors such as the daily availability of feed material and the retention time.

The choice of the retention time in turn is influenced by the type of feed material, the digestion temperature, the plant type, and financial capabilities of the user, among others. The

[36] Even though, 50 installations were visited, a total 93 digesters were surveyed. Several installations had digesters of different capacities working together as a unit. It was therefore realistic to base the classification of digester capacities based on the total number of digesters.

table below gives the retention times used by the various biogas companies in the design of their plants.

Table 4-5: Retention time used by some biogas service providers[37]

Service provider	Retention time (days)	Service provider	Retention time (days)
BTWAL	60	UNIRECO	-
BCL	20 - 30	GRES	30 - 60
BCEL	20 – 30	BEL	30 - 60
IIR	30 - 60	RESDEM	30 - 60

If a biogas plant is designed to treat waste such as nightsoil, then the determining factor of the retention time lies in the time period within which the waste can be effectively treated and discharged in a condition that does not make it a health hazard to the environment. The average retention time must be high enough to enable the degradation of the biomass; on the other hand, it must be kept as low as possible, because a high retention time always means high investment cost. Considering the high pathogen levels of human excreta, it is obvious that retention time of 30 days or less may not be adequate to kill enough pathogens during mesophilic digestion.

According to Sasse *et al* (1991), plants less than 30 m^3 should not be used for treating blackwater from flushing toilets because of the danger of reducing the retention time. It has also been recommended that a retention time between 70 and 80 days is needed for plants handling nightsoil, in order to ensure the destruction of pathogens (FAO-Nepal, 1996).

As seen in Table 4-4, most service providers use a retention time ranging from 30 to 60 days in designing their systems. BCL, BCEL, IIR and BTWAL have been installing systems

[37] For the treatment of nightsoil under mesophilic conditions

that have post-treatment facilities ranging from filtration tanks to solar concentrators for further treatment of the effluent. Even though, BCL and BCEL employ post-treatment facilities, the retention time used in their designs is quite low and inappropriate. It is therefore necessary to conduct a thorough analysis of effluent samples to determine the safety of the 'treated effluent.'

4.9 Gas Utilization

As a result of the low level of dissemination of plants handling cow dung, especially after the Appolonia Electrification project in 1992, the focus on biogas technology has shifted from provision of energy (use of gas) to improvement in sanitation (treatment of waste). Thus, users of biogas plants rely on the ability of the plants to treat excreta, thereby replacing septic tanks. Similarly, biogas service companies rely on the sanitation improvement capability of biogas plants to market the technology rather than the use of the gas for energy or the use of the effluent for fertilizer. This development has created a situation where some plants are constructed without making adequate arrangements for the usage of the gas thereby leading to gas leakage.

Gas leakage is a serious problem. In addition to the discomfort and health implications caused by inhalation of the gas, there is the potential of fire outbreak since mixtures of biogas and air in certain concentrations (6 – 12 % biogas) can be explosive and may cause damage to human life and property. Moreover leakage of biogas, which contains about 60 % methane, into the atmosphere offsets environmental gains made by putting up the plant. Out of the 32 plants operating, 12 of them have gas leakage problems. At both the Holy Family and the St. Dominic hospitals, the balloon gasholder is completely deteriorated and gas leaks freely into the air making the biogas stoves unused. Likewise, gas produced by most biotoilets is not used neither is it flared. Flaring the gas is the most effective way of getting rid of unused gas.

This is practised in a few locations, including the biogas plants constructed at AngloGold Ashanti, where caretakers have been trained to flare the gas at regular periods in order to avoid high pressures within the digester. Gas usage pattern of surveyed plants is shown in Figure 4-6.

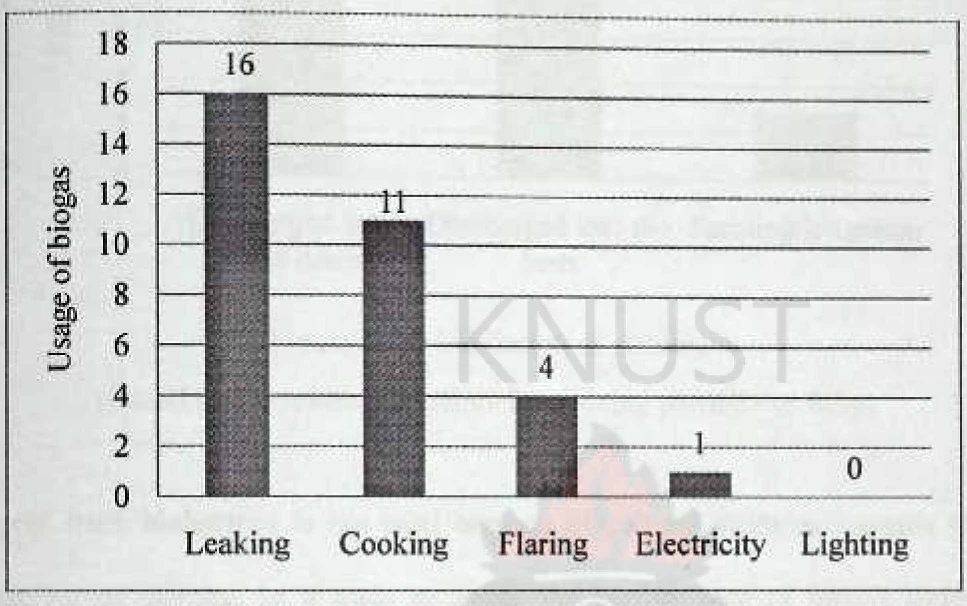

Figure 4-10: Gas utilization in surveyed installations
(Based on the number of plants functioning partially or fully)

4.10 Effluent (Digested Slurry) Utilization

Biogas plants built with the ultimate aim of generating organic fertilizer are rare in Ghana. The digested slurry is not seen as a resource and most plants discharge their effluent into the nearby bush or the public drain. Some plants built by Beta Construction Ltd. and BTWAL have systems designed to pump the treated effluent for use in flushing toilets. Figure 4-7 highlights how the effluent is seen as a resource by users of biogas plants.

The major concern pertains to ~~the safety~~ of the effluent discharged into the public drain. There is the need to conduct a comprehensive analysis of samples of the effluent in order to determine the efficiency of the digestion process of sanitary plants in Ghana.

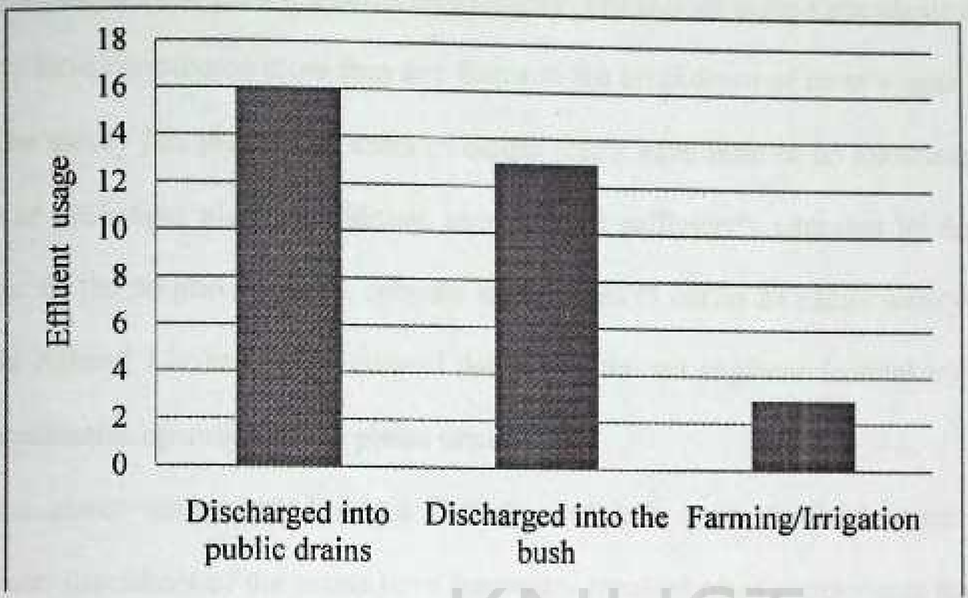

Figure 4-11: Utilization of effluent

(Based on the number of plants functioning partially or fully)

The effluent from biolatrines is not used because of cultural attitudes towards the use of human excreta as manure. In a study to assess the performance of biogas technology in Tanzania, Kellner (2007) advocates for the use of the effluent from biolatrines as fertilizer in the cultivation of fodder grass. This approach, if adopted in Ghana, will eliminate the stigma regarding the use of human manure in agriculture. Moreover, there is also the need to design and promote programmes that target farmers practicing mixed farming where the effluent can be easily and appropriately used as organic fertilizer.

4.11 Operation and Maintenance

A biogas plant may be well designed and constructed but still fail to perform efficiently if it is operated wrongly. Poor operation and maintenance can easily lead to the collapse of the plant. In a typical plant, good operational activities include daily feeding, cleaning of stoves and other appliances, checking of gas leakages especially at pipe joints and gas valves, and inspection of balloon gasholders, among others. A well engineered plant will function properly as long as these tasks are performed reliably. The lack of skilled attendants of biogas plants may have contributed more than any factor to the breakdown of most biogas plants in Ghana. The survey has shown that users of biogas plants have little or no knowledge of the functions of the biogas plant. In addition, users are not sufficiently educated by the service companies. Of the 50 plants visited, only the installations (3 out of 24 plants were visited) at Anglogold Ashanti Limited are monitored daily by a trained engineer (caretaker); this has ensured continuous operation of the plants since 2001.

Biogas plants disseminated in all Catholic hospitals have received some level of maintenance; caretakers of the plants have frequently repaired plant components such as the digester, the mixing tank, the expansion tank, and the steel gasholder in floating-drum plants. Unfortunately, balloon gasholders were found deteriorated at St. Dominic and Holy Family hospitals at Akwatia and Nkawkaw, respectively; moreover, gas appliance were not been used since the gas escapes freely into the atmosphere through holes in the balloon.

Other notable maintenance problems were found in biotoilet systems. The survey revealed that caretakers of biotoilets do not have basic understanding of the components and functions of the biogas plant. Service providers do not spend enough time to take users through rudiments and functions of various components of the biogas plant. Broken down plants are not repaired because owners are reluctant to spend additional financial resources on the upkeep of plants and this makes the floating-drum digester especially unfavourable due to the regular maintenance of the steel drum. Follow-up services are almost nonexistent. Service providers attribute this to the unavailability of funds to carry out follow-up programmes. Otoo Addo[38] asserts that the IIR must do a comprehensive auditing of all plants disseminated in order to assess the state of biogas plants built and the impact of biolatrine projects on beneficiary communities.

[38] A biogas engineer at IIR

Chapter 5 – DEVELOPMENT OF STANDARDIZED MODELS

5.1 Introduction

Standardization is the process of removing variations and irregularities in the design and construction of biogas plants. Standardization of technical and engineering designs is needed because it cannot be expected that all artisans will fully understand the requisites of a biogas unit. Clear and exact restrictions must be put on measurements, materials, and methods of work. For larger biogas programs, especially when aiming at a self-supporting dissemination technicians must be trained to incisively observe all details and methods of construction.

The cost of construction of biogas plants is high in Ghana and it is necessary to develop a plan of action that highlights cost issues. Since the cost of materials takes up a major portion of the investment cost of biogas plants (KITE, 2008), it is imperative that Ghana promotes durable models that require the least raw materials per unit digester volume. Moreover, there is the need to agree on retention periods that reduce investment cost whiles optimizing the digestion efficiency for specific feedstock.

5.2 Fixed-dome Versus Floating-drum

Even though the floating-drum digester possesses some advantages over the fixed-dome digester as enumerated in Chapter 3, the fixed-dome plant is recommended for dissemination for both domestic and institutional programmes, with the exception of slaughterhouse plants. Building biogas plants are expensive in Ghana and therefore it is prudent that low-cost but proven technologies are promoted. Floating-drum plants are expensive to construct due to the cost of fabricating the steel drum. Moreover, it is obvious from Chapter 4 that owners of biogas plants are reluctant to spend additional financial resources on the upkeep of plants and this makes the floating-drum digester unfavourable due to the regular maintenance requirement of the steel drum.

However, the floating-drum (BORDA model) digester is recommended for digesting fibrous feed materials such as slaughterhouse waste. In Chapter 4, it was observed that all fixed-dome biogas plants built in slaughterhouses collapsed after a few years of operation due to the formation of scum. Welded-in steel drums are better suited to dislodging scum since they have internal spikes that help in breaking scum as a result of the vertical movement of the drum. Moreover, in the event of intense scum accumulation, it is easier to remove the drum for easy access to the digester. It should however be noted that, sound maintenance of a biogas plant is crucial in ensuring the longevity of the plant.

5.3 Technical Evaluation of Fixed-dome Models Disseminated in Ghana

In proposing a fixed-dome model for a major dissemination programme, experience from biogas dissemination programmes in Ghana and other countries including Tanzania, Kenya, Nepal, India and China will be taken into account. Designs of digester models used by the major service providers in Ghana are technically analyzed and the model that best suits local conditions is recommended.

The following disseminated fixed-dome digester designs are examined:

1. Chinese fixed-dome digester;
2. Deenbandhu model;
3. CAMARTEC model; and
4. Puxin digester.

To evaluate the aforementioned designs, the following criteria are used:

a. Structural design for the gasholder and the digester;
b. Structural design for inlet pipe and the mixing tank;
c. Structural design for the central manhole (entry hatch);
d. Structural design for the bottom slab (digester base);
e. Structural design for the outlet pipe and the expansion chamber;
f. Operation and maintenance;
g. Durability and reliability;
h. Ease of construction; and
i. Construction cost

5.3.1 Structural Design for the Gasholder and the Digester

A well-grounded structure can withstand high external loads and internal pressure, which result in a long lifespan with little repairs. Furthermore, it reduces the probability of cracks in the plastering and thus reduces gas leakage. A dome shape can support heavier loads than a flat slab of the same material and thickness as shown in the Figure 5.1.

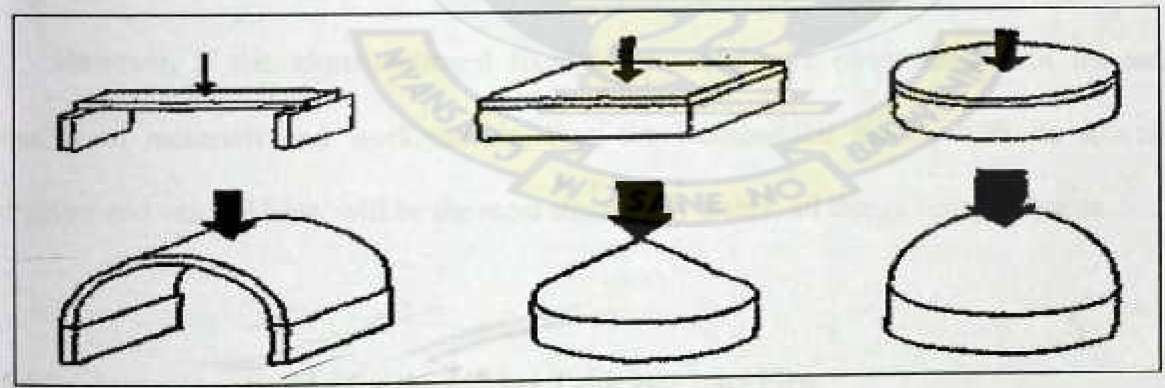

Figure 5-1: Shape in relation to load bearing capacity - the thicker the arrow the larger the load bearing capacity

Source: Sasse, 1988

Deenbandhu and CAMARTEC digesters have dome structures forming both the digester and the gasholder. However, the presence of the central manhole in the CAMARTEC model makes the dome less stable relative to the Deenbandhu model. In a recent evaluation of biogas plants in Tanzania, the central manhole was identified to be a major weak point in the CAMARTEC model (Marree *et al*, 2007). The Chinese model and the Puxin digester, on the other hand, have cylindrical-shaped digesters and dome-shaped gasholders; this makes them less robust. However, the fibreglass gasholder of the Puxin digester eliminates gasholder cracking and gas leakage.

At Appolonia, remains of Deenbandhu and Chinese models disseminated over 20 years ago are still structurally stable; these plants broke down due to unavailability of feed materials and poor maintenance of gas pipelines and appliance but not due to structural failure. This indicates that all fixed-dome plants, if engineered properly, can stand the test of time. Well constructed CAMARTEC models have also shown structural strength. Since Puxin digesters were introduced in 2006, it would be premature to make conclusions regarding its adaptability to Ghana's environment. From the survey, all Puxin digesters were functioning properly at the time of visit. More time is needed to fully assess its suitability for large-scale dissemination.

However, if the aforementioned fixed-dome models are constructed with the same quality of materials and workmanship, then the Deenbandhu model, with its spherical digester and vaulted base, will be the most structurally stable, all things being the same.

5.3.2 Structural Design for the Mixing Tank and Inlet Pipe

The mixing tank is not an essential feature of the digester since any digester can be adapted to include it. A round structure with a slightly sloping flat base is ideal (Sasse, 1988;

CEM, 2005) even though, a square-like structure is easy to construct. The pipe is raised slightly to prevent grit and stones from entering the digester. The use of a plug allows slurry to be kept in the sun where it can later be fed into the digester. According to Kulschewski (2004), the flow of feed material in the digester is affected by the positioning of the inlet pipe; if the inlet pipe ends exactly at the wall of the digester, circular patterns of fluid are formed and fluid spend relatively longer periods in the digester. In contrast, jet-like patterns are formed if the pipe protrudes the digester wall; this leads to relatively lower retention periods.

In Ghana, most service providers including BTWAL, IIR, and BCL design their plants with the inlet pipe protruding into the digester. This arrangement allows the feed material to enter the digester with enough thrust and this induces slurry agitation. Agitation is beneficial since it distributes bacteria and increases gas production (Sasse, 1988) especially in Deenbandhu, CAMARTEC, and Chinese dome models where the inlet pipe is usually directed towards the centre of the digester base. In the Puxin digester, agitation through the entering of slurry is reduced due to the vertical positioning of the inlet pipe.

5.3.3 Structural Design for the Central Manhole (Entry Hatch)

The manhole allows access to the digester so that it may be cleaned or repaired. The CAMARTEC and the Chinese dome models have manholes at the top of the digester, which are sealed to prevent gas leaks. However, they reduce the strength of the dome structure, as the openings create structural weaknesses (CEM, 2005). The Deenbandhu is designed such that the digester can be accessed through the outlet tank. The Puxin digester can only be accessed by removing gasholder and this can be laborious. In addition, refitting the gasholder requires the services of a trained technician.

In Ghana, fixed-domes with central manholes have been disseminated largely by BEL, BCL, RESDEM, IIR, and BTWAL. Deenbandhu models, majority of them located in Appolonia and Okushibli, have been constructed by RESDEM, IIR, and GRES. Deenbandhu models, compared to CAMARTEC and Chinese dome models, have fewer problems regarding gas leakage, due to the absence of the central manhole. In a recent technical study of digester models in Tanzania, the central manhole in the CAMARTEC model was found to be a major weak point (Schmitz *et al*, 2007). In conclusion, a single opening through the expansion chamber is sufficient and additional large openings increase the probability for gas leakages and structural failure.

5.3.4 Structural Design for the Bottom Slab (Digester Base)

The bottom slab carries the weight of the digester walls, the slurry inside it, and the weight of the earth load if the digester is spherical. It further distributes the weight over the ground beneath it (Sasse, 1988; Sasse *et al*, 1991, CEM, 2005). A vaulted shell, as used in the Deenbandhu, Puxin, and Chinese dome models, provides the best load bearing capacity owing to its shape but a conical base is easier to excavate. The CAMARTEC digester, however, has a flat base and therefore easy to construct. In Ghana, most service providers have disseminated plants having either flat or conical bottoms since they are easy to construct compared to vaulted shapes. Majority of plants built by BTWAL and BCL have a conical base.

