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Institute for Water and Energy Sciences (Incl. Climate Change)

"Investigation on the Utilization of Slaughter Waste Potential towards Energy Self-Sufficiency at Kumasi Abattoir Company Limited in Ghana"

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« La valeur d'une personne se mesure au bonheur qu'elle apporte aux autres dans la vie. »

Proverbe Burkinabé

DEDICATION

Dedicated to:

- ✓ **My mother Maimounata DERRA and my father Moussa NANA.**
- ✓ **My brothers and sisters: Awa, Neimatou, Souleymane, Faridatou, Mariam.**

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ABSTRACT

Biogas, a sustainable renewable energy form, is at a starting point of market development in Ghana. Due to its economic growth and development of the regulatory environment, the Ghanaian renewable energy sector is attractive for foreign companies from the sector interested in investing in Sub-Saharan Africa. As a result of the present day energy situation, characterized by grid instabilities and increasing power prices, commercial and industrial producers from the agricultural industries look for alternative solutions to secure constant energy supply to avoid production loss and to reduce energy costs. The installation of biogas plants on production sites is one of the most attractive solutions. It enables producers to dispose off agricultural waste, generate electricity for self-consumption, use residues as fertilizer and feed-in energy surpluses to the grid at the same time.

Currently, large volumes of Ghanaian slaughterhouse solid and liquid waste are disposed off improperly, causing serious environmental pollution problems, as well as energy and fertilizer losses. Using advanced and recent technologies it is feasible to use anaerobic digestion technology to produce methane and valuable agricultural soil nutrients in addition to treatment of waste generated by slaughter houses. This study assesses the energy recovery potential towards energy self-sufficiency, from anaerobic digestion of the organic industrial by-products of livestock slaughtering located at the Kumasi Abattoir Company Limited in Ghana.

The investigative approach to data collection was adopted in combination with desk research and other strategies. Waste material generated was estimated based on calculations by Ulrike et al. (2014). The Kumasi abattoir slaughters about 241 cattle, 134 sheep/goats and 26 pigs per day. This leads to a daily consumption of 1,305 kWh of electricity and 386 kg of LPG respectively.

The results show that on the average, the quantity of waste produced daily (7.6 ton/day) represents a potential of 200.41 m^3 of Methane (CH_4) per day, covering the daily demand of 57% of electricity, or 47% of Liquefied Petroleum Gas respectively.

Keywords: Abattoir; Slaughterhouse waste; Biogas; Energy sufficiency.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND UNITS

Abbreviations:

ATEX	Atmosphères Explosibles
BOD	Biological Oxygen Demand
C/N (ratio)	Carbon to Nitrogen (ratio)
COD	Chemical Oxygen Demand
CSTR	Continuously Stirred tank Reactor
DM	Dry Matter
ECG	Electricity Company of Ghana
$FeCl_2$	Ferrous Chloride
GHS	Ghana Cedi (1 GHS = 0.254 USD; 1 USD = 3.94 GHS August 2016)
H_2S	Hydrogen Sulphide
HPF	Horizontal Plug Flow
HRT	Hydraulic Retention Time
IRR	Internal Rate of Return
KACL	Kumasi Abattoir Company Limited
LPG	Liquefied Petroleum Gas
LWK	Live Weight Killed
NPV	Net Present Value
O&M	Operation and Maintenance
TS	Total Solids
UNIDO	United Nation Industrial Development Organisation
VS	Volatile Solids

Units

a	year
°C	degrees celcius
d	day
g, kg, mg	gram, kilogram (1kg = 1000g), milligram (1mg = 0.001g)
kVA	kilovolt-ampere (unit for electrical apparent power)
kW	kilowatt (unit of power) 1 kW = 1000 Joules/second
kWh	kilowatthour (unit for energy) 1 kWh = 3,600,000 Joules
L, l	litre
m^3	cubic metre. *NB when used as unit for biogas quantities, m^3 refers to a cubic metre under standard conditions of pressure and temperature, i.e. at 0 °C and 1 atmosphere*
t	ton = 1000 kg
%wt	% on weight basis

1

GENERAL INTRODUCTION

1.1. Background

The increasing large volume of waste generation (from industries, municipalities, agriculture, etc) poses a major environmental challenge in term of waste collection, management and disposal in all cities across the world. This situation results from the fast growing populations and its intrinsic increased density with higher demand for foodstuffs and goods; coupled with an increasing demand in transportation, building and health infrastructures, plus a larger number of industries. In the rural areas, the most common ways of managing waste are composting and incineration whereas landfills continue to be largely the disposal method for urban waste.