In the Appolonia Household programme, the Chinese dome and Deeenbandhu digesters were built with vaulted bottoms. Majority of digesters disseminated by BEL are CAMARTEC models and have flat bottoms. UNIRECO has constructed digesters (most of them rectangular in shape) with flat bottoms; an example is the biogas plant at Ofori Panin Senior High School in the Eastern Region.

Even though, conventional Puxin digesters have round bottoms, majority of plants constructed by Beta Construction has flat bottoms; an example is the tandem Puxin system at Pope John's Seminary in the Eastern Region.

5.3.5 Structural Design for the Outlet Pipe and the Expansion Chamber

The outlet pipe and the expansion chamber are important parts of the fixed-dome digester. In the Chinese dome, the outlet pipe (usually PVC) connects the digester to the expansion (compensating) tank, whereas the Deenbandhu and the CAMARTEC models have no outlet pipe and the expansion tank is directly attached to the digester. The conventional Puxin digester has a vertical outlet pipe. However, Beta Construction has disseminated Puxin digesters with oblique outlet pipes; this, according to Kofi Ahenkorah[39], is to ensure easy movement of digested slurry out of the digester.

In the Deenbandhu model, the size of the outlet hole linking the digester to the expansion tank is designed such that the digester can be easily accessed via the hole. Moreover, the hole makes it suitable, relative to other fixed-dome models, to be used for digesting fibrous and other scum-forming feed materials such as slaughterhouse waste. The expansion tank of the Deenbandhu model is either rectangular or spherical; spherical systems are found at Appolonia while rectangular systems are located at Okushibli. According to Dr. Kwame Ampofo[40], rectangular systems are more in tune with the local environment since they are easier to construct.

[39] Executive director of Beta Construction and Puxin biodigester installation expert

[40] Founder of RESDEM and biogas expert

5.3.6 Operation and Maintenance

Maintenance and operation of all the plants is not essentially different. Proper designing and construction prevent the need to carry out frequent repairs. A biogas digester usually requires emptying and repainting every five years due to accumulation of grit and stones that reduce the efficiency of the plant (Myles *et al*, 1987; Sasse *et al*, 1991). Access to the digester of the Deenbandhu design is through the outlet tank, from which it is emptied.

Access to the Chinese dome and the CAMARTEC is through the central manhole, which is more awkward and laborious than the others. Firstly, the seal at the manhole would have to be broken and emptying the digester through the manhole would require more than one person (CEM, 2005; Balasubramaniyam *et al*, 2008). Once the maintenance work is completed, the manhole needs to be resealed to ensure gas tightness. With the Puxin digester, the gasholder has to be removed and refitting it requires good workmanship.

5.3.7 Durability and Reliability

The average life expectancy of the fixed-dome plant is similar (more than 20 years) and construction techniques and quality of materials play a major role in determining it (Sasse, 1988; Sasse *et al*, 1991; CEM, 2005; Myles, 2008). In practice the Chinese dome has a lower life span relative to the Deenbandhu due to its relatively low structural strength (Daxiong *et al*, 1990; Nazir, 1991; GTZ, 1999c).

Experience from Ghana has shown that Deenbandhu, CAMARTEC, and Chinese dome models are all durable, reliable, and can stand the test of time. All Deenbandhu and Chinese dome digesters disseminated at Appolonia in 1987 are still structurally stable. The CAMARTEC digester, with its hemispheric dome, has also proved to be durable both in Ghana, Tanzania, and other countries. According to Idan (2007), the Chinese dome should be recommended for mass dissemination because it can be built up to 200 m^3 and it requires little operation and maintenance. Despite this assertion, majority of plants disseminated by BTWAL has dome-shaped digesters. The Puxin digester has shown reliability since it was introduced in Ghana in 1996. More time (at least 5 years), however, is needed to assess its long term suitability.

5.3.8 Ease of Construction

The simplicity in construction is one of the main factors that will affect the popularity of one model over another. Of all the models considered, the Puxin digester is the easiest to construct due to the used of the prefabricated moulds; the dome-shaped gasholder is made of gas-tight fibreglass and it requires no painting. All other digesters need extensive plastering, which requires a lot of attention and care.

The Deenbandhu, the Puxin, and the Chinese dome models require more complicated excavation for the base of the digester than the CAMARTEC design, which has a flat bottom. The Chinese dome model has vertical cylindrical walls and requires the same skill required to construct straight, vertical walls. The construction methods for the CAMARTEC and Deenbandhu domes are similar – all employ a trammel to create the dome. The curved base for the Deenbandhu and Chinese dome models make it more difficult to construct the rest of the dome above it, as there is no flat surface from which to construct.

The CAMARTEC and Chinese dome models have a manhole on top of the dome and the curved cap of the dome does not have to be constructed. The Deenbandhu has a full dome made of bricks, and scaffolding has to be erected within the dome to allow the cap to be finished, and this makes it more arduous in constructing the dome. All the models, with the exception of the Puxin digester, require extensive plastering with mortar and gastight paint.

For very large plants (more than 60 m^3), Chinese domes are favourable (Idan, 2007) even though BTWAL has constructed 100 m^3 hemispheric domes at Central University College – Miotso campus. Beta Construction intends to build plants having a volume of 100 m^3 at New Legon, a collection of hostels at the University of Ghana.

5.3.9 Construction Cost

The cost of construction is a crucial factor in developing a model for mass promotion. Investments costs are dependent on many aspects such as type of material, amount of material, availability of certain materials and input of technical know-how (KITE, 2008; Balasubramaniyam *et al*, 2008). Unfortunately, there has not been any work comparing investment costs of digester models in Ghana. KITE (2008) points out that the concrete-based Puxin digester cost more to construct than the brick-based digesters in Ghana.

From the survey, the cost of investment of a 10 m^3 Puxin digester with a biogas cooker was between Gh¢ 4000 – 5000 in 2008. The same digester volume cost about Gh¢ 2500 when disseminated by IIR and RESDEM; and about Gh¢ 3800 when constructed by BTWAL. In 2006, the average cost of 50 m^3 plants constructed by BCL was Gh¢ 7500.

In summary, the cost of biogas plants in Ghana is difficult to quantify since it depends on several factors including plant location, availability and cost of construction materials within the locality where the plant is to be built, cost of transportation, soil conditions and the depth of the water table at a particular location, cost of labour within the locality, etc. Thus, the cost of a Puxin digester built in Tamale where a 50 kg bag of cement cost over Gh¢ 12 will be different from the cost of the same digester built in Accra where a bag of cement is sold for Gh¢ 8.5, bearing in mind that construction materials account for the largest share of the construction cost.

At the Eastern Regional hospital in Koforidua, the total cost of the biogas plant (comprising mainly two 40 m^3 digesters, drains, a balloon gasholder, and a biogas stove) built by BTWAL in 2006 was GH¢ 59,335.43. In addition, the total cost of the biogas plant (comprising four 10 m^3 Puxin digesters, 8-seater toilet, a biogas stove, a Poly tank, and a pump) disseminated by Beta Construction at Pope John's seminary in Koforidua, cost GH¢ 60,000 in 2007.

5.3.10 Overall Assessment

The aforementioned criteria, equally weighed, are used to rank all the digester models (Table 5.1). The Deenbandhu design is rated as the most suitable for mass dissemination in Ghana. It is an improved version of the Janata digester which is based on the Chinese dome. It has the most structurally sound base to counter uplift forces. The positioning of the expansion chamber in relation to the digester allows easy access for cleaning and maintenance, without compromising on the structural strength of the dome.

Deenbandhu systems have been disseminated in Ghana, mainly by GRES, IIR, and RESDEM. Majority of them are found in Appolonia and Okushibli in the Greater Accra Region.

Table 5-1: Overall Assessment of Fixed-Dome Digester Models[41]

Criteria	Chinese dome	Deenbandhu	CAMARTEC	Puxin
Structural design for gasholder and digester	2	4	4	4
Structural design for mixing tank and inlet pipe	3	3	3	2
Structural design for the central manhole	2	4	2	4
Structural design for bottom slab	4	4	2	4
Structural design for outlet	3	4	3	2
Operation and maintenance	2	4	2	2
Durability and reliability	3	4	3	3
Ease of construction	2	2	2	3
Construction cost	3	4	3	2
Overall score	**24**	**33**	**24**	**26**

From the table, the Deenbandhu digester scores best due to, inter alia, its structural superiority and the ease with which it is operated and maintained. The model has been disseminated appreciably in Ghana and is well adapted to Ghana's conditions.

[41] *4 = best score on a criterion, 1 is the least*

5.3.11 Modification of the Proposed Model

The design for the inlet pipe can be improved by not making it protrude into the digester. This will make the slurry stay longer in the digester (see sub-section 5.3.2) Kulschewski (2004). Since excavating a vaulted floor is arduous, a conical shell is proposed – the only implement required is a straight piece of wood (Sasse, 1988). The shape of the expansion tank should be made rectangular in order to make construction easier; moreover, the expansion tank is not subjected to high internal pressures characteristic of the digester. Figure 5-2 shows the model proposed for large scale promotion in Ghana.

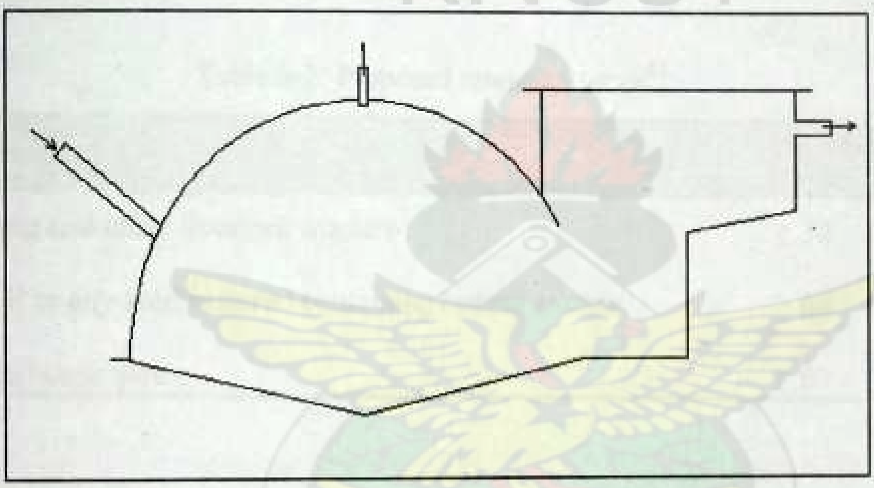

Figure 5-2: Proposed fixed-dome digester model

Apart from the BORDA model, no other floating-drum model has been built in Ghana. The BORDA model has superior structural stability and is easy to operate. It is therefore recommended for promotion in slaughterhouses in future dissemination programmes.

5.4 Choosing the Retention Time

Mesophylic digestion is used since it perfectly reflects local environmental conditions. A retention time (RT) of 21 days is just enough to kill most pathogens in dung (Sasse *et al* (1991), but from the energy point of view, a RT time less than 30 days under mesophilic conditions is still considered low in terms of gas production and the completeness of the digestion process. Since the dissemination of biogas technology among cattle farmers or cattle-owning households will highlight the energy and agricultural aspects of biogas, it is recommended that a RT of at least 30 days is used for plants receiving only dung or livestock manure.

For nightsoil and slaughterhouse waste, a RT time of at least 60 days is recommended. This will ensure that most pathogens are killed by the time the feed materials leave the digester. Moreover, post-treatment of the effluent should be mandatory for all sanitary plants discharging their contents into public drains or watercourses. Table 5.2 summarizes the proposed retention time for various feed materials.

Table 5-2: Proposed retention times[42]

Feed material	Retention time (days)
Cow dung and other livestock manure	≥ 30
Nightsoil or any feed material containing human excreta	≥ 60
Slaughterhouse waste	≥ 60

5.5 Determination of Digester Volumes

The digester volume, as discussed in Chapter 3, is a function of the daily slurry flowrate into the digester and the RT. It is laborious and unnecessary to design plants to specifically address the quantum of feed material for every household or institution. Rather, it is time-saving to design a plant to handle a range of flowrates of the feed material. Recommendations for digester volumes will be done under the following categories: domestic plants for households with cattle, domestic plants treating nightsoil, and institutional plants.

[42] *Assuming Mesophilic digestion*

5.5.1 Domestic Plants for Households with Cattle

According to the Ghana Statistical Service (GSS), the Upper West Region has the highest average cattle per household which is about 33. The Northern and Upper East Regions come next, each having an average of 11.5. Table 5-3 provides more information on cattle population in Ghana.

Table 5-3: Distribution of cattle population in four Regions

Region	Cattle population	No. of cattle owning households	No. of cattle owning agric. households	Average cattle per household
Northern	982,847	98,090	85,142	11.5
Upper West	787,681	28,250	23,645	33.3
Upper East	454,112	47,577	39,441	11.5
Ashanti	36,355	6,455	4,874	7.5
TOTAL	**2,260,995**	**180,372**	**153,102**	**14.8**

Source: (GSS, 2008; KITE, 2008)

According to KITE (2008), at least 7 Short-horn[43] cattle can produce about 20 kg of dung in overnight kraaling; a minimum daily feed of 20 kg is needed to produce enough gas for cooking (KITE, 2008). Based on cattle data in Table 5-3 and lessons from biogas programmes in Ghana and other African and Asian countries, the following plant volumes (Figure 5-4) are proposed for large-scale dissemination in Ghana.

5.5.2 Sanitary Plants Digesting Blackwater from Flushing Toilets

Digester volumes for household plants treating sewage will depend primarily on the number of persons in each household and the volume of water used per visit in flush toilets.

[43] The Short-horn is the predominant cattle breed in Ghana. Dung produced by other breeds such as Crosses and Zebus do not vary much in terms of quantity of dung generated per animal.

Table 5-4: Proposed plant volumes for household plants fed with dung only

Plant volume	Daily fresh dung (kg)	Daily water (litres)	Approx. no. cattle required
4	20 – 40	20 – 40	7 – 14
6	41 – 63	41 – 63	15 – 22
8	64 – 86	64 – 86	23 – 30
10	87 – 109	87 – 109	31 – 38

Based on retention time of 40 days and dung: water ratio of 1:1

(See Appendix E for details)

According to the 2000 Population and Housing Census, there is a total of 3,701,241 households[44], with each household unit having an average size of 5.1 persons; this shows an increase of 0.2 from the 1984 figure of 4.9 (GSS, 2002; KITE ,2006). The average household size is important since it will serve as a guide in deciding the minimum digester volume that must be constructed to treat nightsoil.

As already stated, a minimum retention time of 60 days must be used in designing the plant. In Chapter 4, household nightsoil plants built by BCEL have a volume of 10 m^3 (excluding gasholder) whiles the other service providers disseminate 10 m^3 (including gasholder) plants.

Assuming a digester (excluding the gasholder) volume of 10 m^3 and a retention time of 60 days, this digester is fed by

$$\frac{10\,\text{m}^3}{60\,\text{days}} \approx 166.7 \text{ litres per day of blackwater}$$

Assuming that each member of the household visits the toilet twice a day, and taking the amount of water flushed per visit to be 8 litres; then, the daily slurry of 167 litres will be

[44] A person or group of persons who lives together in the same house or compound, share the same house-keeping arrangements and are catered for as one unit (GSS, 2002)

produced by 10 persons. Since most household plants are designed to discharge their effluent into the public drain, it is recommended that the minimum plant (digester and gasholder) for treating sewage from closets must be 10 m^3 with a minimum retention time of 60 days.

The size of plants disseminated at the institutional level will also depend on the population of that institution as well as other factors such as the volume of water used for flushing toilet. Most plants built for institutions by service providers have a volume of 50 m^3, with a few having volumes of 30, 60, and 100 m^3. Appendix F analyzes the variation of plant volume with the amount of flush water used for institutional plants mesophilically treating nightsoil from 1000 persons. The trend observed is shown in Figure 5-3.

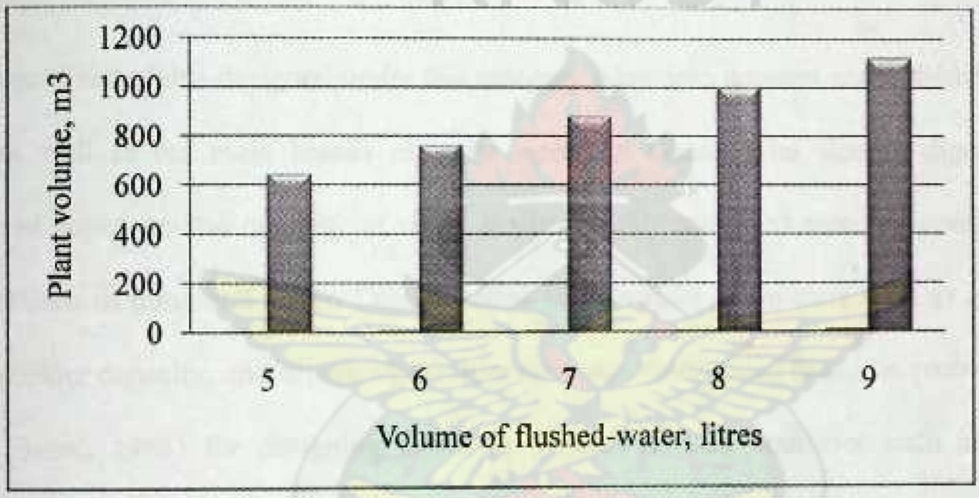

Figure 5-3: Variation of plant volume with volume of water used for flushing closets.

From Figure 5-3, the amount of flush-water used in closets is a major factor that determines the volume and hence the investment cost of the plant. KITE (2008) has shown that the major cost of biogas plants is taken by the cost of raw materials. It is against this backdrop that any dissemination programme on biogas technology must highlight the use of water-saving water-closets (WWCs) in order to reduce the size of biogas plant required.

In conclusion, standardized institutional plant volumes of 10, 30, 50 and 60 m^3 are proposed for dissemination. This is elaborated in Table 5-5.

Table 5-5: Proposed plant volumes for sanitary plants handling blackwater from closets[45]

Plant volume, m^3	Daily mass of nightsoil, kg	Daily flowrate of feedstock (litres)	No. of persons
10	4.8	150	12
30	14	434	35
50	24	744	60
60	26	868	70

Based on a retention time of 60 days

Volume of water used per flush: 6 litres

5.6 Proposed standardized fixed-dome model

5.6.1 Standardized model for digesting cow dung

Standardized plants designed under this category takes into account cattle distribution in Ghana as well as the main breeds of cattle reared in Ghana. The size of digester was determined based on the quantity of dung available daily and feed material consisting of equal portions of dung and water. Determination of important parameters such as gasholder size, gasholder capacity, and digester/gasholder ratio was determined based on recommended figures (Sasse, 1988) for designing plants in tropical African countries such as Ghana. Dimensioning was mainly based on experience from service providers in Ghana and recommended figures by Sasse (1988). The rate of gas production was estimated at a temperature range of 26 – 28 ^{0}C using a retention time of 40 days (see Appendices E and G for detailed analysis). Figure 5-4 gives the detailed drawing for the 4 m^3 standardized plant.

5.6.2 Standardized model for treating nightsoil

The volumes of standardized plants proposed for treating nightsoil (from WCs) were determined based on daily amount of fermentation slurry (feed material) and a retention time

[45] See Appendix E for details

of 60 days. The digester sizing was also based on the daily amount of fermentation slurry (nightsoil and water) and the maximum amount of nightsoil (0.4 kg) an individual can generate in a day. The volume of water used per visit was taken to be 6 litres; this was based on the predominant volume of cisterns used in Ghana. It must, however, be noted that proper quantification of daily waste material is necessary in order to decide which plant volume is suitable for dissemination under any particular situation (see Appendices F and G for detailed analysis). The detailed drawing of the proposed standardized model for the 10 m^3 nightsoil plant is shown in Figure 5-5.

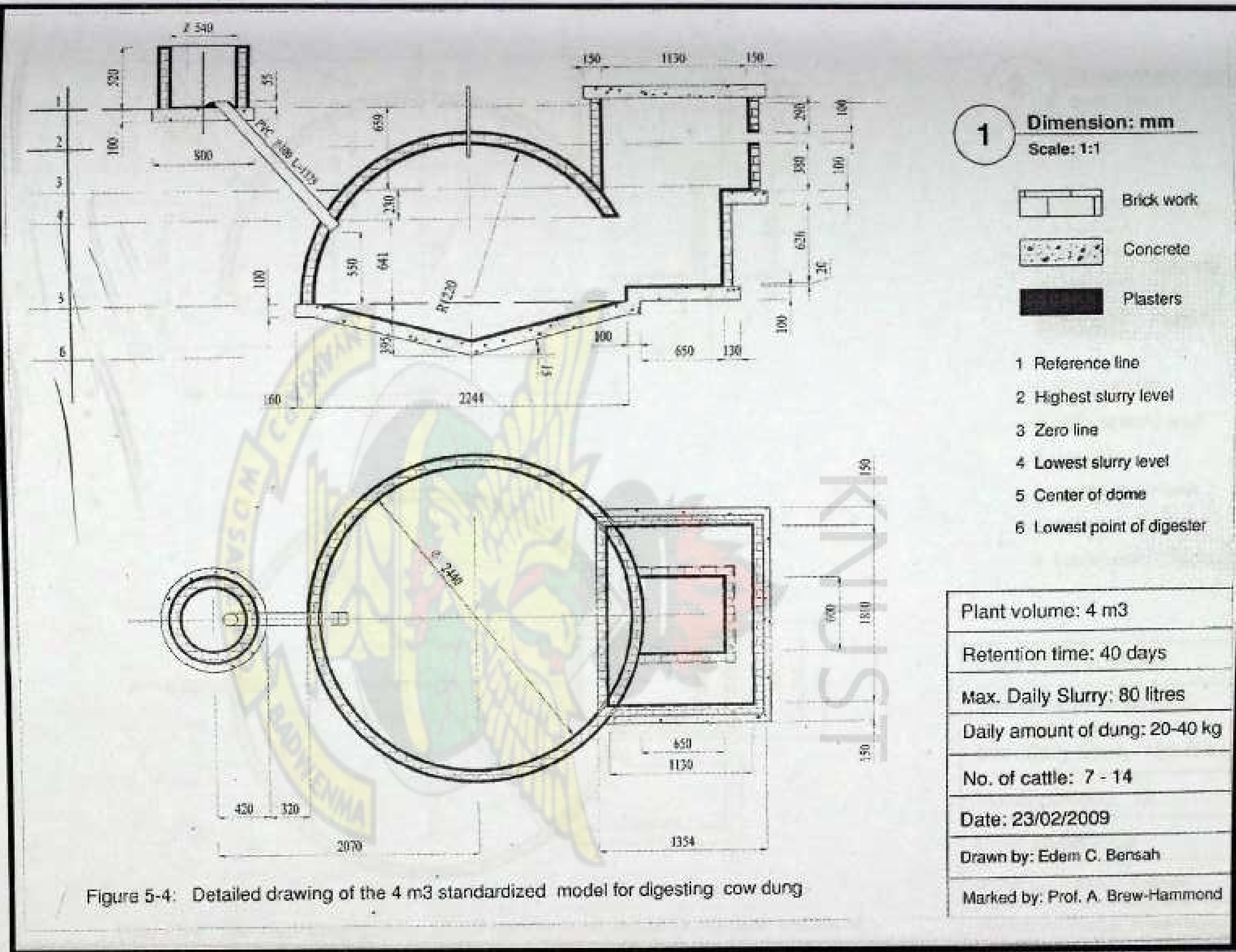

Figure 5-4: Detailed drawing of the 4 m^3 standardized model for digesting cow dung

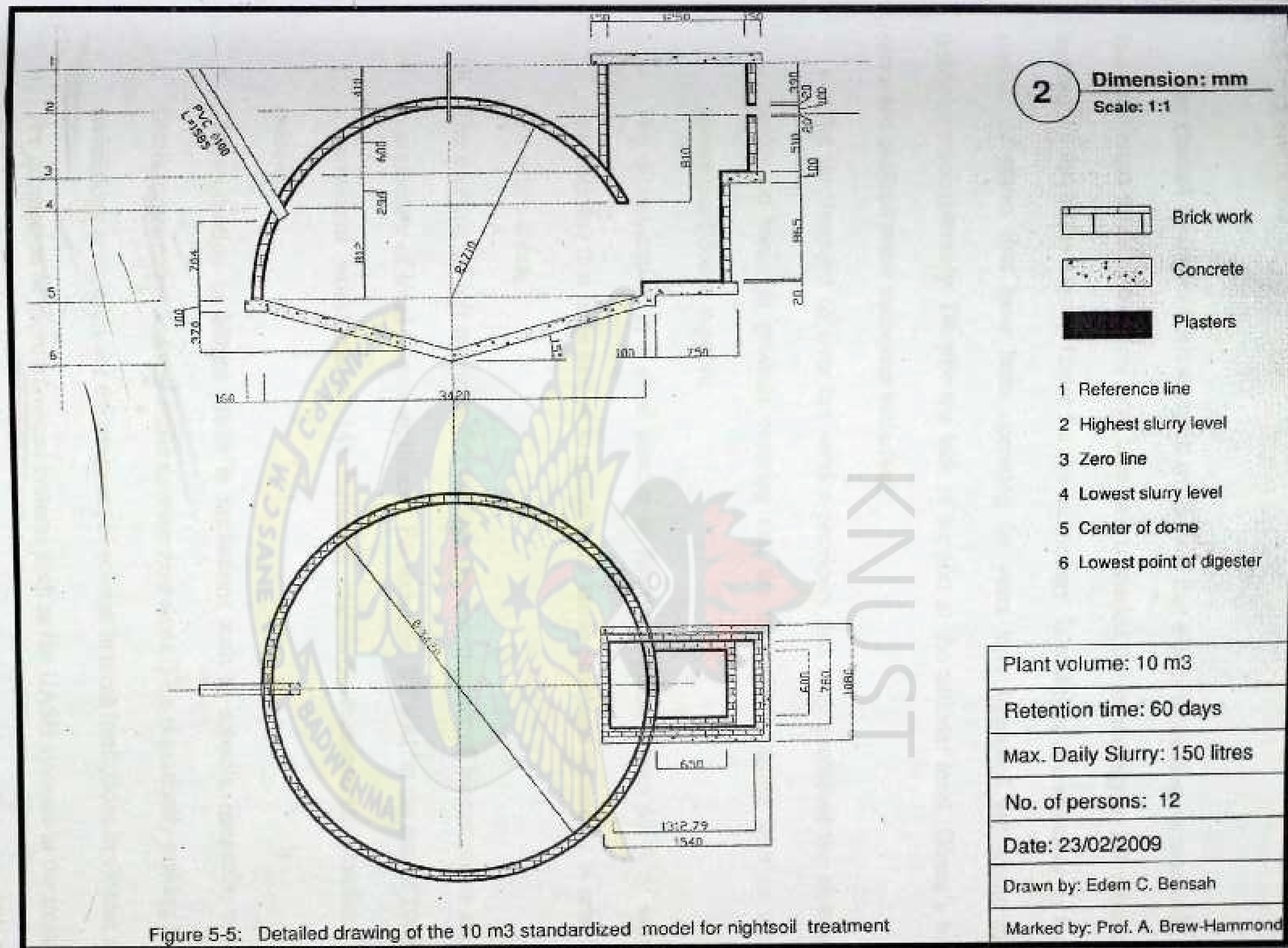

Figure 5-5: Detail drawing of the 11 m^3 standardized model for nightsoil treatment

Chapter 6 – CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The general findings of this research work show that biogas technology is workable. The fact that biogas service providers have been able to market the technology to individuals and institutions forebodes a good future for the technology. In addition, the existence of a good number of plants that have been operating for years have improved the image of the technology considerably. Despite the lack of support at the national level, Ghana's biogas sector has chalked some successes including:

- The involvement of over ten service providers that have promoted the technology solely on business grounds ensuring that the technology thrives with or without government/donor support;
- The dissemination of a good number of functional plants (about 65 % of sampled installations) that have helped to mitigate sanitation problems especially in urban and peri-urban areas;
- The creation of job opportunities through the construction of biogas plants and the manufacture of local biogas appliances. For example, BTWAL at the end of 2007 had a permanent workforce of 148 including engineers, accountants, plumbers, and masons;
- The promotion of biogas plants in institutions such as schools, hospitals, prisons, hotels, orphanages and real estate development areas. This is gradually making biogas technology acceptable for the treatment of sewage in most institutions in Ghana; and
- The promotion of more advanced systems such as the UASB systems in the treatment of industrial waste as seen in Guinness Ghana Limited in Kumasi; Oil Palm

processing companies such as GOPDC[46] are also considering the adoption of advanced anaerobic waste handling systems for the treatment of their wastewater.

There are some challenges that must be tackled holistically in order to ensure a sustainable future of biogas technology. It is obvious that Ghana needs a coordinated national programme that will promote the technology in both households and institutions, and in both urban and rural areas.

Out of 50 installations surveyed, only 22 (44 %) plants were functioning satisfactorily. Among the major causes of failure are inappropriate operation and lack of maintenance, formation of scum in slaughterhouse plants, bad odour in toilet chambers of biotoilets, poor design of inlet pipes in biotoilets, building of biotoilets close to rubbish dumps, and behavioural problems including the use of indigestible materials such as polythene bags, menstrual pads, and cloth pieces in biotoilets which cause choking of inlet pipes.

Two main types of digesters have been disseminated in Ghana: the fixed-dome and the floating-drum. Fixed-dome models constructed by the companies included the Chinese dome, the Deenbandhu, the CAMARTEC, and the Puxin digester. Most floating-drum digesters are hemispherical and have water jackets. Digester volumes disseminated include 10, 16, and 30 m^3 for households and 10, 30, 40, 50, 60, and 100 m^3 for institutions. Most sanitary digesters treating blackwater from flushing toilets are designed to discharge their effluents into public drains.

Finally, the survey found that improvement in sanitation is the major concern of most users of biogas plants; the two other benefits – energy (biogas) and agriculture (fertilizer) – are not seen as major resource. This partially explains why 16 (32 %) plants have gas leakage problems while owners show no concern.

[46] Ghana Oil Palm Development Company Limited

6.2 Limitations

The survey was meant to cover all installations in order to come out with the true picture of the state of biogas technology in Ghana. However, as in surveys of this nature, there are always some limitations. The limitations include: time and financial constraints, lack of adequate information on the number of biogas plants installed in Ghana, inability of service providers to provide detailed information on some of the plants constructed, extreme difficulty in locating some of the plants, and inability of some users to provide required information especially on broken down plants.

All the aforementioned challenges affected the smooth gathering of data and information. Despite the problems enumerated above, the findings from this study provide a true picture of the state of biogas technology in Ghana since sample size used is representative and gives adequate information about the current state of plants built by all the major service providers.

6.3 Recommendations

The suggestions below should be given maximum consideration.

6.3.1 Development of a National Programme on Biogas Technology

There is the need to develop a national biogas programme with a three-pronged focus: agriculture (organic fertilizer production), sanitation, and energy. This national initiative must have distinct programmes for both domestic and institutional plants. Promotion of farm plants among livestock farmers or those interested in improving their yields will encourage the utilization of digested slurry in agriculture and reduce the dependence on imported inorganic fertilizers. The gas generated can also be used for cooking, water heating, and lighting. There is the need for Government and donor agencies to support biogas training and microfinance programmes targeted at certain social groups with high prospects for adopting biogas technology such as poor farmers in the three Northern Regions. This is imperative since the lowest cost of investment of a 6 m^3 plant in Ghana is $ 1,200, which is extremely high and beyond the means of most rural farmers (KITE, 2008). Figure 6-1 captures the main facets of the proposed national programme.

Large-scale dissemination of sanitary plants will improve hygiene in both urban and rural areas. Replacement of KVIPs and VIPs with biotoilets will ameliorate sanitation problems experienced in public toilets especially in communities where water is scarce. Moreover, the incidence of excreta-related diseases such as dysentery and cholera will be substantially minimized since micro-organisms that cause these diseases are eliminated during the anaerobic digestion process.

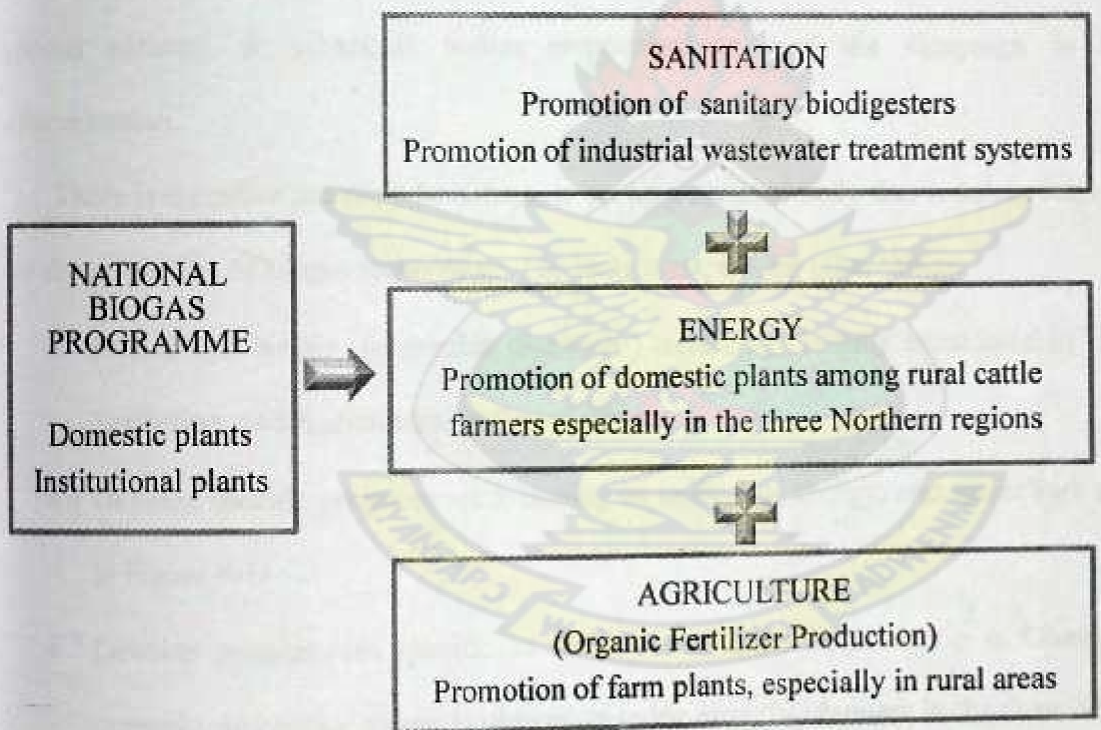

Figure 6-1: Proposed three-pronged approach for future biogas dissemination programmes in Ghana

Large-scale local industries such as oil palm processing and brewing companies generate large volumes of wastewater that pollute the environment when discharged untreated or partially treated. The use of anaerobic fermentation systems in the treatment of industrial wastewater will reduce pollution and improve the quality of the environment.

6.3.2 Formation of a National Biogas Promotion Body

From the experience of biogas technology dissemination in developing countries such as Ghana, Tanzania, China, India, and Nepal, it is obvious that biogas promotion cannot be left in the hands of private companies alone. The success story of the technology dissemination in China, India, and Nepal can be partly attributed to the direct involvement of the State through special national or parastatal bodies empowered to lead the campaign in biogas dissemination.

There is therefore the need for Ghana to set up a national body that is solely responsible for the promotion of biogas technology. The body must, among other things:

- Ensure that biogas (anaerobic digestion) technology is fully considered in Energy, Sanitation, and Agricultural policy of Ghana;
- Develop specific programmes focussing on sanitation, energy, and agriculture as seen in Figure 6-1;
- Develop programmes specific to the needs of a particular region in Ghana – for example, any major dissemination programme targeting farmers in the three Northern Regions must include the construction of water storage systems as part of the plant;
- Develop sound business model based on public-private-partnership as a way of promoting the technology especially among household systems;

- Identify and involve all stakeholders in disseminating the technology – potential stakeholders in Ghana include Ministry of Energy, Ministry of Agriculture, Ministry of Science, Technology and Environment, The Energy Centre - KNUST, CSIR/IIR, Energy Commission, GRATIS[47] Foundation, CWSA[48], NGOs such as GTZ, New Energy, KITE, and SNV, Biogas Service Providers, Metropolitan, Municipal and District Assemblies, Association of Ghana Industries, Ghana Education Service, Ghana Health Service, among others:
- Form a strong team of researchers that must include engineers from KNUST, IIR, and Biogas Service Providers to continuously work on development of new and efficient digester models ;
- Develop training programmes for engineers, artisans, technicians, and all professionals involved in biogas dissemination in Ghana;
- Develop standardized biodigesters and quality control standards; and
- Develop a CDM project for which Certified Emissions Reductions can be earned.

6.3.3 Recommended Fixed-dome Digester Model for Large Scale Dissemination

This model, Figure 6-2, is proposed based on the structural analysis of models disseminated by the various biogas companies in Ghana and with experience from other countries including Tanzania, Nepal, India, and China. The spherical shape of the digester ensures structural stability. Moreover, internal and external stresses are distributed uniformly along the contours of the digester. The shape of the digester base and the expansion chamber

[47] GRATIS (Ghana Regional Appropriate Technology Industrial Service) Foundation is a parastatal institution that ~~disseminate~~ appropriate technologies by training technicians and artisans in technical construction.

[48] CWSA (Community Water and Sanitation Agency) is a state institution in charge with the provision of potable water and sanitation facilities in rural communities in Ghana.

allows for easy construction. The absence of a central manhole further improves the structural integrity and gas leakage through the gasholder is minimized considerably.

Furthermore, the conical base improves the overall digestion process by creating room for grit and stones to accumulate. Equally important is the relative ease with which this model is evacuated if there is the need to get rid of the accumulated grits and stones after years of operation.

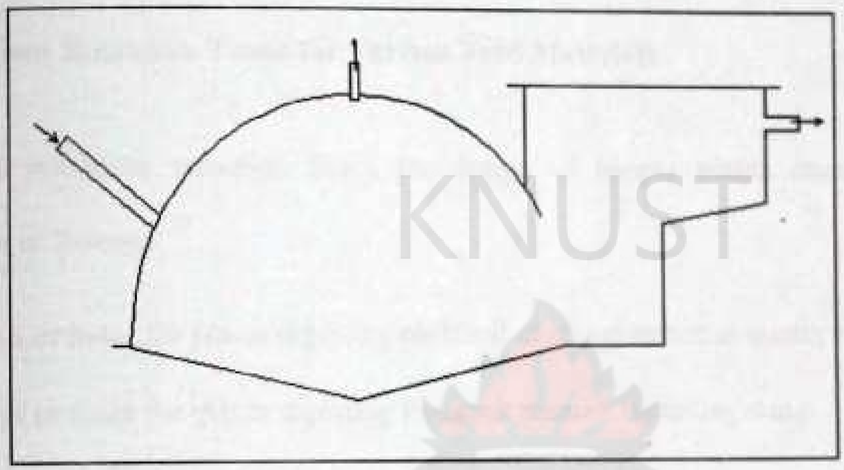

Figure 6-2: Proposed fixed-dome digester model

6.3.4 Recommended Floating-drum Digester Model

This model has a hemispherical-shaped digester, a conical base, and a steel drum. It is structurally stable and the water-jacket reduces the corrosion rate of the drum relative to the arrangement where the drum floats directly in the slurry. All service providers are already disseminating this model.

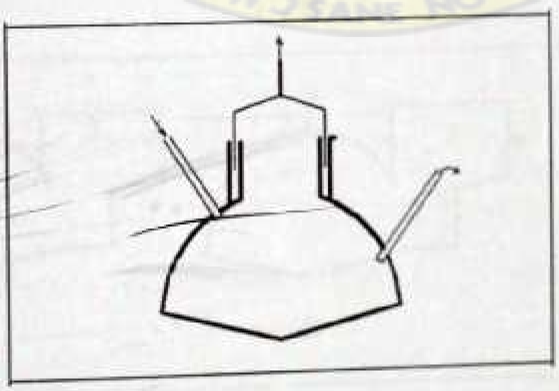

Figure 6-3: Proposed floating-drum digester model

6.3.5 Recommended Layout of Tandem (Series) Digesters

Figure 6-2 shows the layout recommended in designing tandem digesters. This layout ensures that the effluent enters the second digester after spending the designed retention time in the first digester. Similarly, the retention time for the second digester is enforced since it also acts as a separate digester.