Abattoir waste has been classified by the Environmental Protection Agency as one of the most harmful to the environment (Walter, R. et al., 1974). In the developing countries, the authorities face a real preoccupation about disposal of waste generated from slaughterhouses and abattoirs operation. In Ghana for instance, the solid abattoir waste (composed of dung, rumen content, small meat fragments, bone dust, bile) is collected and dumped in landfills or open areas. The liquid waste (mainly consisted of part of the blood produced; water, liquid rumen content, bone and hair dust) is sent to municipal sewerage system or water bodies, thus endangering public health as well as terrestrial and aquatic life. The communities located downstream from the slaughterhouse are particularly affected, as they used the polluted river water for domestic purposes, like washing and sometimes even for consumption (Rockson, 2014).

The dumping sites contribute to methane (CH4) emission which potency is about 21 times that of carbon dioxide (CO2) in trapping heat in the atmosphere. The chemical properties of slaughterhouse wastes are similar to that of municipal sewage, however the former is highly concentrated wastewater with 45% soluble and 55% suspended organic composition. Blood has a very high Chemical Oxygen Demand (COD) of around 375,000 mg/l and is one of the major dissolved pollutants in slaughterhouse wastewater. The development of new landfill sites or technical solutions to waste disposal (such as composting) treats only the symptoms of the problem but not the problem itself. Waste disposal in landfills create environmental damages such as water pollution, unpleasant odours, explosion and combustion, asphyxiation, vegetation damage, and greenhouse gas (GHG) emissions. These problems render the whole waste collection operation unsustainable.

The best method for beneficial use of slaughter wastes is generation of biogas through anaerobic digestion. The biogas potential of slaughter waste is higher than animal manure, and reported to be in the range of 120-160 m^3 biogas per ton of wastes (Zafar, 2015). By constructing adequate biogas plant in their facilities, abattoirs can be able not only to manage better the generated waste (effective pollution control in abattoirs and reduction in GHGs emissions), but also to produce energy-rich biogas that can supply their own energy needs (electricity and heat). This approach offer two important benefits of environmentally safe waste management and disposal, as well as the generation of clean electric power and fertilizer.

Energy is the driving force for development in all countries of the world. Biochemical processes, like anaerobic digestion, can produce clean energy in the form of biogas which can be converted to power. Using advanced and recent technologies it is now possible to develop eco-friendly processes in addition to treatment of wastewater generated by slaughterhouses (Ahmad & Ansari, 2012). At the bigger level, this is an appreciable strategy for greening cities. It can lead to the attainment of the twin objective of sustainable waste management strategy and augmenting other renewable energy sources to foster socio-economic development of the country.

The high-tech biogas plant currently under construction at the Kumasi Abattoir Company Limited (KACL) is the first to be built in the West African sub-region, and is funded by the United Nations Industrial Development Organization (UNIDO) with technical support from the Korean government. The KACL which is the largest abattoir in Ghana, slaughters on average daily, some 200 heads of cattle, 134 head of sheep and goats, plus 23 pigs (UNIDO, 2014). In term of volume of waste, the company generates on average 8 ton of solid waste and 170 ton of liquid waste per day to which correspond a total biogas potential of 846 m^3/day, that has a concentration of 65% methane and 25 % carbon dioxide (UNIDO, 2014). It is one such company that suffers from the inconsistent supply of fossil fuel and electric power blackouts that disturb daily administrative operations.

The energy production from the plant (currently, under construction) would be the perfect remedial to this grief. Other co-benefits include the reduction of waste disposal costs, production of a valuable fertilizer. Using recycled wastewater, improved energy efficiency technologies, energy saving practices, and other related approaches would help the KACL to become more ecologically and economically sound. Bio-energy not only contributes to energy diversification strategy but also substitution of energy imports making it an important energy source for economic and national security. This represents the opportunity to enhance Ghana's potentials in the production of energy from industrial waste to reduce the country's dependence on fossil fuels.

1.2. Problem Statement and Justification

Just like most other slaughterhouses operating in Ghana, the Kumasi Abattoir Company Limited (KACL) suffers from dependence on fossil fuel for its energy need. The power supplied by the national utility (Electricity Company of Ghana, ECG), is subject to frequent power cut. Unreliable grid electricity forced the abattoirs to depend on diesel generators for lighting the main buildings and powering the cold store. Sometimes, gas shortages also occur and thus the abattoir alternatively, resorts to the use of firewood for smouldering the slaughtered animal and for hot water supply. The use of firewood eventually leads to deforestation and global warming. Fossil fuel which is currently the major global source of energy, especially in Ghana, is long-term depleting in reserves and its usage contributes to climate change, environmental degradation, and human health problems.