6.3.6 Proposed Retention Times for Various Feed Materials

Proposed minimum retention times for design of biogas plants under mesophilic conditions are as follows:

- 60 days or more for plants digesting nightsoil or slaughterhouse waste; and
- 30 days or more for plants digesting livestock manure including dung.

The proposed retention time will ensure that the digestate from biogas plants is free from pathogens and make it safe to use in agriculture.

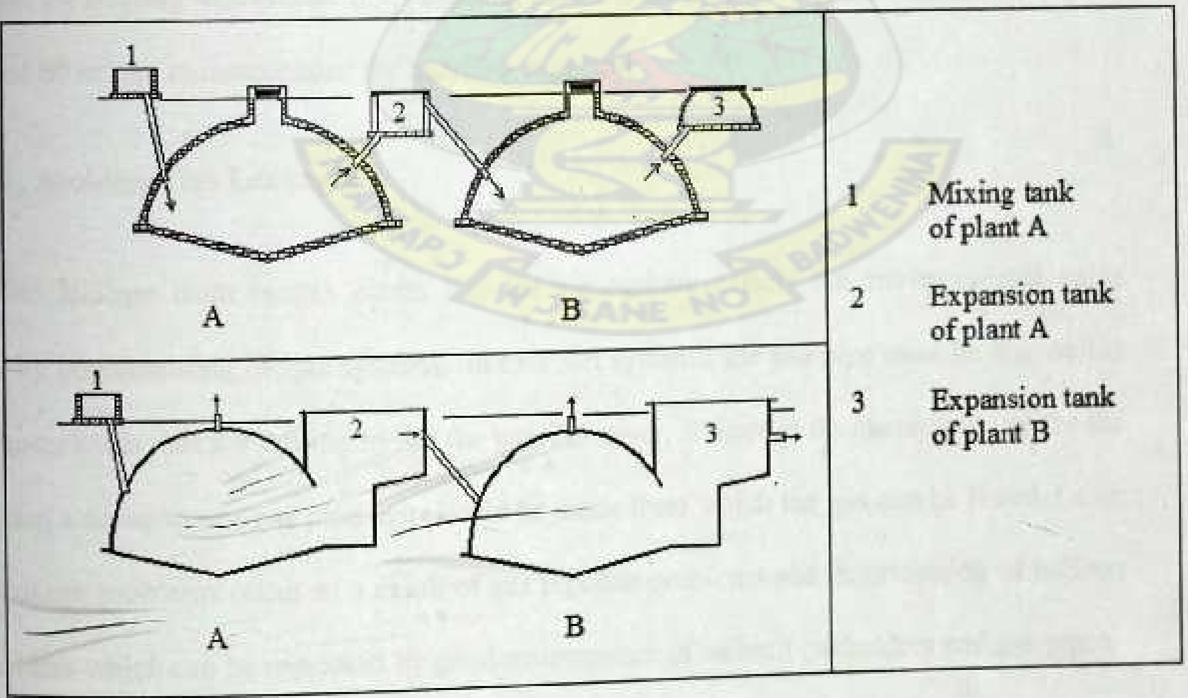

Figure 6-4: Recommended layout for tandem digesters

6.3.7 Proposed Digester Volumes

1. *Plants Handling Cow Dung*

Based on data on cattle owning households in Ghana, the following domestic plant volumes are recommended for large scale dissemination:

- 4 m^3 plant for households having 7 – 14 cattle;
- 6 m^3 plant for households having 15 – 22 cattle;
- 8 m^3 plant for households having 23 – 30 cattle; and
- 10 m^3 plant for households having 31 – 38 cattle.

The above volumes were determined based on a retention time of 40 days.

2. *Plants Handling Nightsoil*

Due to the high pathogen level of human excreta, a minimum retention time of 60 days should be used in designing sanitary digesters. It is recommended that the minimum plant volume for treating blackwater from flushing toilets must be 10 m^3. Plant volumes of 10, 30, 50, and 60 m^3 are recommended for handling nightsoil.

6.3.8 Avoiding Gas Leakages

Gas leakage from biogas plants into the atmosphere offsets the environmental gains made by implementing biogas systems. In biotoilet systems, the gas pipe must be channelled into households that are willing to use the gas. However, if there is no immediate use for the gas, then a conspicuous gas pipe exit should be made from which the gas can be flared. Other gas leakage problems occur as a result of gas pipeline problems and deterioration of balloon gasholders which can be remedied by good maintenance of balloon gasholders and gas pipes.

6.3.9 Avoiding the Discharge of Partly Treated Sewage into Public Drains

Since most sanitary plants discharge their waste into public drains, it is important that the digestate is safe and therefore poses no threat to public health. Therefore, all sanitary plants that are designed to discharge their effluent into public drains must have post-treatment systems such as filter tanks, after undergoing the recommended retention time. Moreover, in order to achieve the designed retention time in practice, the tip of the inlet pipe should just end at the wall so that circular patterns of fluid are formed and which in turn increases the retention time.

6.3.10 Research and Development

1. Design of Biotoilets

A large scale dissemination of well-engineered biotoilets will improve sanitation in Ghana considerably especially in places with scarce water resources. The major problem with biotoilets lies in the design of the inlet pipe; it must be done such that faeces do not get accumulated within it. This is where some research is needed. Finally, there is need to develop standardized toilet chambers for rapid and efficient dissemination; the toilets should, if possible, have tanks where rain water can be stored for use in flushing the toilet.

2. Design of Standardized Tandem Plants

Tandem plants are complicated to design and construct. Since some biogas companies are already constructing tandem plants using wrong layouts, there is the need to develop standardized tandem systems for the treatment of sewage.

3. Use of Affordable and Durable Local Materials for the Construction of Biodigesters

Most biogas plants are constructed with bricks with the exception of Puxin digesters which are constructed with concrete. The IIR, for some time now, has been constructing some digesters with pavement bricks[49], which can be manufactured at the construction site. Other materials that should be considered as building materials for biodigesters include Kaolin - rocks rich in kaolinite[50] - and Pozzolana[51].

Both Pozzolana and Kaolin are readily available in Ghana. Pozzolana has the potential to reducing considerably the cost of digesters since it can replace a third of the quantity of cement, which is quite expensive in Ghana. A bag of Pozzolana cost Gh ¢ 5 whiles the same quantity of cement is sold for at least Gh ¢ 8.5. There is the need to conduct research into the suitability of the aforementioned materials as building materials for biogas plants. The cost of biogas plants will always remain an important parameter in deciding which material to use in future dissemination programmes and therefore research must focus on the testing and development of cement substitutes such as Pozzolana. The average cost of plants can also be significantly reduced if the dissemination of biogas technology is given the attention it deserves from government, academia, and other stakeholders, thus creating large markets for biodigesters, resulting in increased dissemination and reduction in the cost of construction.

6.3.11 Biotoilets

1. *Biotoilets and Rubbish Dumps*

Siting KVIPs, VIPs, and biotoilets within the vicinity of rubbish dumps is not uncommon in Ghana. The survey has shown that biotoilets sited near rubbish dumps experienced low patronage. Biotoilets must therefore be constructed at least 100 m from rubbish dumps.

[49] Made mainly from sand, cement, and quarry dust in a distinct ratio.

[50] A clay mineral, with composition $Al_2Si_2O_5(OH)_4$, used in ceramics, medicine, coated paper, etc.

[51] A fine siliceous and aluminous material that reacts with $Ca(OH)_2$ and H_2O to form cementitious compounds, that has the ability to set under water (Wikipedia, 2009)

2. Building Biotoilets without the Involvement of Beneficiary Communities

The involvement of communities in the planning and construction of biotoilets is crucial towards a successful implementation of these systems. Since most biotoilets are implemented with funds from the SIF (Social Investment Fund) and NGOs, service providers do not pay attention to the concerns of the communities in planning and constructing the biotoilet. This has resulted in the low patronage of most biotoilets. The concerns of the community must be given the needed attention. Moreover, service providers must educate communities that benefit from these systems.

Finally, there is the need to develop hygienic effluent disposal systems. In cattle growing areas, the discharge of biotoilet effluent into fields where fodder grass is cultivated may be advantageous.

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APPENDICES

APPENDIX A – RESOURCE PERSONS INTERVIEWED

Date of Interview	Name of Interviewee	Position
4 Jun 2008	Prof. A. Brew-Hammond	Dean, Faculty of Agricultural and Mechanical Engineering, KNUST; Ag. Director, The Energy Centre, College of Eng., KNUST; Energy Policy Expert
4 Jun 2008	Mr. I. Edjekumhene	Senior Projects Manager – Kumasi Institute for Technology and Energy
5 Jun 2008	Prof. F. Akuffo	Associate Professor, Mechanical Engineering Dept., KNUST; RE Policy Expert
7 Jun 2008	Mr. Abu Bukari	Sanitation Engineer – Anglogold Ashanti Limited; Senior Technician – BCL
10 Jun 2008	Mr. Odame	National Best Farmer, 1987; Biogas user
11 Jun 2008	Mr. A. Idan	Founder and CEO, Biogas Technologies West Africa Limited; Biogas Expert
12 Jun 2008	Mr. W. Ahiataku-Togobo	Head – Renewable Energy, Ministry of Energy, Ghana; Founder – REES; Biogas Expert
13 Jun 2008	Mr. Degraft Addo	Industrial Designer; Biogas Expert – IIR
18 Jun 2008	Dr. F. Addo-Yobo	Project Coordinator – Institute for Industrial Research; Biogas Expert
5 Aug 2008	Mr. Tony Mensah	Head of Waste Management, KMA; Member – Biosanitation Company Limited
15 Sep 2008	Mr. Kofi Ahenkorah	Executive Director – Beta Construction Engineers Limited; Puxin Biogas Plant Specialist
2 Oct 2008	Dr. E. Aklaku	Senior Lecturer – Agricultural Eng. Dept., KNUST; Founder – TIE, BEL; Biogas Expert
8 Jan 2009	Dr. A. Anyimadu	Senior Lecturer – Civil Engineering Dept., KNUST; Founder – BCEL; Biogas Expert
4 Feb 2009	Hon. Dr. K. Ampofo	Founder/CEO – RESDEM; Biogas Expert
7 Feb 2009	Mr. Otoo Addo	Biogas Expert – IIR

APPENDIX B – STRUCTURED INTERVIEW AND SURVEY QUESTIONNAIRE

B-1 MAJOR QUESTIONS USED IN PERSONAL INTERVIEWS WITH EXPERTS

Most questions asked bothered on the technical challenges facing the design, construction, operation, and maintenance of biogas plants in Ghana. An interactive approach was used in all the interviews rather than a 'question and answer' format. Specific questions, inter alia, asked included the following:

- What reasons account for the poor image of biogas technology in Ghana?
- Why has technology gained little support at the national level?
- How will a large scale dissemination of biogas plants benefit the country?
- How many plants have you/your company constructed and how many are not functioning and why?
- What specific technical/engineering problems have negatively affected the promotion of biogas plants?
- Are there problems concerning design, construction, operation, and maintenance of plants that need to be dealt with? If yes, what remedies would you propose to solve them?
- What type of digester and/or digester model would you propose for promotion under future dissemination programmes and why?
- What design parameters (retention time, digester volume, etc.) would you recommend for designing biogas plants and why?
- What local construction materials (bricks, concrete, etc.) ensure high structural integrity of the plant whiles making the overall cost as low as possible?
- Are there technological challenges facing the dissemination of biolatrines? If yes, how can they be tackled?
- How will standardized plant designs improve the dissemination of biogas plants in Ghana?
- What role should government, academia, private biogas companies, NGOs, and other stakeholders play in future dissemination programmes?

B-2 USER SURVEY QUESTIONNAIRE

Plant location; Name of plant owner/caretaker; Size of household/institution...........................

Year of construction: ....; Cost of plant: ....; Installed by: ....

Main reason for purchasing a biogas plant:

- Organic fertilizer
- Energy
- Improved sanitation
- Other

Status of plant: Operating..........................; Not operating...

Type of biogas plant: ....; Digester model: ....

Type/nature of gasholder: ....

Use/disposal of gas

- Cooking
- Lighting (use of biogas lamps)
- Electricity generation
- Other
- Gas is flared
- Gas leaks freely

Use/disposal of digested slurry

- Irrigation
- Farm manure
- Compost
- Discharged into the public drain
- Discharged into the bush
- Other (specify)

Feed material

- Dung
- Nightsoil
- Agricultural waste
- Other (specify)

Construction materials

- Burnt bricks
- Pavement bricks
- Concrete
- Other (specify)

Presence of caretaker

- Present
- Absent

Possible causes of plant breakdown (for plants not operating)

- Choked inlet pipes or digester
- Lack of feed material
- Breakdown of gas appliance
- Poor design of digester
- Poor design of toilet
- Poor siting of plant
- Other (specify)

B-3 OBSERVATION CHECKLIST

Plant component	Observation			Comments
	Good	Defective but operating	Not operating	
Condition of plant as a whole				
Condition of inlet tank				
Condition of digester and gasholder				
Condition of outlet chamber				
Condition of post-treatment tanks				
Condition of compost pits				
Condition of gas pipeline				
Condition of gas appliance				
Condition of toilet (for biotoilets)				

APPENDIX C – A CATALOGUE OF BIOGAS INSTALLATIONS IN GHANA

No	Beneficiary	Project type	Digester type	Plant capacity	Year constructed	Construction company	Current status
			HEALTH				
1	St. Dominic Catholic Hospital, Akwatia	Sewage treatment	Fixed dome with separate balloon	$280m^3$ (5 Plants)	1994	TIE	Operational
2	Holy family Hospital, Nkawkaw	Sewage treatment	Fixed dome with separate gas balloon	$120m^3$ (2 Plants)	1994	TIE and a German priest	Operational
3	Battor Catholic Hospital	Sewage treatment and storm water disposal	Fixed dome with separate gas balloon	$240m^3$ (4 Plants)	1995	TIE	Operational
4	Tamale Regional Hospital	Sewage treatment	Fixed dome	120 m^3 (twin digester)	2001	BTWAL	Operational
5	Tamale West Hospital	12 scater biolatrine	Fixed dome	$40m^3$	2002	BTWAL	Operational
6	Bekwai hospital	Sewage treatment	Floating-drum		2003	BCL	Not operational
7	Koforidua Regional Hospital	Effluent/sewage treatment	Fixed dome	$80m^3$	2004	BTWAL	Operational
8	Accra Psychiatric Hospital	Sewage system rehabilitation	Fixed dome	Twin $50m^3$	2003	BTWAL	Operational
9	Gushegu hospital	Sewage treatment	Fixed dome		2002	UNIRECO	
10	Family hospital, Teshie	Sewage treatment	Fixed dome		2007	BEL	
			EDUCATION				
11	Dept. of Animal Science, KNUST	Slaughterhouse waste treatment	CAMARTEC fixed dome	$50m^3$	1994	TIE	Not operational

12	Tema East Basic Exp. School, Bethlehem	Sewage treatment	Fixed dome	$30m^3$	2002	BTWAL	Operational but not used
13	Ofori-Panin Senior High School (SHS)	Biolatrine	Fixed dome		2002	UNIRECO	Not operational
14	Tetrem SHS	10 seater biolatrine	Fixed dome		2002	UNIRECO/RESDEM	Operational
15	Achimota SHS, Accra	Biolatrine	Fixed dome				
16	Aburi Girls School	Biolatrine	Fixed dome		2002	UNIRECO/RESDEM	-
17	St. Martins SHS	Sewage treatment	Fixed dome				Operational
18	Valley View University, Oyibi	Sewage treatment	Fixed dome	$78.3m^3$	2003	BTWAL	Operational
19	Central University College	Sewage treatment	Fixed dome	$310\ m^3$ (4 digesters)	2006	BTWAL	Operational
20	Adullam Orphanage, Obuasi	Biolatrine	Fixed dome	$20m^3$	2001	BTWAL	Operational
21	Children Orphanage, Prampram	Biolatrine	Fixed dome	$50m^3$	2004	BTWAL	Operational
22	SOS Village, Asokore Mampong	Sewage treatment	Puxin digester	$40\ m^3$	2009	Beta Construction	Ongoing
23	Garden City Special School, Kumasi	Biolatrine	Fixed dome with seperate gas balloon		2004	TIE	Operational*
24	UCEW, Winneba	Biolatrine	Sewage treatment	$30m^3$	2006	UNIRECO	Operational
25	GIMPA, Legon	Sewage treatment rehabilitation	Floating drum	100^3 (twin digester)	2007	BTWAL	Not operational
26	Pope Johns Sch.	Sewage treatment	Puxin biodigester	$40\ m^3$	2007	Beta	Not completed

	and Seminary, Koforidua					Construction	
27	Tsito Vocational Institute	Sewage treatment				RESDEM	
28	Ejisuman SHS	Sewage treatment	Fixed dome		2009		Operating
			INDUSTRY				
29	Ejura slaughterhouse	Waste treatment	CAMARTEC model with separate balloon	50 m^3	2002	BEL	Not operational
30	Tepa slaughterhouse	Waste treatment	Floating drum	60 m^3	2005	BCL	Abandoned
31	Nestle Ghana Ltd.	Sewage system rehabilitation	Sewage Treatment Plant	Twin 60m^3	2004	BTWAL	Not operational
32	Kotoka International Airport	Sewage system rehabilitation	Puxin digesters	60m^3	2007	Beta Construction	Under construction
33	Guinness Ghana Ltd., Kumasi	Wastewater treatment	UASB	800 m^3	2008	British company	Operational
34	BCEL Office Complex, Dome	Sewage treatment	Puxin biogas digester	10m^3	2007	Beta Construction	Operational
			REAL ESTATE DEVELOPMENT AREAS				
35	Trasacco Valley Estates	Sewage and kitchen waste treatment	Fixed dome	260m^3 (4 plants)	2002	BTWAL	Operational
36	AngloGold Ashanti	Sewage/Effluent treatment	Fixed dome	886 m^3 (14 plants)	2000	BCL/BTWAL	Operational
37	Newmont Estates, Kenyasi II, B/A	Sewage treatment	Fixed dome	1000 m^3 (4 digesters)	2008	BTWAL	Ongoing
38	Presidential palace, Accra	Sewage treatment	Fixed dome		2008	BTWAL	Operational
			HOTELS				

39	Airport West Hospitality, Accra	Sewage treatment	Fixed dome	50 m^3	2006	BTWAL	Operational
40	Ntiamoah Hotels - Agona Swedru	Sewage treatment	Puxin biodigesters	30 m^3	2007	Beta Construction	Operational
41	Ntiamoah Hotels – Akyem Oda	Sewage treatment	Puxin biodigesters	30 m^3	2007	Beta Construction	Operational
42	Fiesta Royale, Accra	Sewage treatment	Fixed dome	60 m^3	2007	BTWAL	Operational
43	Airport West Hospitality, Accra	Sewage treatment	Fixed dome	50 m^3	2006	BTWAL	Operational
44	Silicon Valley Hotel, Kumasi	Sewage treatment				BCL	Not operational
45	African Regent Hotel, Accra	Sewage treatment	Fixed dome			BTWAL	Operational
46	Southern Fried Chicken, Burma Camp	Sewage treatment	Fixed dome		2008	BEL	
			COMMUNITY				
47	Kaasi, Kumasi	Biolatrine	Fixed dome	100 m^3	1998/1999	TIE	Not operational
48	Apollonia	Community lighting project	Floating Drum	500 m^3 (10 plants)	1992	GRES/IIR	Not operational
49	Appolonia	Digesters for household cooking	Fixed dome: Chinese and Deenbandhu	210 m^3 (16 plants)	1987	IIR/RESDEM	Not operational
50	Sege- Sokorpe	8-seater biolatrine	Fixed dome	30 m^3	2002	GRES	Operational
51	Abeman/ Oshiuman, GAR	16-seater biolatrine	Fixed dome	40 m^3	2000	BTWAL	Operational
52	Okushibli, GAR	Digesters for household cooking	Fixed dome: Deenbandhu	50 m^3 (5 plants)		GRES	Not operational
53	Gambaga	6 seater biolatrine	Fixed dome	30 m^3		IIR	Not

	Community, N/R						operational
54	Kotoku Community, Ga West District	8 seater biolatrine	Fixed dome with steel gasholder	40 m^3 (2 digesters)	1995	IIR	Operational
55	Mankranso Community, A/R	8 seater biolatrine	Fixed dome		1995	IIR	Not operational
56	Wamfie (Dormaa) Community, B/A	Biolatrine	Fixed dome			IIR	
57	Manya Krobo Community, E/R	Biolatrine				IIR	
58	Aboadze Community, W/R	10 seater biolatrine	Fixed dome				
59	Parkoso Community, A/R	6 seater biolatrine	Fixed dome		1997	TIE	Not operational
60	Patriensa Community, A/R	Biolatrine			1997	TIE	
61	Juaso Community, A/R	Biolatrine			1997	TIE	
			PRIVATE DOMESTIC INSTALLATIONS				
62	Jisonayilli, Tamale	Domestic	Fixed dome		1987	RESDEM	Not operational
63	Mr. Odame, Aboageykurom - Obuasi	Biogas plant for farm	CAMARTEC fixed dome		1988	Dr. E. Aklaku	Abandoned
64	Dr. E.N. Mensah, of Tema	Effluent and kitchen waste treatment	Fixed dome	8 m^3	2002	BTWAL	Operational
65	Mr. Kofi Ayim, Tema	Effluent and kitchen waste treatment	Fixed dome	12 m^3	2002	BTWAL	Operational
66	Mr. Ransford Tetteh	Effluent and kitchen waste treatment	Fixed dome	8 m^3	2002	BTWAL	Operational

67	Mr. Bonfah of Accra	Effluent and kitchen waste treatment	Fixed dome	10 m^3	2004	BTWAL	Operational
68	Mr. Quainoo, Accra	Effluent and kitchen waste treatment	Fixed dome	10m^3	2004	BTWAL	Operational
69	Bethlehem All Family, Tema	Sewage treatment	Fixed dome	10 m^3	2005	BTWAL	Operational
70	Private residence Nungua Accra,	Effluent and kitchen waste treatment	Puxin fixed dome	10m^3	2006	Beta Construction	Operational
71	Private residence Taifa, Accra	Effluent and kitchen waste treatment	Puxin fixed dome	10 m^3	2006	Beta Construction	Operational
72	New Legon – Hostel Apartment	Effluent and kitchen waste treatment	Puxin fixed dome	40 m^3	2007	Beta Construction	Ongoing
73	Private residence, Achimota	Effluent and kitchen waste treatment	Puxin fixed dome	10 m^3	2007	Beta Construction	Operational
74	Private residence Tema, Com. 18	Effluent and kitchen waste treatment	Puxin fixed dome	10 m^3	2007	Beta Construction	-
75	Mama Jastina, Dome, Accra	Effluent and kitchen waste treatment	Puxin fixed dome	10 m^3	2007	Beta Construction	Operational
				OTHERS			
76	Hebron Prayer Camp, Amasaman	Sewage treatment	Puxin fixed dome	40 m^3 (4 digesters)	2007	Beta Construction	Operational
77	Ankaful Prisons	Sewage treatment	Fixed dome	200 m^3 (4 plants)	2008	GRES/IIR	Ongoing
78	Catholic Mission House, Kaleo, U/W	Sewage treatment			1987	PANAJOF Constructors	Not operational
79	Christian Hope Ministry, Ohwim	Sewage treatment	Fixed dome			BEL	

SOURCE: KITE, 2008; UPDATED

APPENDIX D – PROFILE OF VISITED BIOGAS PLANTS IN GHANA

1. DEPARTMENT OF ANIMAL SCIENCE SLAUGHTERHOUSE (KNUST)

Date of visit:	03/06/2008
Interviewee	Kofi Akowuah, Slaughterhouse manager
Year of construction:	1994
Built by/ financed by:	BEL/ GTZ
Present status:	Not operating
Feed material:	Slaugh terhouse waste, dung
Digester type	Fixed-dome
Digester capacity:	50 m^3
Utilization of gas:	Previously used for singeing and heating water
Utilization of effluent:	Previously used as fertilizer on the Department's farm
Post-treatment of effluent	No
Problems	Plant produced enough gas for about four years until it broke down. Gas production halted, burners became corroded, and attempts to seek technical help from the constructors failed.
Caretaker present	No

Conclusion

The formation of scum is likely to play a major role in the demise of the plant. Since the digester has an entry hatch, it can be easily repaired.

Figure D- 1: A broken down digester at KNUST slaughterhouse

2. TIME OFFICE BIOGAS PLANT, ANGLOGOLD ASHANTI LIMITED (AAL) - OBUASI MINE

Date of visit:	07/06/2008
Interviewee:	Abu Bukari, Environmental Engineer, Sanitation Dept., AAL
Year of construction:	2000
Built by/financed by:	Biosanitation Company Limited (BCL)/ AGC
Present status:	Operating
Feed material:	Nightsoil

Digester type	Fixed-dome
Plant capacity (m^3):	10
Utilization of gas:	Gas is flared
Utilization of effluent:	Used to fertilize a plantain and cocoyam farm
Post-treatment of effluent	No
Problems	No serious problem
Caretaker present	Yes

Conclusion

It is obvious that plants designed to treat human excreta experience no problem with scum formation. The presence of a maintenance technician has ensured a continuous functioning of the plant.

Figure D- 2: A fixed dome plant at Power Station, Anglogold-Ashanti, Obuasi

3. HOSPITAL PLANT, AAL – OBUASI MINE

Date of visit:	07/06/2008
Interviewee:	Abu Bukari, Environmental Engineer, Sanitation Dept., AAL
Year of construction:	2000
Present status :	Operating
Feed material:	Nightsoil, waste from wards
Digester type	Floating-drum (water-jacket type)
Plant capacity (m^3):	Twin digester – 50 each
Utilization of gas:	Gas is flared
Utilization of effluent:	Discharged into municipal drains
Post-treatment of effluent	Yes
Problems	No serious problem
Caretaker present	Yes

Observation/conclusion

According to Abu Bukari, the two digesters were connected via a horizontal channel near the base of the digesters. This arrangement may lead to inefficient digestion since the second digester merely serves as an expansion chamber of the first digester. The correct arrangement of tandem plants is to connect a pipe near the base of the first digester to the second plant at a higher elevation or to an expansion chamber which in turn has an inlet pipe to the second digester.

Figure D- 3: Water-jacket plant at Anglo-Ashanti's hospital, Obuasi

4. HOLY FAMILY HOSPITAL – NKAWKAW

Date of visit:	09/06/2008
Interviewee	Frances Yeboah, caretaker
Year of construction:	1994
Built by:	A German priest
Present status:	Operating
Feed material:	Nightsoil, waste from wards
Digester type	Two tandem floating-drum digesters (water-jacket type)
Plant capacity (m^3):	Two 60 m^3
Utilization of gas:	Gas leaks due to gasholder (balloon) deterioration
Utilization of effluent:	Discharged into municipal drain
Post-treatment of effluent	Yes
Problems	Gas meter destroyed due to corrosion, gasholder deteriorated, gas leaks freely into the atmosphere, filter tank in bad shape
Caretaker present	Yes

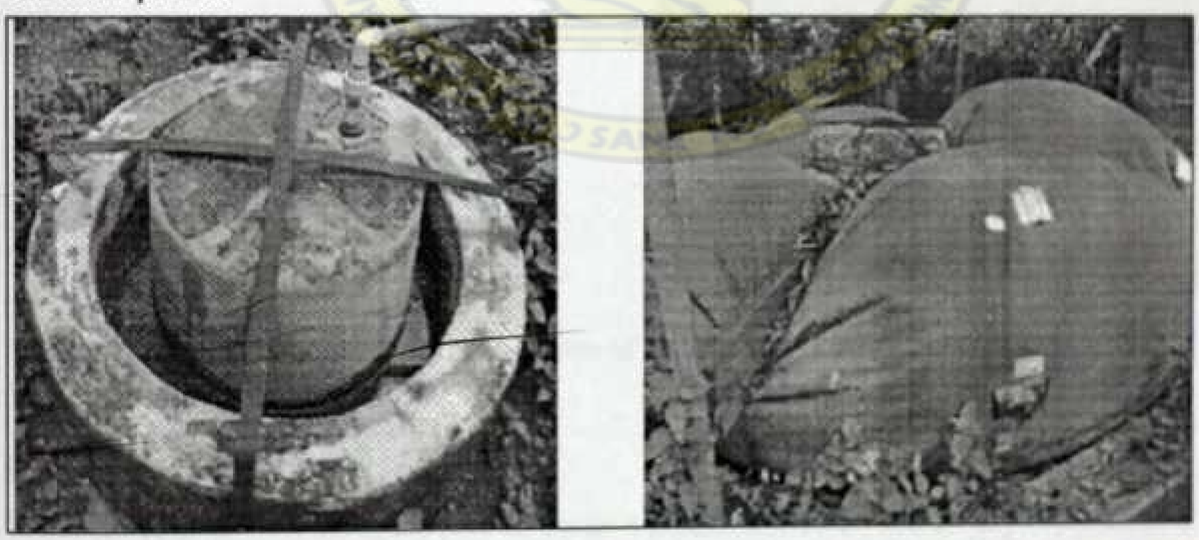

Figure D- 4: Left, Water-jacket plant at Holy family hospital; Right, deteriorated gasholder

Conclusion

The BOD of effluent from the digesters must be determined periodically to ascertain the efficacy of the process. It is also obvious that methane is directly released into the atmosphere due to breakdown of the gasholder and this must be discontinued. Gas flaring should be the appropriate option.

5. OFORI PANIN SENIOR HIGH SCHOOL – NEW TAFO

Date of visit:	09/06/2008
Interviewee	Adu Boahen, Senior House Master
Year of construction:	2002
Built by:	UNIRECO
Present status:	Not operating
Feed material:	Nightsoil
Plant capacity (m^3):	-
Utilization of gas:	-
Utilization of effluent:	Previously used on school farm
Post-treatment of effluent	No
Problems	Blockage of inlet pipe with polythene bags, menstrual pads and other foreign materials.
Caretaker present	-

Plant Description

This plant broke down after two years of usage. It consists of a fixed dome plant directly connected to the toilet house via an overflow inlet pipe. An overflow outlet channel takes the fluent into a storage tank. Gas produced was formally used by a teacher for cooking whiles the effluent was used for fertilizing the soil in a nearby farm.

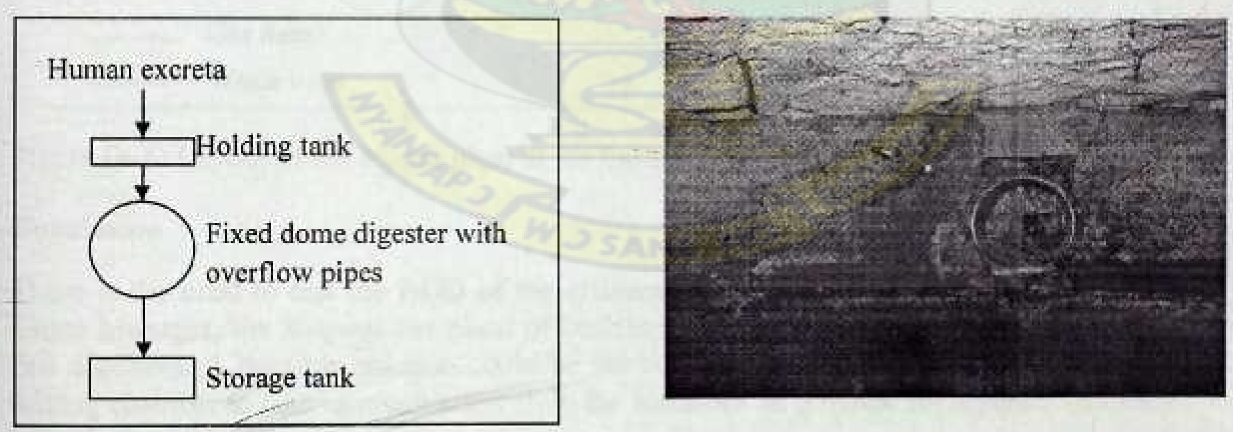

Figure D- 5: Left, Plant layout; Right, remains of the digester showing the overflow pipe at Ofori Panin SHS

Conclusion

The absence of screens along the path of the inlet pipes contributed to the early breakdown of the plant.

6. EASTERN REGIONAL HOSPITAL - KOFORIDUA

Date of visit:	10/06/2008
Interviewee	Samuel Grant, estate manager
Year of construction/Cost:	2006/ GH¢ 59,335.43
Built by/financed by:	BTWAL/Ghana Health Service
Present status:	Operating
Feed material:	Nightsoil, waste from wards
Digester type	Fixed-dome with separate balloon gasholder
Plant capacity (m^3):	80 m^3 (2 digesters)
Utilization of gas:	Heating water
Utilization of effluent:	Discharged into municipal drain
Post-treatment of effluent	Yes
Problems	Low gas pressure, inefficient treatment of waste due to feedstock exceeding design limit.
Caretaker present	Yes

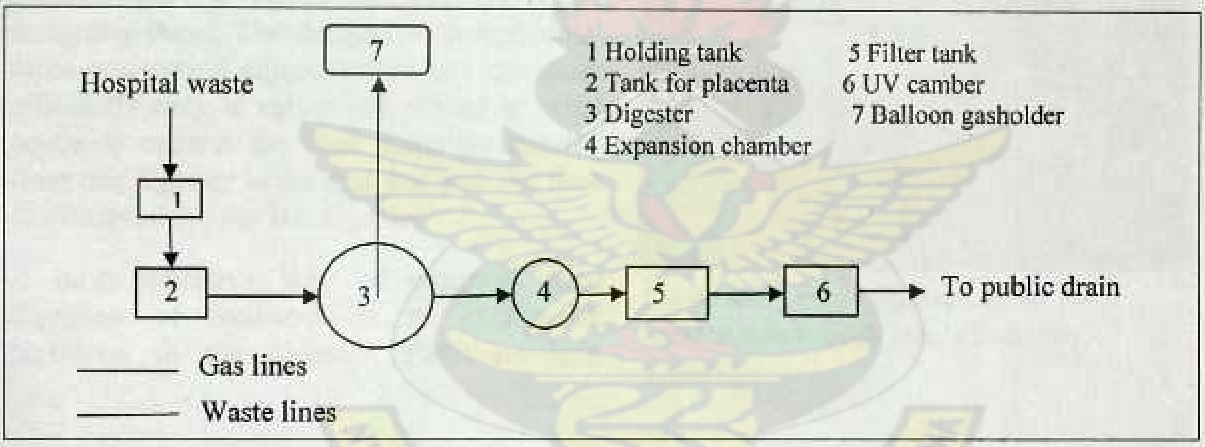

Figure D- 6: Layout of the biogas plant at the Eastern Regional hospital, Koforidua

Conclusion

There is the need to test the BOD of the effluent to verify this assertion. According to the Estate Manager, the hospital has plans of building a third digester to relieve pressure on the two digesters. A possible solution could be the construction of an overflow tank before the mixing chamber to take as much water from the feedstock as possible for separate treatment.

7. POPE JOHN'S SENIOR HIGH SCHOOL - KOFORIDUA

Date of visit:	10/06/2008
Interviewee	George Amoah, Beta Construction Ltd.

Year of construction/Cost[52]:	2007/ GH¢ 60,000.00
Built by/financed by:	Beta Construction/Parent Teacher Association
Present status:	Under construction
Feed material:	Nightsoil, kitchen waste
Digester type	Puxin digesters with separate balloon gasholder
Plant capacity (m^3):	40 m^3 (four 10 m^3 digesters in series)
Utilization of gas:	Expected to be used for cooking
Utilization of effluent:	To be recycled and used for flushing water closets
Post-treatment of effluent	Yes
Problems	Low gas pressure, inefficient treatment of waste due to feedstock exceeding design limit.
Caretaker present	-

Conclusion

The connection system between digesters is technically wrong and will not lead to efficient digestion of the slurry. Tandem plants require a lot of calculations before designing them. The designs with horizontal pipes connecting adjacent digesters can work efficiently only if valves are placed at vital points to control the feed materials moving from one digester to another and also the flow of effluent from the last digester.

Figure D- 7: Puxin digesters under construction at Pope John's Seminary, Koforidua

A more effective way of ensuring good digestion of feedstock is to incorporate partitions in the digester. Partitions help

8. VALLEY VIEW UNIVERSITY (VVU) - OYIBI

Date of visit:	10/06/2008
Interviewee	Louis Addy, VVU
Year of construction/Cost[53]:	2004/ GH¢ 20,000.00
Built by/financed by:	BTWAL/VVU
Present status:	Operating

[52] Includes a toilet facility

[53] Includes a toilet facility

Feed material:	Nightsoil[54], kitchen waste
Digester type	Fixed-dome digesters with separate balloon gasholder
Plant capacity (m^3):	78.3 m^3 (two digesters in series)
Utilization of gas:	Cooking
Utilization of effluent:	Discharged into the bush
Post-treatment of effluent	Yes
Problems	Low gas pressure, no utilization of effluent due to uncertainties regarding its safety.
Caretaker present	Yes

Conclusion

It is imperative that BOD samples of the effluent are determined in order to find out the effectiveness of the plant. Once the BOD of the effluent is determined and if the digesters are efficient in treating the waste, then there is the need to include the urine as part of the feed into the digesters. This will create a conducive atmosphere for the anaerobic process and thus ensure a higher volume and quality of the biogas in addition to a richer (nutrient-wise) effluent.

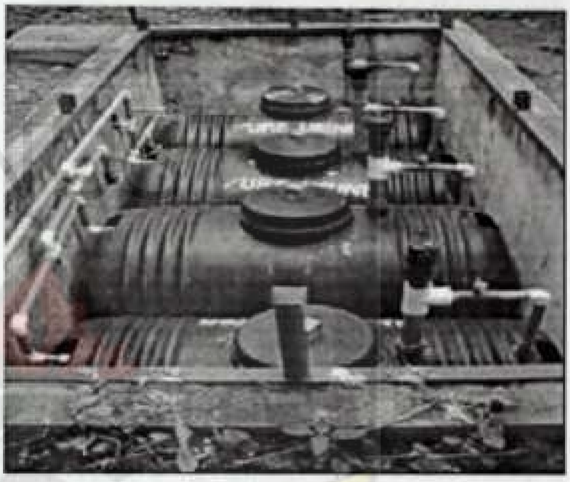

Figure D- 8: Storage containers for urine at Vallev View Universitv

9. KINDER PARADISE CHILDREN'S ORPHANAGE - PRAMPRAM

Date of visit:	11/06/2008
Interviewee	Adwoa Sarkodie, Manager
Year of construction/Cost:	2004
Built by/financed by:	BTWAL/German Embassy
Present status:	Operating
Feed material:	Nightsoil[55], kitchen waste
Digester type	Fixed-dome digester
Plant capacity (m^3):	50 m^3
Utilization of gas:	Cooking
Utilization of effluent:	Discharged into the bush

[54] From 800 students and staff

[55] From about 300 students and staff

Post-treatment of effluent	Yes
Problems	Regular choking of inlet pipes, intermittent gas production
Caretaker present	Yes

Conclusion

Choking of the inlet pipe is due to the large sizes of the kitchen waste dumped into the mixing tank. Moreover, flushed-water from the kindergarten, which is at a lover elevation, become stagnant when there is choking of the inlet pipe. Size reduction of the kitchen waste will ensure free movement into the digester in addition to quick digestion and scum prevention.

It is also obvious that there is some level of scum formation in the digester which has led to intermittent gas production. This could have been easily solved if it were possible to poke the digester directly from the MT.