The unreliable power and gas supply definitely affect the productivity and quality of the whole abattoir operation, while the waste disposal and its associated cost continue to be a rising issue. All the meat industries are concerned by this business burden, which constitute a treat to their durable existence. The challenge remains on how to provide sustainable energy self-sufficiency for these industries while making effective management of inevitable waste and to mitigate climate change.

Consequently, selecting and designing an appropriate and sustainable biogas technology for slaughterhouses has become an important issue considering the significant energy value of those high amount of waste stream ending up at landfill or dumpsites from these sources. This calls to move towards combined slaughter facility/biogas plant to ensure reliable, affordable and sustainable energy sources. Very few abattoirs in Africa have integrated biogas plants at their facilities. In Ghana, the Kumasi abattoir is the first to pave the way and serve as an example to be replicated in other cities and far beyond on a regional level.

1.3. Study Objective

The focus of this paper is to determine the methane potential of the available organic waste streams, in order to identify the potential energy that could be recovered through the exploitation of the future biogas plant facility (currently under construction) at the Kumasi Abattoir. The potential energy recovery is assessed in terms of subsidizing the process energy of the abattoir and evaluating the degree of energy self-sufficiency that could be achieved.

Specifically, the study aims to:

- Determine the waste generation capacity corresponding to livestock slaughtering operation at KACL.
- Assess the energy potential of the slaughter waste.
- Evaluate the possible amount of energy production by digestion of the waste through the future biogas plant (currently under construction)
- Determine the energy demand (electricity, heat and fuel) of the abattoir.
- Evaluate the degree of energy substitution of the abattoir's energy needs (electricity and/or gas) by use of the generated biogas energy.

2

LITERATURE REVIEW

2.1. Slaughterhouses Operation

2.1.1. Categories of slaughter-plants

Plants for red meat slaughtering may be categorized on the basis of the final products. A plant that processes meat into products such as canned, smoked and cured meats is significantly different from a plant with facilities for slaughtering without further processing (FAO, 1996)

- **Abattoirs:**

The abattoir's equipment and facilities are the most modern ones of their kind. Nowadays, the abattoir still has two slaughter lines (since 1984); one for pigs and one for large animals (cows, horses, calves, sheep and deer). Each year, about 230,000 animals are slaughtered in abattoirs.

Slaughterhouses and packinghouses (slaughtering and meat processing) may each be divided into two categories on the basis of the quantity of waste produced (EPA, 1974).

- **Simple slaughterhouse:**

A Simple slaughterhouse refers to a plant that slaughters animals and does a very limited amount of by-product processing. Its main products are fresh meat in the form of whole, half or quarter carcasses or in smaller meat cuts.

- **Complex slaughterhouse:**

Here the plant slaughters and does extensive processing of by-products. Usually at least three of the following operations take place: rendering, paunch and viscera handling, blood processing, and hide and hair processing.

- **Low-processing packinghouse:**

A plant that both slaughters and processes fresh meat into cured, smoked, canned and other meat products. Only the meat from animals slaughtered at the plant is processed. Carcasses may also be sold.

❖ **High-processing packinghouse:**

A plant that also processes meat purchased from outside. Sometimes, a high-process packinghouse has facilities for tanning operations.

There are also plants that do not slaughter themselves but restrict their activities to the processing of meat (meatpacking). These plants have a waste production comparable to that of a simple slaughterhouse (FAO, 1996).

2.1.2. Slaughter Activities

According to the Food and Agriculture Organisation (FAO, 1996), pigs, cattle and poultry make up almost 93% of the total world meat production. In the slaughter process the following main by-products and waste products become available:

- Manure, contents of rumen and intestines;
- Edible products such as blood and liver;
- Inedible products such as hair, bones, feathers;
- Fat (recovered from the wastewater by means of fat-separators); and
- Wastewater.

In most developed countries, slaughtering is a centralized activity. The consumer in these countries has a preference for lean meat and a few selected offal only, such as brain, kidney, sweetbread, tongue, etc. For this reason, the carcass is often deboned at the slaughterhouse and cooled before being sent to retail outlets. As a result, large quantities of by-products (bones, lungs spleen, oesophagus etc.) are left behind at the slaughterhouse. They fall in the category of inedible offal. For economic and environmental considerations, these need to be suitably processed and utilized. Clean fatty tissues (mesentery fat for instance), may be processed into edible fat. Other tissues may be used to produce composite bone-cum-protein meals or individual products like bone-meal, meat-meal and blood-meal. In principle all edible and inedible by-products can be processed and put to further use (e.g. human consumption, pet food, feed industry or fertilizer). Modern abattoirs are well equipped and are in the possession of running water, steam, power, refrigeration, transport and other facilities. These facilities make it also possible that glands are preserved for the production of glandular products (FAO, 1996).