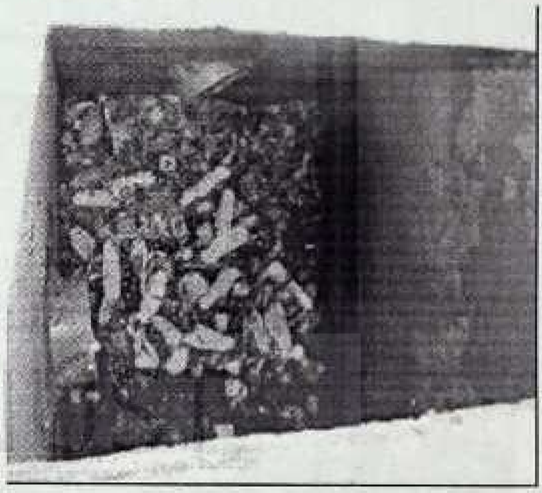

Figure D- 9: Mixing tank showing kitchen waste at Kinder Paradise orphanage, Prampram

10. CENTRAL UNIVERSITY COLLEGE (CUC) – MIOTSO CAMPUS

Date of visit:	11/06/2008
Interviewee	A. Idan, CEO, BTWAL
Year of construction/Cost[56]:	2006/ GH¢ 220,000.00
Built by/financed by:	BTWAL/CUC
Present status:	Operating
Feed material:	Nightsoil[57], kitchen waste
Digester type	Fixed-dome digester
Plant capacity (m^3):	410 m^3 (one 100 m^3, three 100 m^3 in series, and one 10 m^3)
Utilization of gas:	Cooking, laboratory fuel
Utilization of effluent:	Used for irrigation and flushing of toilet
Post-treatment of effluent	Yes
Problems	None

[56] Includes gas accessories, effluent channels, and other civil works

[57] Expected from about 15,000 students

Caretaker present	Yes

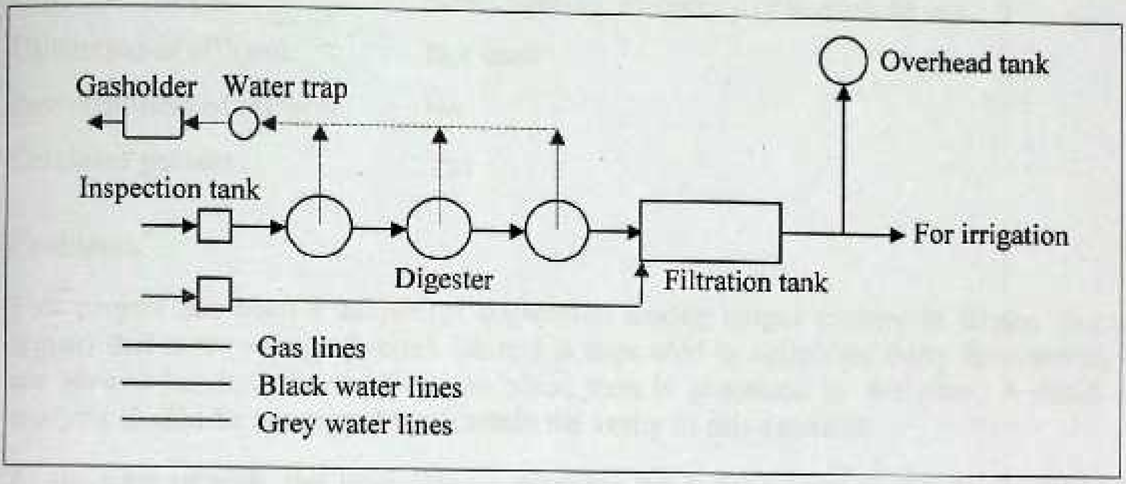

Figure D- 10: Plant layout of the three series digesters at Central University College, Miotso

Conclusion

The issue of connecting tandem digesters must be looked into. Poor design of tandem plants lead to inefficiencies in the digestion process.

Moreover, it is not very prudent to connect wastewater from the laboratories to the filtration tank because of potential contamination with toxic chemicals.

Figure D- 11: Three tandem digesters at CUC, Miotso

11. THE BIOGAS PLANTS IN APPOLONIA (RURAL ELECTRIFICATION PROJECT)

Date of visit:	11/06/2008
Interviewee	William Tetteh, Plant Attendant
Year of construction/Cost[58]:	1992/ -
Built by/financed by:	W. Ahiataku-Togobo[59] and Otto Addo[60]/ Ministry of Energy
Present status:	Operating below capacity
Feed material:	Nightsoil and cow dung
Digester type	Fixed-dome digester with separate gasholder (floating-drum)

[58] Includes gas accessories, effluent channels, and other civil works

[59] Wisdom is the director of the Renewable energy section at the Ministry of Energy.

[60] Addo is a researcher at the Institute of Industrial Research

Plant capacity (m^3):	500 m^3 (ten 50m^3 digesters and two 25 m^3 gasholders)
Utilization of gas:	Street lighting, electricity of household use
Utilization of effluent:	Not used
Post-treatment of effluent	No
Caretaker present	Yes

Problems

This project has been a subject of contention among biogas experts in Ghana. Some have argued that more energy (human labour) is expended in collecting dung from kraals, which are several hundred meters from the plant, than is generated by the plant. A detail energy analysis should be conducted to ascertain the verity of this assertion.

At the time of visit, the inlet pipes connecting the toilet houses to the digesters have been blocked by unidentifiable materials. The inhabitants had stopped using the toilets as places of convenience. The dried fertilizer in the compost pit has not been used for a long period and weeds have taken over. Moreover, the cables connecting the generators to the grid have developed faults. Other problems include unwillingness of inhabitants to contribute towards the upkeep of the plant and extremely low wages received by the caretaker of the plant.

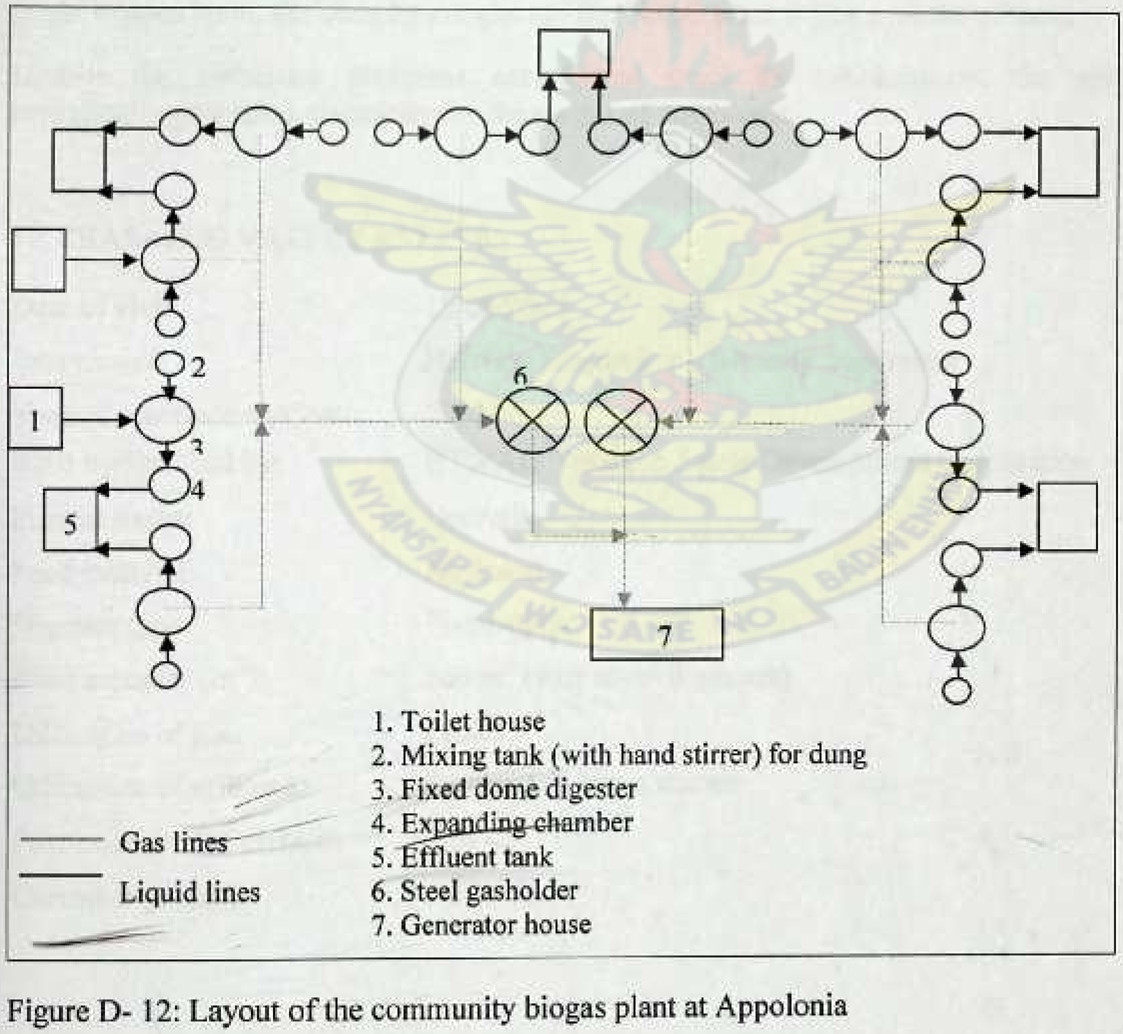

Figure D- 12: Layout of the community biogas plant at Appolonia

 

Figure D- 13: Left – Mixing tank with hand stirrer; Right – Remains of dilapidated fertilizer pit at Appolonia

Conclusion

At the time of visit, plans were far advanced by the Ministry of Energy to revamp the plant. The plant is technically sound and the real challenges bother more on the issue of acceptability. With the people clamouring for extension of the central grid to the area, which might happen soon, the complete neglect of the biogas plant is just a matter of time.

Despite the numerous problems encountered since its establishment, the plant has periodically generated electricity for the people of Appolonia.

12. TRASACCO VALLEY ESTATES

Date of visit:	12/06/2008
Interviewee	Harrison Gbedzeker – Security Supervisor
Year of construction/Cost:	2002/ -
Built by/financed by:	BTWAL/ Trasacco Estate Development Corporation
Present status:	Operating
Feed material:	Nightsoil
Digester type	Fixed-dome
Plant capacity (m^3):	260 m^3 (four 60m^3 digesters)
Utilization of gas:	Leaks
Utilization of effluent:	Discharged into a stream
Post-treatment of effluent	~~Yes~~
Caretaker present	No

Conclusion

It is obvious that the gas leaks through any available exit as the gas is neither flared nor used. There is the need for a caretaker to operate and maintain the plants.

Figure D- 14: A fixed dome plant at Trasacco Valley Estates, Accra

13. NEW ANKARFUL PRISON

Date of visit:	13/06/2008
Interviewee	Degraft Addo, Industrial designer, IIR
Year of construction/Cost[61]:	2008/ -
Built by/financed by:	IIR/ Ghana Prisons Board
Present status:	Under construction
Feed material:	Nightsoil from over 2000 inmates and staff
Digester type	Fixed-dome [62] digester with separate gasholder (floating-drum)
Plant capacity (m^3):	200 m^3 (four 50m^3 digesters and one 100 m^3 gasholder)
Utilization of gas:	Expected to be used for cooking
Utilization of effluent:	To be used for irrigation
Post-treatment of effluent	Yes
Caretaker present	Yes

Conclusion

The incorporation solar concentrators in the treatment of digester effluent are commendable. However, if energy generation is the main reason for building a biogas plant, then the contents in a mixing tank could rather be heated using solar before channelling the waste into the digester. This has the effect of increasing gas production whiles reducing the retention time considerably and thus the digester volume and cost. The performance of the plant can only be accessed when it starts operating. The effectiveness of the effluent treatment via solar optics must be studied. It appears this plant is the most sophisticated in Ghana.

[61] Includes gas accessories, effluent channels, and other civil works

[62] Constructed from pavement bricks

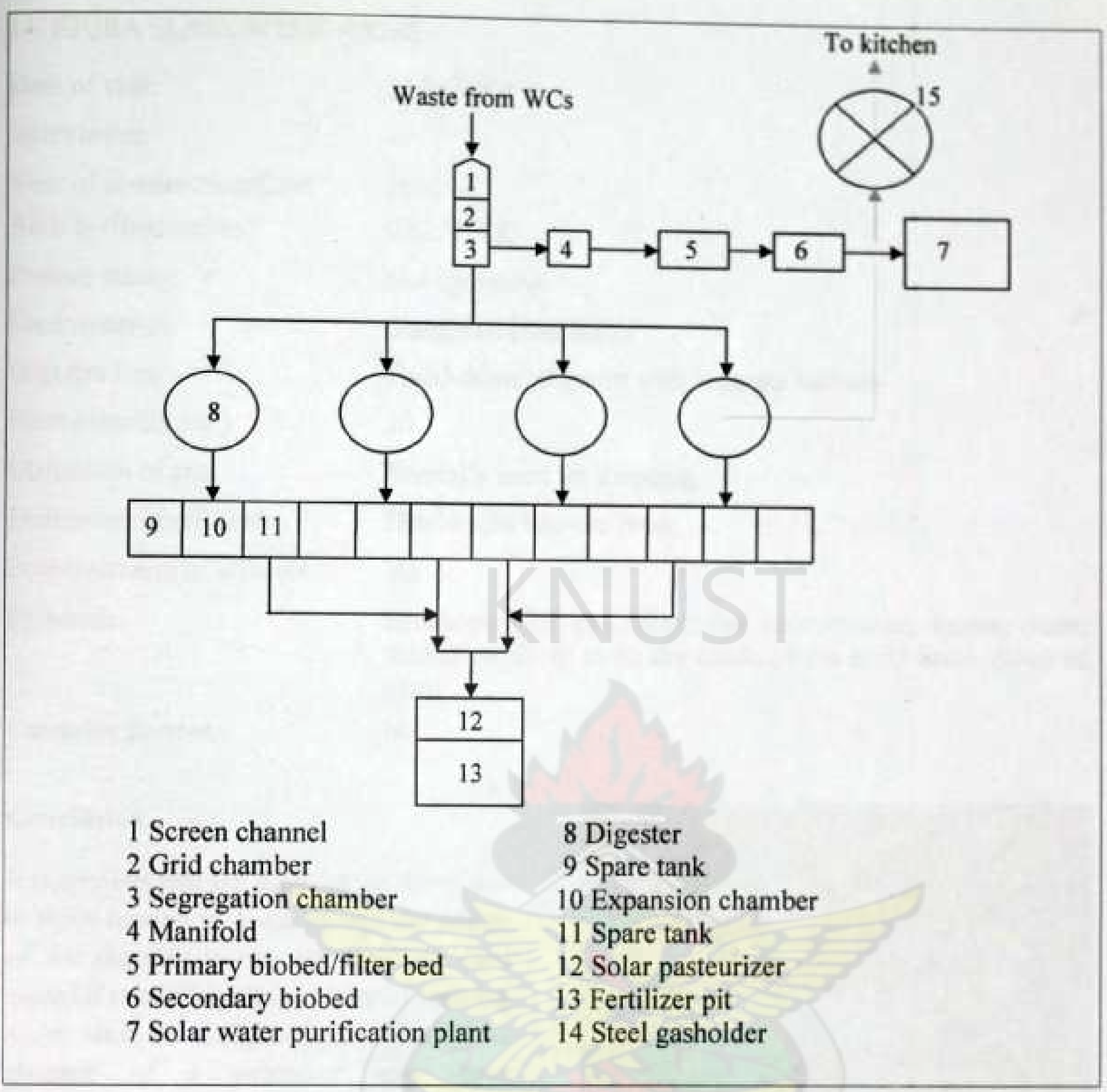

Figure D- 15: Layout of the biogas plant at the new Ankarful prison

Figure D- 16: Left – A fixed-dome with a central manhole; Right – Expansion chambers being constructed at Ankarful Prison

14. EJURA SLAUGHTERHOUSE

Date of visit:	24/06/2008
Interviewee	-
Year of construction/Cost[63]:	2002/ -
Built by/financed by:	BEL/ GTZ
Present status:	Not operating
Feed material:	Slaughterhouse waste
Digester type	Fixed-dome digester with separate balloon
Plant capacity (m^3):	50
Utilization of gas:	Formally used for singeing
Utilization of effluent:	Discharged into the bush
Post-treatment of effluent	No
Problems	Breakdown of gas meter due to corrosion, intense scum formation likely to be the cause of the early break down of plant
Caretaker present	No

Conclusion

It is obvious that the plant broke down due to scum formation. Even though the design of the digester is not net ideal for feed material with a high propensity of forming scum such as slaughterhouse waste, the absence of a caretaker may have contributed most towards the early demise of this plant. Scum needs to be occasionally rip to ensure continuous performance of slaughterhouse plants.

Figure D- 17: A fixed-dome digester with two expansion chambers at Ejura

Water-jacket plants with drums having internal spikes are better suited for high-scum formation feed materials.

15. WASTEWATER AT GUINNESS GHANA LIMITED (GGL), KUMASI

Date of visit:	18/07/2008
Interviewee	Saeed Abdul-Mumeed, Effluent Treatment Engineer

[63] Includes gas accessories, effluent channels, and other civil works

Year of construction/Cost:	2008/ -
Built by/financed by:	
Present status:	Operating
Feed material:	Waste malt, waste water containing soda
Digester type	Upflow Anaerobic Sludge Blanket (UASB)
Plant capacity (m^3):	800 m^3
Utilization of gas:	Flared (about 1800 m^3 a day)
Utilization of effluent:	Discharged into public drain
Post-treatment of effluent	Yes
Problems	Flaring of over 1500 m^3 of biogas daily
Caretaker present	Yes

Conclusion

Even though the BOC and COD levels are reduced drastically before discharging the treated wastewater into the public drain, the levels are still high than the accepted amounts by the Environmental Protection Agency (EPA). The treatment process must be opitimized.

Finally, the large volumes of gas flared daily can rather be used to generate electricity for the company's use.

Figure D- 18: A UASB bioreactor at Guinness Ghana Limited - Kumasi

16. TEPA SLAUGHERHOUSE

Date of visit:	11/09/2008
Interviewee	Musah Mohammed, Butcher
Year of construction/Cost:	2005/ GH¢ 5,500
Built by/financed by:	BCL/ District Assembly
Present status:	Abandoned
Feed material:	Slaughterhouse waste
Digester type	Floating-drum (water-jacket)
Plant capacity (m^3):	60 m^3
Utilization of gas:	Expected to be used for singeing
Utilization of effluent:	Expected to be used as organic fertilizer

Post-treatment of effluent	Yes
Problems	Abandoned due to location of plant
Caretaker present	No

Conclusion

Since the new slaughterhouse is located about 500 m from the town, the butchers have refused to relocate, thus making the slaughterhouse and the biogas plant a white elephant.

Figure D- 19: A water-jacket plant at an abandoned slaughterhouse at Tepa

17. GHANA INSTITUTE OF MANAGEMENT AND PROFESSIONAL ADMINISTRATION (GIMPA)

Date of visit:	15/09/2008
Interviewee	-
Year of construction/Cost:	2007/ -
Built by[64]/financed by:	BTWAL/ GIMPA
Present status:	Not charged
Feed material:	Nightsoil
Digester type	Floating-drum with drum made of polymer
Plant capacity (m^3):	100 m^3 (two tandem digesters)
Utilization of gas:	-
Utilization of effluent:	-
Post-treatment of effluent	Yes
Caretaker present	-

[64] This plant, initially a fixed-dome, developed problems and was later redesigned by BEL. The floating-drum plants (Figure D-20) are a modification of the original fixed-dome digesters.

Conclusion

It is obvious that the gas leaks through any available exit as the gas is neither flared nor used. There is the need for a caretaker to operate and maintain the plants.