In developing countries a large variety of slaughter sites exists. Slaughter sites vary from simple slaughter slabs to very modern slaughterhouses. Large scale industrial processing units are imported from developed countries, often without rendering or waste treatment facilities. Many slaughterhouses (of various types) are insanitary and pose threats to health, particularly around rapidly expanding population areas. Often old slaughterhouses discharge blood and untreated wastewater. The elimination of sick animals and subsequent destruction are frequently carried out inappropriately. Blood may coagulate in drains where it putrefies, causing bad odours and sanitary and environmental problems. Edible and inedible by-products are frequently wasted during the slaughtering and further processing owing to amongst others (FAO, 1996):

- ✓ Insufficient skills and discipline in slaughtering;
- ✓ Poor quality of slaughtering equipment in the slaughterhouse,
- ✓ Slaughtering on the floor, no slaughter line,
- ✓ Lack of adequate maintenance and lack of spare parts;
- ✓ A non-cost-effective processing of by-products either because of the small quantities involved, the high costs of processing or the low value of the end product;
- ✓ Lack of equipment for the processing of by-products; and
- ✓ Lack of regulations on the discharge of wastes or the inability of the authorities to enforce regulations.

Charges for slaughtering in abattoirs are often kept low to prevent illegal slaughtering. Furthermore, slaughter fees constitute a source of income for the municipality. As however these funds are not used for the operation and maintenance of the abattoir, abattoirs have difficulties in maintaining certain standards (FAO, 1996).

Approximately 80 percent of the population in developing countries lives in rural areas. The great majority of animals is likely to be slaughtered and processed domestically or in small slaughter slabs. The processing and the utilization of offal require a technology and capital lay-out which are completely different from those in developed countries. Huge capital investments in infrastructure of plants and machinery, as is the case in developed countries cannot be justified. In developing countries also most of the soft and fat tissues are used for consumption purposes. This reduces the amount of offal with 10-15% of the live weight killed (LWK) (FAO, 1996).

2.1.3. Description of the slaughter process and meat processing

❖ **Red meat slaughtering**

In slaughterhouses animals are received and kept around in stockyards and pens for 1 day. The animals are watered, but in most cases not fed unless they are kept more than 1 day (FAO, 1996).

The animals are then driven from the holding pens to the slaughtering area where the following activities take place:

- Stunning;
- Suspension from an overhead rail by the hind legs;
- Sticking and bleeding over a collecting trough. The collected blood may be sewered or processed;
- Hide removal (cattle) or scalding and dehairing (hogs). In some plants hogs are skinned to eliminate scalding and dehairing. Scalding is a method to loosen hair before removal. For several minutes the hogs are held in a scalding tank at 45°C to 65°C. After scalding, the hogs are mechanically dehaired by abrasion and singed in a gas flame to complete the hair removal process.
- Decapitation and opening of the carcass by cutting;
- Inspection of the carcass;
- Evisceration (removal of intestines and internal organs);
- Splitting and cutting of the carcass; and
- Chilling or freezing.

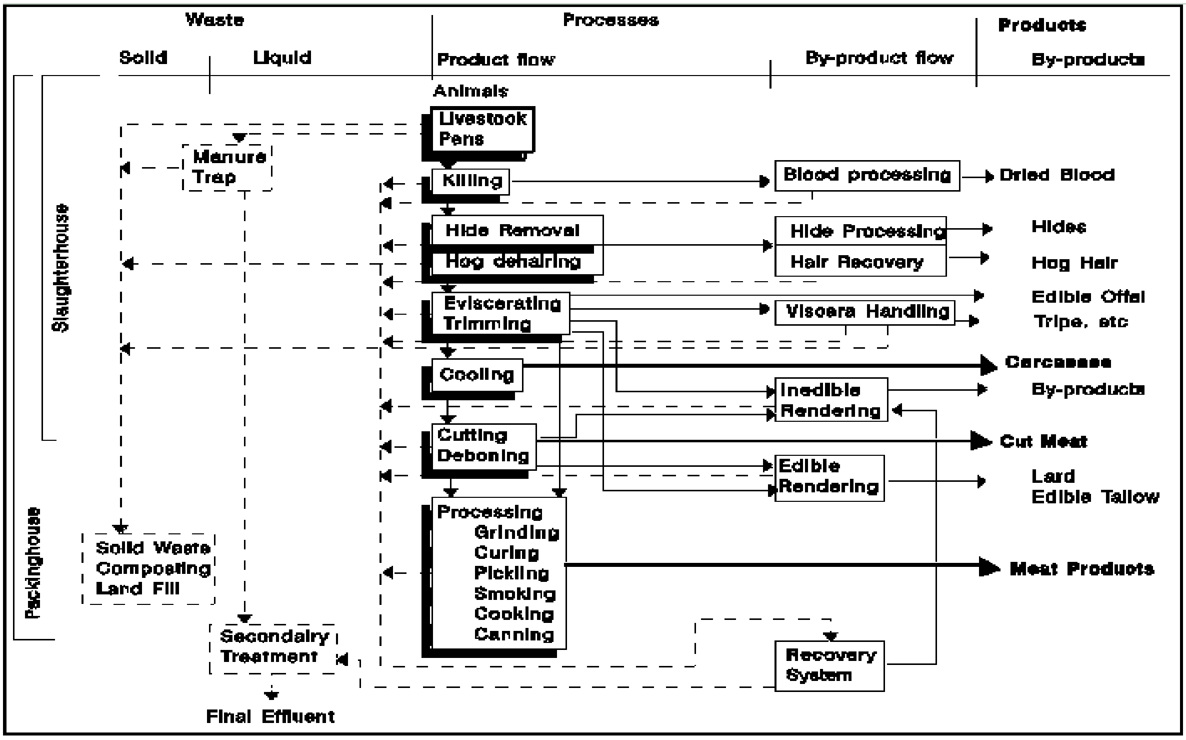


Figure 2.1. Flow diagram of a red meat slaughterhouse.

Source: http://www.fao.org/WAIRDOCS/LEAD/X6114E/x6114e04.htm#TopOfPage

- **Poultry slaughtering**

The inlet to the plant is normally designed in such a way that fluctuations in bird deliveries can be dealt with adequately. This is necessary since the processing capacity has a fixed maximum. At regular intervals birds are unloaded onto the holding areas and attached by their feet to a conveyor belt, transported to the slaughter area (FAO, 1996).

The birds are suspended from the conveyor after which the following actions take place:

- Stunning;
- Killing and bleeding by cutting the jugular veins;
- Collection of blood: The conveyor travels through a blood collection tunnel at a preselected travelling speed;
- Scalding: To loosen the feathers, the birds are held in water of temperatures ranging from 50 °C to 60 °C;
- De-feathering: Feathers are mechanically abraded from the scalded birds, usually by rotating rubber fingers. Removed feathers drop in underlying troughs;
- Washing: The de-feathered carcasses receive a spray wash prior to evisceration;
- Opening of the carcass by cutting manually;

- Inspection of the viscera;
- Evisceration, removal of head, feet and viscera;
- Sorting of the viscera to recover heart, liver and gizzard;
- Final washing to remove blood and to loosen tissues;
- Chilling of the carcasses in a water bath;
- Draining;
- Grading, weighing and packing; and
- Chilling and freezing.

❖ **Meatpacking**

Many large scale plants ship whole graded carcasses to retail markets, others perform some on-site processing to produce retail cuts. The processes are the following (FAO, 1996):

- Cutting and deboning; and
- Meat processing. This includes a variety of operations amongst which grinding, mixing with additives, curing, pickling, smoking, cooking and canning.

❖ **Rendering**

Rendering is a heating process for meat industries waste products through which fats are separated from water and protein residues for the production of edible lards and dried protein residues. Commonly it includes the production of a range of products of meat meal, meat-cum-bone meal, bone meal and fat from animal tissues. It does not include processes where no fat is recovered (FAO, 1996).

There are basically two different rendering processes:

- High temperature rendering: through cooking or steam application (five systems are known: simple cooking; open pan rendering; kettle rendering; wet rendering; and dry rendering.)
- Low temperature rendering (around 80°C). This process requires finely ground material and temperatures slightly above the fat melting point. It results in better quality lard. The rendering at low temperatures is a highly sophisticated process requiring large throughputs and trained personnel. For many developing countries the system is not suitable.

- **Handling of viscera, paunch and intestines**

Viscera can be recovered as edible products (e.g. heart, liver). They can also be separated for inedible rendering or processing (e.g. lungs).