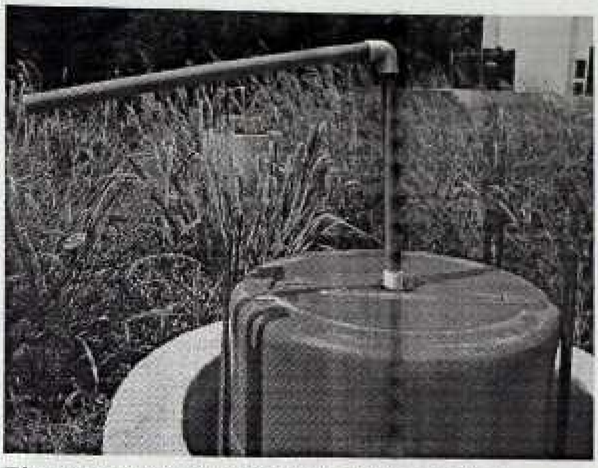

Figure D- 20: Two tandem water-jacket floating-drum plants at GIMPA

18. HEADQUATERS OF BETA CONSTRUCTION LIMITED - DOME

Date of visit:	15/09/2008
Interviewee	Kofi Ahenkorah, Executive Director, BCL
Year of construction/Cost:	2007/ -
Built by/financed by:	BCEL/ BCEL
Present status:	Operating
Feed material:	Nightsoil and kitchen waste
Digester type	Puxin digester
Plant capacity (m^3):	10 m^3
Utilization of gas:	Cooking and lighting
Utilization of effluent:	Recycled for use in flushing toilet
Post-treatment of effluent	Yes
Problems	-
Caretaker present	Yes

Conclusion

It is good that the effluent is treated and reused for flushing. So far, the plant has performed creditably owing to expert maintenance. There is, however, the need to determine the BOC, COD, and pathogen levels of the effluent to be certain about its safety.

Figure D- 21: A biogas lamp in use at the office of BCL at Dome – Accra.

19. ACCRA PSYCHIATRIC HOSPITAL

Date of visit:	16/09/2008
Interviewee	Gladys Owusu, Assistant Environmental Officer
Year of construction/Cost:	2003/ -
Built by/financed by:	BTWAL/ -
Present status:	Operating
Feed material:	Nightsoil from about 1300 inmates and staff
Digester type	Fixed-dome digester with separate gasholder (balloon)
Plant capacity (m^3):	100 m^3 (twin digester - 50m^3 each)
Utilization of gas:	Cooking
Utilization of effluent:	Discharged into the public drain
Post-treatment of effluent	Yes
Problems	Discharged effluent emits bad odour suggesting inefficient digestion.
Caretaker present	Yes

Conclusion

The population of the inmates and staff of the hospital has increased steadily since 2003 when the plant was built. With this increase, there is a concomitant upsurge in the quantum of blackwater released into the digesters, thus reducing the designed *retention time* and therefore the digestion efficiency. A third plant must be constructed to relieve the pressure on the digesters.

Figure D- 22: Twin digesters at Accra Psychiatric Hospital

20. ABEMAN/OSHIUMAN COMMUNITY

Date of visit:	17/09/2008
Interviewee	Nii Oku, Attendant
Year of construction/Cost[65]:	2000/ -
Built by/financed by:	BTWAL/ GoG[66], AfDB[67], and UNDP[68] – Social Investment Fund
Present status:	Operating
Feed material:	Nightsoil
Digester type	Fixed-dome with a 16 – seater latrine
Plant capacity (m^3):	40 m^3
Utilization of gas:	Not utilized
Utilization of effluent:	To be used for irrigation
Post-treatment of effluent	Yes
Problems	Gas leaks into the toilet house creating a potential fire outbreak
Caretaker present	Yes

[65] Includes gas accessories, effluent channels, and other civil works

[66] Government of Ghana

[67] African Development Bank

[68] United Nations Development Programme

Conclusion

It appears the toilet is under-utilized owing to its location, which is about 50 m from the community centre. The leakage of gas into the toilet rooms via the inlet pipe is a serious health risk. This problem is exacerbated by the non-utilization of the gas, thus creating very high pressures in the dome which in turn force the gas through any available opening.

Figure D- 23: Fixed-dome plant at Abeman

21. MAMA JASTINA, DOME

Date of visit:	17/09/2008
Interviewee	Joyce Sarfo
Year of construction/Cost[69]:	2008/ GH¢ 7,000
Built by/financed by:	Beta Construction Ltd./ Private funds
Present status:	Operating
Feed material:	Nightsoil and kitchen waste
Digester type	Puxin digester
Plant capacity (m^3):	10 m^3
Utilization of gas:	For cooking
Utilization of effluent:	For watering lawns or discharged into the public drain
Post-treatment of effluent	Yes
Problems	-
Caretaker present	Yes

Conclusion

There has not been any major problem with the plant.

Figure D- 24: Rubber gas line with pressure gauge at Dome, Accra

[69] Includes gas accessories, effluent channels, and other civil works

22. ADULLAM ORPHANAGE - OBUASI

Date of visit:	04/10/2008
Interviewee	Pastor James, Chaplain/Welfare officer
Year of construction/Cost:	2002/ -
Built by/financed by:	BTWAL/ AAL
Present status:	Operating
Feed material:	Nightsoil from over 200 orphans and staff
Digester type	Fixed-dome (Deenbandhu model)
Plant capacity (m^3):	60 m^3
Utilization of gas:	Cooking
Utilization of effluent:	Discharged into the public drain
Post-treatment of effluent	Yes
Problems	-
Caretaker present	Yes

Conclusion

This plant has performed efficiently since its construction in 2002. There is still the need to determine the BOD level in the effluent in order to ascertain the efficacy of the fermentation process.

Figure D- 25: The expansion chamber and the digester (far back) at Adullam orphanage,

23. POLICE POST – OBUASI

Date of visit:	04/10/2008
Interviewee	Abu Bukari/Sanitation Engineer (AAL)
Year of construction/Cost:	2002/ -
Built by/financed by:	BCL/ AAL
Present status:	Operating
Feed material:	Nightsoil
Digester type	Fixed-dome
Plant capacity (m^3):	50 m^3

Utilization of gas:	Cooking
Utilization of effluent:	Discharged into the public drain
Post-treatment of effluent	Yes
Problems	Temporal breakdown of gas stove
Caretaker present	Yes

Conclusion

The only problem was with the gas appliance which was not being used due to extreme corrosion. Notwithstanding, the plant has performed efficiently and it is currently in good shape. Plans are far advanced to replace the worn-out stove, says Abu.

Figure D- 26: A closed gas valve due to breakdown of burner at Post Post, Obuasi

24. ST. MARTINS SENIOR HIGH SCHOOL – NSAWAM-ADOAGYIRI

Date of visit:	29/11/2008
Interviewee	Michael Mumuni – School Prefect
Year of construction/Cost:	2006
Built by/financed by:	- /PTA
Present status:	Operating
Feed material:	Nightsoil
Digester type	Fixed-dome (6-seater biotoilet)
Plant capacity (m^3):	
Utilization of gas:	Not used (leaks)
Utilization of effluent:	Not used (effluent storage tank periodically emptied)
Post-treatment of effluent	Yes
Problems	Frequent choking of inlet pipes with polythene and pieces of cloth creating serious sanitation problems
Caretaker present	Yes

Conclusion

The gas is not used since the school lacks a stove. Gas escapes freely into the atmosphere. The gas meter is completely deteriorated. Moreover, frequent choking of the inlet pipes have caused serious hygiene problems as the toilet seats are filled with excreta to the brim, with some overflowing onto the floor. Some students have defaecated on the floor and near the entrance of the toilet house. The authorities seemed not very much concerned.

Figure D- 27: The effect of a choked inlet pipe at St. Martins S.H.S, Nsawam

25. HEBRON PRAYER CAMP – NSAWAM-ACCRA ROAD

Date of visit:	29/11/2008
Interviewee	Brother Emmanuel, Deacon
Year of construction/Cost:	2007/
Built by/financed by:	BCL/Church
Present status:	Operating
Feed material:	Nightsoil
Digester type	Puxin digesters
Plant capacity (m^3):	40 m^3 (four 10 m^3 digesters in series)
Utilization of gas:	Cooking
Utilization of effluent:	Discharged into nearby bush
Post-treatment of effluent	Yes
Problems	No problem observed
Caretaker present	Yes

Conclusion

No major problem was observed. Presence of sulphur removers has created a more conducive atmosphere at the kitchen due to reduction of the odour.

Figure D- 28: Four series Puxin digesters at Hebron Prayer Camp, near Nsawam

26. BATTOR CATHOLIC HOSPITAL – BATTOR

Date of visit:	30/11/2008
Interviewee	Joyce Anku, Assistant Sanitation Manager
Year of construction/Cost:	1995/
Built by/financed by:	TIE/The German Bishop Conference
Present status:	Operating
Feed material:	Nightsoil
Digester type	Fixed dome with a separated gasholder
Plant capacity (m^3):	240 m^3 (four digesters)
Utilization of gas:	Cooking
Utilization of effluent:	Discharged into public drain
Post-treatment of effluent	Yes
Problems	Low gas production
Caretaker present	Yes

Conclusion

Reduction in gas production has been experienced and it is imperative that a major excavation is done to remove accumulated grit and stones in the digester.

Figure D- 29: A balloon gasholder at the Battor Catholic hospital

27. APPOLONIA COMMUNITY – APPOLONIA HOUSEHOLD PROGRAMME

Date of visit:	30/11/2008
Interviewee	William Tetteh, Caretaker
Year of construction/Cost:	1987/
Built by/financed by:	RESDEM/Government of Ghana
Present status:	Not operating
Feed material:	Nightsoil
Digester type	Fixed dome
Plant capacity (m^3):	210 m^3 (14 domestic digesters); six plants were surveyed
Utilization of gas:	Previously for cooking
Utilization of effluent:	Never used
Post-treatment of effluent	No
Problems	Long distances from plant sites to kraals
Caretaker present	-

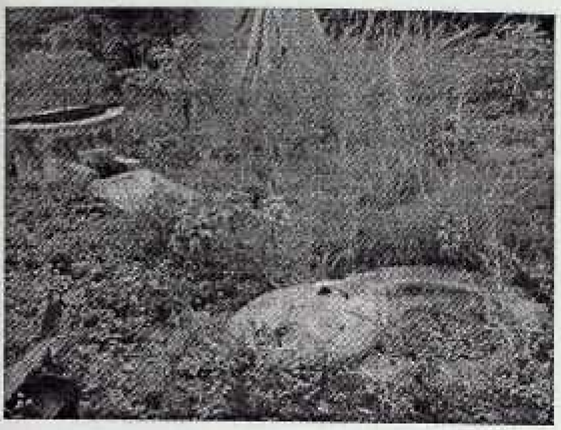 

Figure D- 30: Left – Remains of a 10 m^3 fixed dome plant at Appolonia; Right – Remains of a 15 m^3 fixed dome plant at Appolonia

Conclusion

The major factors that contributed to the demise of the Appolonia household programme included the long distances of the plant from the kraals (between half and three-quarters of a mile), the availability of firewood, the long distances of plant sites from the farms of owners, and the refusal of plant owners to pay for the collection of dung from the kraals. A cursory analysis of energy analysis is likely to reveal a situation where more energy was expended in the collection of dung than was obtained in the burning of the biogas. This situation must always be avoided in the planning of any future project.

28. TEMA EAST BASIC EXPERIMENTAL SCHOOL – BETHLEHEM (TEMA)

Date of visit:	01/12/2008
Interviewee	Jake Owusu, Secretary
Year of construction/Cost:	2002/
Built by/financed by:	BTWAL/School Management
Present status:	Temporarily closed
Feed material:	Nightsoil
Digester type	Fixed dome
Plant capacity (m^3):	10 m^3
Utilization of gas:	Not used
Utilization of effluent:	Discharged into public drain
Post-treatment of effluent	Yes
Problems	No stove connected
Caretaker present	-

Conclusion

The school had temporarily been closed down at the time of the visit. It was also clear that the gas had never been used due to the absence of any biogas appliance.

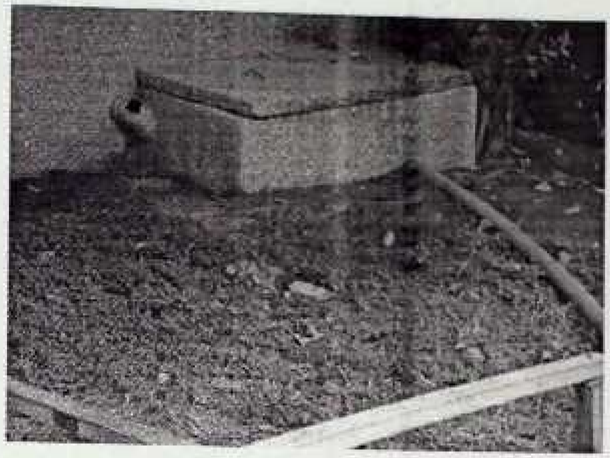

Figure D- 31: A mixing tank at the Tema East Basic Experimental School

29. BETHLEHEM ALL FAMILY (DOMESTIC) – BETHLEHEM (TEMA)

Date of visit:	01/12/2008
Interviewee	Jake Owusu
Year of construction/Cost:	2005/
Built by/financed by:	BTWAL/Private funds
Present status:	Operating
Feed material:	Nightsoil
Digester type	Fixed dome
Plant capacity (m^3):	10 m^3
Utilization of gas:	Not used
Utilization of effluent:	Discharged into public drain
Post-treatment of effluent	Yes
Problems	No stove connected
Caretaker present	No

Conclusion

The gas leaks since it is neither used nor flared.

Figure D- 32: Discharge of plant effluent into the public drain at Bethlehem, Tema

30. FIESTA ROYALE HOTEL – ACCRA

Date of visit:	02/12/2008
Interviewee	Mr. Mensah, Maintenance Manager
Year of construction/Cost:	2007/
Built by/financed by:	BTWAL/Company funds
Present status:	Operating
Feed material:	Nightsoil
Digester type	Fixed dome
Plant capacity (m^3):	60 m^3
Utilization of gas:	Flared
Utilization of effluent:	Discharged into public drain
Post-treatment of effluent	Yes
Problems	-
Caretaker present	Yes

Conclusion

Even though the gas is not used, it is flared putting out any concern of environmental pollution. There are plans to use the treated effluent for watering lawns as a way of conserving water.

Figure D- 33: A fixed dome digester showing the gas pipe at the Fiesta Royale

31. TAMALE TEACHING HOSPITAL – TAMALE

Date of visit:	04/12/2008
Interviewee	Paul Ayambilla, Assistant Administrative Manager
Year of construction/Cost:	2001/
Built by/financed by:	BTWAL/GHS
Present status:	Operating
Feed material:	Nightsoil
Digester type	Fixed dome
Plant capacity (m^3):	120 m^3 (twin digesters)
Utilization of gas:	Leaks
Utilization of effluent:	Discharged into public drain
Post-treatment of effluent	Yes
Problems	No stove connected
Caretaker present	Yes

Conclusion

There is no gas appliance and the gas escapes freely into the atmosphere. Moreover, the wastewater from the mortuary is discharged into the public drain without being treated by the biogas digested.

Figure D- 34: The exit of the gas pipe showing the absence of a gas stove at the Tamale teaching hospital

32. TAMALE WEST HOSPITAL – TAMALE

Date of visit:	04/12/2008
Interviewee	Osman Nuhu, Biotoilet cleaner
Year of construction/Cost:	2002/
Built by/financed by:	BTWAL/GHS
Present status:	Operating
Feed material:	Nightsoil

Digester type	Fixed dome (8 seater biotoilet)
Plant capacity (m^3):	40 m^3 (twin digesters)
Utilization of gas:	Leaks
Utilization of effluent:	Periodically taken from the effluent storage tank for disposal
Post-treatment of effluent	No
Problems	Exit of gas pipe unclear
Caretaker present	Yes

Conclusion

The presence of a large water reservoir has ensured improved sanitation in the toilet house. However, the absence of a gas appliance has created a condition where the gas leaks freely into the atmosphere. The caretaker seemed to have no idea regarding the exit of the gas pipe.

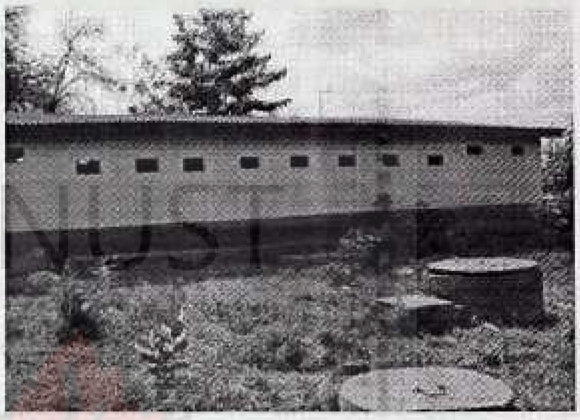

Figure D- 35: An 8-seater biotoilet at Tamale West hospital

33. PRIVATE (ALHAJI MAHAMADOU MAHAMA) – JISONAYILLI

Date of visit:	04/12/2008
Interviewee	Alhaji M. Mahama, Beneficiary
Year of construction/Cost:	1986/
Built by/financed by:	RESDEM/J. J. Rawlings[70]
Present status:	Not operating
Feed material:	Cow dung
Digester type	Fixed dome
Plant capacity (m^3):	10
Utilization of gas:	Previously for cooking
Utilization of effluent:	Never used
Post-treatment of effluent	No
Problems	-
Caretaker present	-

[70] Former president of Ghana

Conclusion

This plant was initiated by ex-PNDC Chairman during a visit to Jasonayilli in 1986. The plant produced gas for cooking and lighting until 1999 as a result of the relocation of kraal far away from village. Even though the benefits of the plant were known to inhabitants in the village, most of them could not afford to pay for the cost of the digesters.

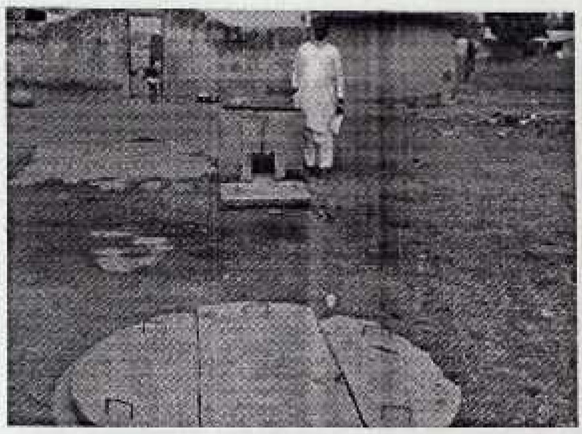

Figure D- 36: Remains of a domestic biogas plant at Jisonayilli, near Tamale

34. GAMBAGA COMMUNITY – GAMBAGA

Date of visit:	05/12/2008
Interviewee	Mallam Yusif, Opinion leader
Year of construction/Cost:	2005
Built by/financed by:	IIR/SIF (Social Investment Fund)
Present status:	Not operating
Feed material:	Nightsoil
Digester type	Fixed dome (6 seater biotoilet)
Plant capacity (m^3):	30
Utilization of gas:	Never used
Utilization of effluent:	Never used
Post-treatment of effluent	No
Problems	Leakage of gas into toilet chamber due to poor design of inlet pipes and non-usage of gas
Caretaker present	-

Conclusion

This biotoilet failed probably due to the non-involvement of community members in its planning and implementation. The leakage of gas into the toilet chambers created unpleasant conditions which repelled people from using the plant. It was also observed that a substantial number of inhabitants practice open defaecation and most public toilets (the biotoilet and KVIPs) are not used.

Figure D- 37: A failed biotoilet project at Gambaga

35. OSEI TUTU II SENIOR HIGH SCHOOL[71] – TETREM

Date of visit:	12/12/2008
Interviewee	Alex Boateng, Head – Agric Department
Year of construction/Cost:	2002/
Built by/financed by:	UNIRECO/ DANIDA
Present status:	Operating
Feed material:	Nightsoil
Digester type	Fixed dome (10 seater biotoilet)
Plant capacity (m^3):	-
Utilization of gas:	Not used (leaks)
Utilization of effluent:	Not used
Post-treatment of effluent	No
Problems	Breakdown of gas meter
Caretaker present	Yes

[71] Formally Tetrem Senior Secondary School

Conclusion

This 10 seater biosanitation project serves over 700 students. Overdependence of the facility has created some hygiene problems in the toilet chambers. Bad odour persists in and around the chambers and lots of flies are seen buzzing in the toilet chambers.