The paunch contents, ‘paunch manure’ (partially digested feed), is estimated to range from 27 to 40 kg. The paunch can be handled in four ways (FAO, 1996):

- ✓ Total dumping. All of the paunch contents are flushed away into the sewer.
- ✓ Wet dumping. The paunch contents are washed out and the wet slurry is screened on the presence of gross solids, which are subsequently removed.
- ✓ Dry dumping. The paunch contents are dumped for subsequent rendering or for disposal as solid waste without needless water flushing.
- ✓ Whole paunch handling. The entire paunch may be removed, intact, for rendering or for disposal as solid waste.

Intestines may be rendered directly, or hashed and washed prior to rendering. For the processing of intestines de-sliming prior to thorough washing is necessary.

2.1.4. Waste minimization options

Prior to any planning step being taken with respect to treatment systems, there should be a comprehensive examination of process by-products and wastes to identify options for waste minimisation. Re-use or recycling of by-products will often reduce the total waste production, sometimes a substitution or change of raw material may lead to changes in the process, contributing to waste minimisation. The recovery of valuable materials from waste streams will in most cases be both economically and environmentally sensible (GATE, 2001).

Some general waste minimisation options to be considered during the planning stages are:

- ✓ Change of processes or equipment;
- ✓ Change of packaging of products;
- ✓ Improvement of process control;
- ✓ Improvement of material handling and cleaning operations;
- ✓ Improvement of maintenance and repair of equipment;
- ✓ Process-internal recycling of waste ;
- ✓ On-site re-utilisation of waste;
- ✓ Recovery of materials from waste streams.

However, waste minimisation options in slaughterhouses are rather limited, at least speaking of solid wastes such as feed left over, paunch and other manure. As the cattle owners are usually responsible for fodder provision and animal care, the only organisational measure that can be taken is to shorten the time between animal reception and the actual slaughtering date (GATE, 2001).

2.2. Environmental Problems Encountered in Slaughterhouses

2.2.1. Solid waste

Sources of solid wastes generated at abattoirs include (EPA, 2016):

- ✓ Animal holding areas: manure, faeces and urine, sometimes mixed with straw and fodder (dependent on kind and duration of animal keeping before slaughtering);
- ✓ Slaughterhouse and processing areas ;
- ✓ Waste treatment plant ;
- ✓ Unwanted hide or skins and pieces, and unwanted carcasses and carcass parts.

Manure is generated in animal holding areas. Materials not suitable for rendering, such as unwanted carcasses, come from the processing areas, along with paper, cardboard and plastics (EPA, 2016).

2.2.2. Waste water

It is estimated that for every cow and pig processed 700 and 330 litres of wastewater are generated, respectively, with an increase of 25% if further processing is carried out to produce edible products (Hosseiny, 2013). A comparative volumes of slaughterhouse wastewater generated in several countries is showed in Table 2.1.

Usually, the slaughterhouse wastewater is discharged into a municipal sewer system or directly into water bodies (streams, rivers or lakes)), thereby putting these ecosystems at risk. Lack of treatment systems at slaughterhouse facilities is deeply rooted the shortage of financial and technical resources. Other factors, such as lack of governmental and societal pressures and a lack of knowledge of alternative practices also impede the implementation improved slaughterhouse wastewater management (Hosseiny, 2013).

Table 2.1: Water consumption in slaughterhouses as reported by several international authors.

Reference	Nation	(m^3/head)	Water use (m^3/ton live weight)
Schultheisz & Karpati (1984)	US slaughterhouses	2.1 – 8.3	4.2 – 16.7
Schultheisz & Karpati (1984)	US meat packing	3.2 -14.6	6.3 – 29.2
Stebor et al. (1990)	US beef slaughterhouse (265/h)	1.3[a]	2.6[a]
Hopwood (1977)	UK slaughterhouses	< 2.5 – 7.5	< 5 – 15
Jorgensen (1979)	Europe	2.5 – 5	5 – 10
Schultheisz & Karpati (1984)	Hungary	1 – 1.9	2 – 3.8
Tritt & Schuchardt (1992)	Germany	0.4 – 3.1[a]	0.8 – 6.2[a]
Metzner & Temper (1990)	Germany (rendering) only	-	1.25[a]

[a] – Effluent production

- **Wastewater by red meat slaughtering**

Production of blood: Of all waste products, the waste in the form of blood has the highest polluting value. Blood itself has a high biochemical oxygen demand (BOD): 150,000 - 200,000 mg/l, the extreme value being 405,000 mg/l (domestic wastewater has a BOD of 300 mg/l). In the killing, bleeding and skinning phases, blood is produced which, when completely sewered, leads to a total waste load of 10 kg BOD per ton of live weight killed LWK (FAO, 1996).

Paunch: Paunch manure is the second most important source of pollution. It may substantially contribute to the total waste load if not properly handled. Dumping of the entire paunch content gives a BOD of 2.5 kg per ton of LWK (FAO, 1996).

Wastewater is produced from intentional overflow from scalding tanks that contain blood, dirt, manure and hair (0.15 kg BOD per ton of LWK). The fluming of the mechanically removed hair also results in wastewater containing residual hair, blood and dirt after recovery of the bulk of the hair (0.4 kg BOD per ton of LWK). Recovered hog hair may be be dumped as solid waste, washed and baled for marketing (0.7 kg BOD per ton of LWK) or it may be hydrolysed by pressure cooking (1 kg BOD per of LWK) (FAO, 1996).

Table 2.2: Potential wastewater emissions of red meat slaughterhouses (no water prevention).

	Kg BOD/ton LWK	Remarks
Stockyards and pens	0.25	solid contaminants are removed
Blood	10	All blood sewered
Clean-up hide removal	3	depends on clean-up practices
Scalding, dehairing	0.15	overflow scalding tank
	0.4	Flume water
	0.7	washing of recovered hair
Paunch	2.5	in case of total dumping sewer
	1.5 - 2	in case of wet dumping
	0.2	in case of dry dumping
	0.6 – 1.0	in case of whole paunch handling
Intestine handling	0.6	-
Rendering	2	-
General clean-up	3	depends strongly on clean-up practices
Potential emission:	24.9 – 25.8	
Meat packing	6	Kg BOD/ton product

2.2.3. Air pollution

❖ **Fuel burning emissions**

Fuel burning gives rise to atmospheric emissions. Materials burned at an abattoir include (EPA, 2016):

- Coal or gas fuel for boilers and steam production;
- Diseased animals;
- Sludge;
- Packaging;
- Unusable skins.

The amount of energy needed for non-industrial cutting and deboning is considerably lower than that required in large scale plants, but the energy needed for non-industrial processing is more than twice as high, probably a matter of economies of scale (FAO, 1996).

- **Greenhouse gases**

Slaughtering is an activity that requires great amounts of hot water and steam for sterilisation and cleaning purposes. In the process of generating the energy for heating, gasses are emitted (CO_2, CO, NOx and SO_2). Emissions of chlorofluorocarbon CFC's and ammonia (NH_3) into the air are the result of evaporation of chilling liquids and of the stripping of chilling and freezing-machines, when out of use (FAO, 1996).

The smoking of meat products and the singing of hogs in a gas flame to complete the hair removal lead to the production of mainly CO_2, CO and NOx and obnoxious smells. The degree of air pollution caused by the generation of energy depends on the type of process for which the energy is needed. The processes of "dehairing", "water heating" or "production of electricity" each lead to different levels of emission (FAO, 1996).

Table 2.3: Emissions of CO_2, CO and NOx resulting from the burning of gas for heating and steam production in Netherland (FAO, 1996).

Process	**Air emissions**	
Heating by burning gas:	CO:	0.02 kg/ton carcass weight
	CO_2:	28 kg/ton carcass weight
	NOx:	0.01 kg/ton carcass weight
Dehairing pigs: (using gas)	CO:	0.06 kg/ton carcass weight
	CO_2:	6.5 kg/ton carcass weight
	NOx:	0.015 kg/ton carcass weight

- **Odours**

Potential sources of odours in abattoir operations are (EPA, 2016):

- ✓ The cooking and rendering process;
- ✓ Waste effluent treatment plants;
- ✓ Slaughterhouses;
- ✓ Product storage and handling areas;
- ✓ Material drying areas;
- ✓ Waste disposal techniques such as burning dead stock;

- ✓ Animal holding pens;
- ✓ Livestock transport vehicles;
- ✓ Holding of carcasses before disposal;
- ✓ Odours from skin handling;
- ✓ Odours from skin shed.

Sources of odours in the rendering plant include stale materials and fugitive emissions from cookers. Odours in animal holding pens are produced by manure and urine. Slaughterhouse odours come from solid wastes such as paunch contents and blood residues (EPA, 2016).

- ❖ **Dust**

Potential sources of dust emissions at an abattoir are (EPA, 2016):

- ✓ Unsealed roads;
- ✓ Paddocks, saleyards and holding pens;
- ✓ Stockpiled products and materials;
- ✓ Construction activities.