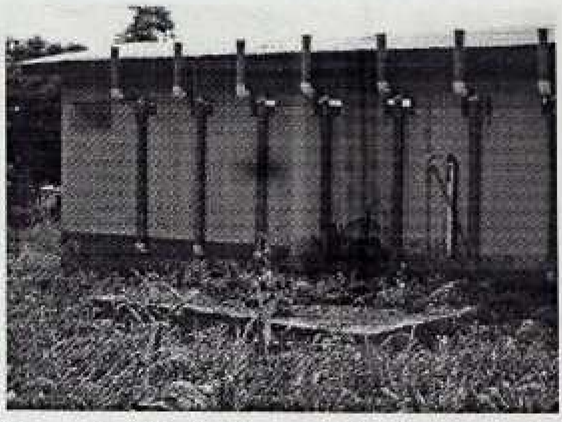

Figure D- 38: A 10 seater biotoilet at Osei Tutu II SHS, Tetrem

36. MANKRANSO BIOTOILET – AHAFO ANO SOUTH DISTRICT

Date of visit:	13/12/2008
Interviewee	Grace Boahen, Caretaker
Year of construction/Cost:	2005/
Built by/financed by:	IIR/ District Assembly
Present status:	Not operating
Feed material:	Nightsoil
Digester type	Fixed dome (8 seater biotoilet)
Plant capacity (m^3):	-
Utilization of gas:	Not used
Utilization of effluent:	Not used
Post-treatment of effluent	No
Problems	Breakdown of gas meter, digester full and choked
Caretaker present	Yes

Conclusion

Figure D- 39: A poorly sited biotoilet at Mankranso

The siting of this project close to a huge rubbish dump created sanitation problems for users (between 50 and 70 daily) of the biotoilet. The choked digesters are engulfed in filth creating extremely bad odour within the vicinity of the toilet. The biotoilet have not been excavated since it got full about 5 months ago and users have resorted to other toilets. Children, however, can be seen defaecating openly around the dump.

37. ASOKORE MAMPONG COMMUNITY/ GARDEN CITY SPECIAL SCHOOL

Date of visit:	16/12/2008
Interviewee	Ama Mensimah, Caretaker of biotoilet
Year of construction/Cost:	2004
Built by/financed by:	BEL/
Present status:	Operating
Feed material:	Nightsoil
Digester type	Fixed dome (12 seater biotoilet)
Plant capacity (m^3):	-
Utilization of gas:	Leaks
Utilization of effluent:	Not used
Post-treatment of effluent	No
Problems	Breakdown of gasholder, biotoilet too close to rubbish dump, toilet chambers are not spacious
Caretaker present	Yes

 

Figure D- 40: Left – A biotoilet engulfed in garbage at Asokore Mampong; Right – A white elephant biogas stove at the kitchen of the Garden City Special School

Conclusion

The biotoilet, which is located about 500 m from the school, was supposed to produce gas for the school's kitchen. The school never used the gas and gasholder leaked raising concerns on the safety of the kids. The gasholder was then deflated and the burner was never used.

38. PARKOSO BIOTOILET - KUMASI

Date of visit:	16/12/2008
Interviewee	Kwame Opoku, Head of local assembly
Year of construction/Cost:	1997
Built by/financed by:	TIE
Present status:	Not operating
Feed material:	Nightsoil
Digester type	Fixed dome (6 seater biotoilet)
Plant capacity (m^3):	-
Utilization of gas:	-
Utilization of effluent:	-
Post-treatment of effluent	No
Problems	Toilet chambers are not spacious, leakage of gas into toilet chambers
Caretaker present	No

Conclusion

This biotoilet has been abandoned due to the high leakage of biogas into the toilet chamber through the inlet pipe to the digester. In addition, bad odour from the aerobic decomposition of faeces in the inlet pipe has repelled users of this toilet.

Figure D- 41: An unused biotoilet at Parkoso, near Kumasi

39. THE HOUSEHOLD BIOGAS PLANTS AT OKUSHIBLI

Date of visit:	03/02/2009
Interviewee	Anthony Nartey, Biogas plant user
Year of construction/Cost:	1990/ -
Built by/financed by:	GRES/ -
Present status:	Not operating
Feed material:	Cow dung
Digester type	Deenbandhu fixed dome digester
Plant capacity (m^3):	50 (five digesters)
Utilization of gas:	Previously used for cooking
Utilization of effluent:	Never used
Post-treatment of effluent	No
Problems	Breakdown of gas pipes and stoves
Caretaker present	No

Conclusion

All the five plants are no more used due to the breakdown of gas pipelines and stoves. Most of the plants functioned for more than eight years and only fell into disuse after the stoves had deteriorated and efforts to reach the constructors failed. It is obvious that the users were unwilling to spend money on the maintenance of the plants. Moreover, woodfuel is readily available in the village.

Figure D- 42: The remains of one of the five Deenbandhu plants at Okushibli

40. KOTOKU BIOTOILET – GA WEST DISTRICT

Date of visit:	04/02/2009
Interviewee	Nancy Fiagbe , Cartaker
Year of construction/Cost:	1995/ -
Built by/financed by:	IIR/ GoG (HIPC Project)
Present status:	Operating
Feed material:	Nightsoil
Digester type	Fixed dome digester
Plant capacity (m^3):	40 (two digesters)
Utilization of gas:	Not used (leaks)
Utilization of effluent:	Discharged into bush
Post-treatment of effluent	No
Problems	Breakdown of gas pipes
Caretaker present	Yes

Conclusion

This biotoilet is underutilized because people find the 5 Pesewa fee being charged high and rather prefer to ease themselves in the bush. Gas is not utilized neither is it flared. The gas leakage can be dealt with if caretakers are trained to flare the gas.

Figure D- 43: Two tandem fixed-dome digesters with a separate floating-drum gasholder at Kotoku

41. THE BIOGAS PLANTS AT ST. DOMINIC HOSPITAL – AKWATIA

Date of visit:	06/02/2009
Interviewee	Tony Wiafe, Cartaker
Year of construction/Cost:	1994/ -
Built by/financed by:	TIE/ German Bishop Conference
Present status:	Operating
Feed material:	Nightsoil
Digester type	Floating-drum digester
Plant capacity (m^3):	180 (five digesters)
Utilization of gas:	Not used (leaks)
Utilization of effluent:	Discharged into the bush
Post-treatment of effluent	Yes
Problems	Deterioration of balloon gasholder
Caretaker present	Yes


Figure D- 44: Left – breakdown gas meters; Right – deteriorated balloon gasholder at St. Dominic hospital, Akwatia

Conclusion

Since the plants were constructed to treat sewage, the usage of gas has not been a priority. Gas leaks freely into the atmosphere due to the breakdown of the balloon. The biogas stoves are also not used because of corrosion.

APPENDIX E – SIZING CALCULATIONS OF PLANTS DIGESTING COW DUNG

a) Plant Volume: 4 m^3

i) Estimation of daily gas production

Feed material : Cattle dung

Number of cattle : 14

Daily amount of dung : 40 kg

Mixing ratio - dung/water : 1/1

Daily amount of feed material (dung and water) : $\frac{40\text{ kg}}{\text{day}} \times 2 = 80$ litre/day

(Density of feed material is assumed to equal that of water)

Minimum retention time, RT = 40 days

Digester volume, $V_D = \frac{80\text{ litres}}{\text{day}} \times 40\text{ days} = 3.2\text{ m}^3$

Digester temperature : 26 - 28 ^0C

Specific gas production (Sasse, 1988), G_{SP} = 29.5 litre/kg of dung

Daily gas production, $D_G = \frac{29.5\text{ litre}}{\text{kg}} \times \frac{40\text{ kg}}{\text{day}} = 1.18 \frac{\text{m}^3}{\text{day}}$

ii) Determination of gasholder volume and gasholder capacity

Hourly gas production , HGP : $1.18 \frac{\text{m}^3}{\text{day}} \times \frac{\text{day}}{24\text{ hr}} = 49.1$ litre/hr

Gas consumptio n : 2 hours in the morning, from 0600 to 0800 hours

3 hours in the evening, from 1600 to 1900 hours

Total duration : 5 hours

Hourly gas consumptio n, HGC : $\frac{D_G}{\text{Total duration}} = \frac{1.18\text{ m}^3}{5\text{ hr}} = 235.96$ litre/hr

Differece between gas production and consumptio n : 235.96 - 49.1 = 186.79 litre/hr

Gasholder size during consumptio n, V_{G1} : $186.79 \frac{\text{litre}}{\text{hr}} \times 3\text{ hr} = 560.37$ litres

Longest interval between periods of consumptio n (from 1900 to 0600) : 11 hours

Gasholder size between periods of consumptio n, V_{G2} : HGP $\times$ 11 hr = 540.76 l

Since $V_{G1} > V_{G2}$, V_{G1} will be used to determine the appropriat e gasholder size. Using a safety margin of 25 %, the required gasholder volume is

$$V_G = 560.37 \text{ litres} \times 1.4 = 728.48 \text{ litres} \approx 0.80 \text{ m}^3$$

$$\text{Gasholder capacity} = \frac{\text{Gasholder size}}{\text{Daily gas production}} = \frac{800 \text{ litres}}{1180 \text{ litres}} = 67.8 \%$$

(This value falls within th e prescribed capacity suggested by Sasse (1988) for domestic plants in developing countries)

$$\text{Digester/g asholder ratio} = \frac{\text{Digester v olume}}{\text{Gasholder volume}} = \frac{3.4 \text{ m}^3}{0.70 \text{ m}^3} = \frac{4.86}{1}$$

$$\text{Plant volume} = \text{digester volume} + \text{gasholder volume}$$
$$= 3.2 + 0.8 = 4 \text{ m}^3$$

The retention time (40 days) used for the calculations is the minimum recommended. The above calculation procedure is applied to all the proposed plant volumes. Table E-1 summarises values obtained for important parameters.

Table E- 1: Calculated values of important parameters of each plant volume

Plant parameter	Plant Volume (m^3)			
	4	6	8	10
Digester volume (m^3)	3.2	5.0	6.7	8.3
Gasholder volume (m^3)	0.8	1.0	1.3	1.7
Daily gas production (m^3/day)	1.2	1.9	2.5	3.2
Gasholder capacity (%)	67	53	53	53
Digester/gasholder ratio	4:1	5:1	5.2:1	4.9:1

APPENDIX F – ANALYSIS OF PLANTS TREATING NIGHTSOIL

Determination of plant volume for various feeding rates

Feed material: Nightsoil

Digester temperature: 26 - 28 ^{0}C

Basis: 100 persons generating a daily maximum of 100×0.4 kg of nightsoil

(Maximum waste generated by an individual in a day = 0.4 kg (Rajam 2003)

Assuming that each person visits the toilet twice a day and uses 8 litres of water per visit, then;

Daily amount of feed material = (volume of nightsoil)[72] + (volume of flushed water)

$$\approx (100 \times 0.4) + (100 \times 8 \times 2) = 1640 \text{ litres} = 1.64 \text{ m}^3$$

Minimum retention time: 60 days

$$\text{Digester volume} = \frac{1.64 \text{ m}^3}{\text{day}} \times 60 \text{ days} = 98.4 \text{ m}^3$$

$$\text{Daily gas production, DGC} = \frac{30 \text{ litres}}{\text{person}} \text{ (Aggarwal, 2003)}$$

$$= \frac{30 \text{ litres}}{\text{person}} \times 100 \text{ persons} = 3 \text{ m}^3\text{/day}$$

$$\text{Hourly gas production} = 30 \frac{\text{m}^3}{\text{day}} \times \frac{\text{day}}{24 \text{ hr}} = 125 \text{ litre/hr}$$

Gas consumption: 3 hours in the morning, from 0600 to 0900 hours
3 hours in the afternoon, from 1500 to 1800 hours

Total duration : 6 hours

$$\text{Hourly gas consumption, HGC}: \frac{\text{DGP}}{\text{Total duration}} = \frac{3000 \text{ litres}}{6 \text{ hr}} = 500 \text{ litre/hr}$$

[72] Assuming the density of nightsoil is the same as that of water.

Difference between gas consumptio n and production : 500 - 125 = 375 litre/hr

Gasholder size during consumption, V_{G1} : $375 \frac{\text{litre}}{\text{hr}} \times 3\,\text{hr} = 1.125\,\text{m}^3$

Longest interval between periods of consumption (from 1800 to 0600) : 12 hours

Gasholder size between periods of consumption, V_{G2} : $\text{HGP} \times 12\,\text{hr} = 1.5\,\text{m}^3$

Since $V_{G2} > V_{G1}$, V_{G2} will be used to determine the appropriate gasholder size. Using a safety margin of 20 %, the required gasholder volume is

$$V_G = 1.5 \times 1.20 = 1.8\,\text{m}^3$$

$$\text{Gasholder capacity} = \frac{\text{Gasholder size}}{\text{Daily gas production}} = \frac{1.8}{3} = 60\,\%$$

$$\text{Digester/gasholder ratio} = \frac{\text{Digester volume}}{\text{Gasholder volume}} = \frac{96\,\text{m}^3}{1.8\,\text{m}^3} = \frac{54.66}{1}$$

Plant volume = digester volume + gasholder volume

$$= 98.4.0 + 1.8 = 100.2\,\text{m}^3$$

Due to the awkwardness in building large plants (volume > 50 m^3), two 50 m^3 plants can efficiently be built to treat the same quantum of waste as the 100.2 m^3 plant. The plant volume is greatly affected by the volume of water used per flush. Moreover, in places where there are no urinary facilities, people may use WCs as urinary facilities and this will affect the size of the plant, all other factors being the same. The usage of water-saving closets (WWCs) (< 6 litres of water per flush) will reduce the digester volume considerably, all other factors being the same. WWCs requiring 4.5 litres of water per flush are used in CUC and VVU. Table G-1 shows how the volume of the digester varies with the volume of water used for flushing.

Table F- 1: Variation of plant volume with volume of flushed-water

Number of persons (kg of nightsoil generated daily)	Volume of water used per flush, litre	Daily amount of feed material (nightsoil and water), m^3	Plant volume (digester and gasholder), m^3
1000 (400 kg)	9	1.84	1122
	8	1.64	1002
	7	1.44	882
	6	1.24	762
	5	1.04	642

From Table F-1, we see that the major factor affecting the digester volumes of sanitary biogas plants, for a specific RT, is the quantity of water used per flush. The use of WWCs reduces the plant volume and the construction cost considerably. Table F-2 gives proposed volumes of sanitary plants treating waste from flushing toilets.

Table F- 2: Summary of proposed plant volumes for plants treating nightsoil

Plant volume, m^3	Daily mass of nightsoil, kg	Daily flowrate of feedstock (litres)	No. of persons
10	4.8	150	12
30	14	434	35
50	24	744	60
60	26	868	70

Based on a retention time of 60 days

Volume of water used per flush: 6 litres

APPENDIX G – DIMENSIONING OF PROPOSED MODEL

Figure G-1 gives the main dimensional parameters of the proposed model

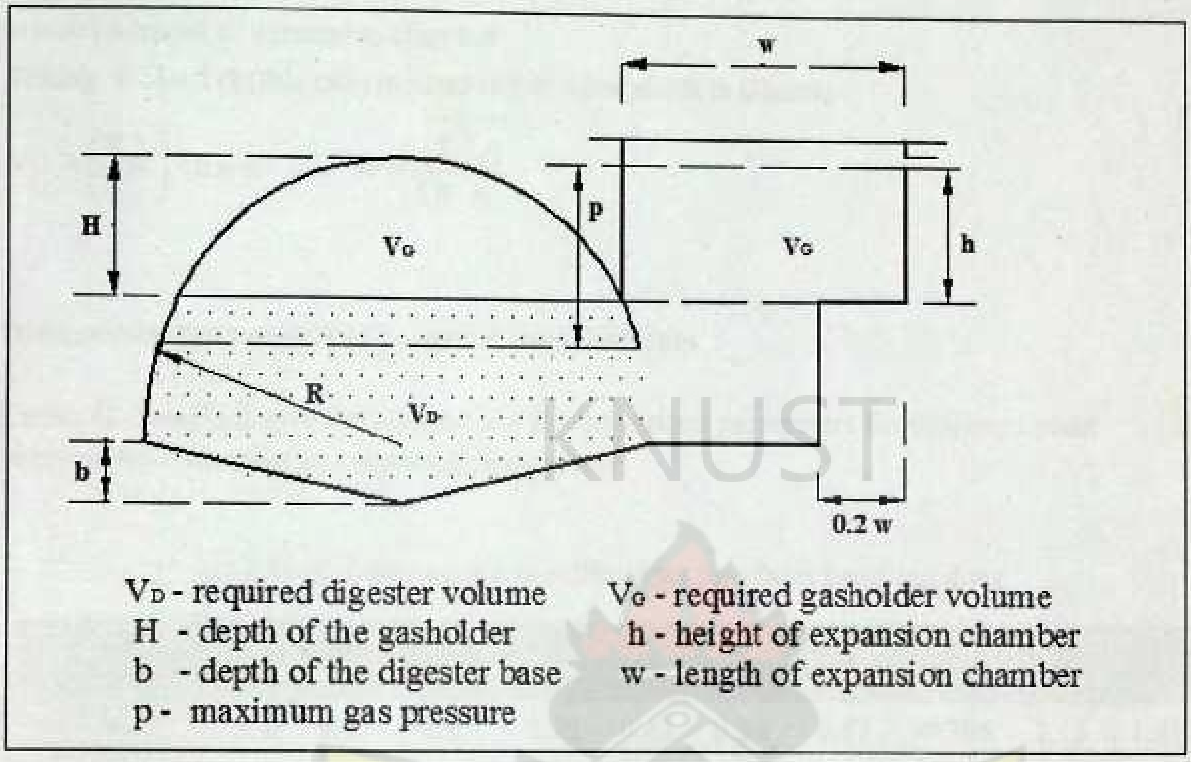

Figure G- 1: Dimensional parameters of proposed model

Adapted from Sasse, 1988; Modified

The relationships between the various digester parameters are shown below in Table G-1 based on a digester/gasholder ratio of 5:1.

Table G- 1: Relationships between digester parameters

V_D:V_G	5:1
R	$(0.48\ V_D)^{1/3}$
H	0.37 R
h	0.32 R
P	0.51 R
b	0.25 R

Adapted from Sasse, 1988; Modified

Determination of the length and the width of the expansion chamber

$$V_G = l \times w \times h$$

where l = length of expansion chamber

Taking $w : l = 5 : 8$ (this ratio is commont to most plants in Ghana)

$$V_G = \left(\frac{8}{5}w\right) \times h \times w \quad \Rightarrow \quad w = \sqrt{\frac{5}{8}\frac{V_G}{h}}$$

Dimensional parameters of proposed plant volumes

Tables G-2 and G-3 give the dimensions for the various parameters for proposed plant volumes for cow dung and nightsoil respectively.

Table G- 2: Dimensional specifications for plants handling dung

Plant volume	V_D	V_G	V_D:V_G	R	H	h	p	b	w	l
4	3.2	0.8	4:1	1.22	0.43	0.36	0.57	0.305	1.13	1.81
6	5.0	1.0	5:1	1.34	0.47	0.40	0.63	0.335	1.25	2.00
8	6.7	1.3	5.2:1	1.47	0.52	0.44	0.69	0.368	1.37	2.19
10	8.3	1.7	4.9:1	1.59	0.56	0.48	0.75	0.398	1.48	2.37

Dimension: Volume – m^3; length – m

Table H- 1: Dimensional specifications for plants handling nightsoil

Plant volume	V_D	V_G	V_D:V_G	R	H	h	p	b	w	l
10	9.4	0.6	15:1	1.71	0.60	0.51	0.81	0.47	0.78	1.25
30	28.1	1.9	15:1	2.39	0.84	0.72	1.13	0.60	1.10	1.77
50	46.9	3.1	15:1	2.84	0.99	0.85	1.33	0.71	1.30	2.08
60	56.3	3.7	15:1	3.02	1.06	0.91	1.42	0.75	1.36	2.1