2.3. Biogas Generation from Abattoir Waste/ Anaerobic digestion of Slaughterhouse Waste

One sustainable approach to manage the large quantities of animal and crop wastes and increase their value is to use them as raw materials for the generation of renewable energy, through appropriate conversion technologies. Biogas technology offers a great way for beneficial management and use of slaughterhouse wastes.

Anaerobic systems are well suited for the treatment of slaughterhouse wastewater. They achieve a high degree of BOD removal at a significantly lower cost than comparable aerobic systems and generate a smaller quantity of highly stabilized and more easily dewatered sludge. Furthermore, the methane-rich gas, which is generated, can be captured for use as a fuel (Johns, 1995 cited in (Hosseiny, 2013)).

Biogas refers to the gas produced by the breakdown of organic biomass in the presence or absence of oxygen, which consists mainly of methane, carbon dioxide and a trace of other compounds. Biogas released by aerobic microorganisms produces less methane than released by non-aerobic microorganisms. Additionally, after anaerobic treatment, the digestate residue can be used as an agricultural fertilizer (Hosseiny, 2013).

Table 2.4: Biogas yield from different manure

	Range of biogas yield [m^3/Mg VSS]	**Mean biogas yield [m^3/Mg VSS]**
Pig manure	350 - 550	450
Cattle manure	150- 350	250
Poultry manure	310-620	460
Horse manure	200-350	250
Sheep manure	100-310	200
Grass	280-550	410
Vegetable residues	300-400	350
Sewage sludge	310-640	450

Amongst anaerobic treatment processes, the up-flow anaerobic sludge blanket (UASB) process appears to be an attractive system to deal with food industry wastes including those from slaughterhouses (Hosseiny, 2013).

Furthermore, new developments in anaerobic technology during the last 15 years have attracted scholars' attention. The developments can be divided into two major categories:

(i) Covered anaerobic ponds;

(ii) High rate anaerobic systems.

2.3.3. Covered anaerobic ponds

Synthetic floating covering on anaerobic ponds has been extensively employed throughout the world in order to trap odour and biogas (Dague et al., 1990; Safley & Westerman, 1992 cited in (Hosseiny, 2013). The advantages of covered ponds outweigh those of the traditional uncovered ones. They reduce odour and make it possible to capture methane-rich gas. The main advantage of this technology is the lower capital costs.

- ***Advantages of covered anaerobic ponds***:

- Mean BOD_5 removal of 85-90 % were consistently obtained and biogas production averaged 51 m^3 methane/kg BOD_5 removed;
- The system paid for itself within two years if biogas is processed in a natural-gas-fired boiler (Dague et al., 1990 cited in (Hosseiny, 2013)). (Please provide initial costs, Capacity of the facilities and the bio-gas market value.)

- ***Disadvantages of covered anaerobic ponds:***

- Variable levels of H_2S (mean, 843 ppm) may be generated from anaerobic ponds and this toxic and corrosive gas must be removed before use, for example by iron sponge filters; (Kayhanian & Hills, 1988 cited (Hosseiny, 2013)).
- These lagoons require high BOD loading to generate economic quantities of biogas; (Safley and Westerman, 1992 cited in (Hosseiny, 2013)).
- Biogas production on lightly loaded (< 0.06 kg VS/m^3) anaerobic ponds generated only low quantities of biogas ;
- Gas production is highly sensitive to pond temperature, although methanogenesis occurs at temperatures as low as 4 °C. The higher temperature of slaughterhouse wastewater should eliminate this problem (Hosseiny, 2013).

2.3.4. High rate anaerobic systems

Testing of high-rate anaerobic system has been done during the last decade, focusing on slaughterhouse-waste treatment. Three high-rate anaerobic systems have been widely utilized in slaughterhouses (Hosseiny, 2013). The anaerobic contact (AC), the up-flow anaerobic sludge blanket (UASB) and the anaerobic filter (AF) processes.

- ***Advantages of high rate anaerobic process:***

- Accelerate treatment and reduce required area, especially in Europe and Asia;
- UASB's average COD removal efficiencies are of 80 - 85% and are efficient when
- operated with an organic loading rate (OLR) in the range of 2.7 10.8 kg COD/m3/d;
- In UASB, average influent COD was 5100 mg/l. Results supported the use of Monod equation for this process (Borja et al., 1993 cited in (Hosseiny, 2013));
- In UASB, COD removal varied from 77% to 91% while BOD removal was 95% (Caixeta et al., 2002 cited in (Hosseiny, 2013));
- The removal of TSS varied from 81% to 86%. It operated for 80 d with hydraulic retention times (HRT) of 14, 18 and 22 h;

UASB seem to be a suitable process for the treatment of abattoir wastewater, due to its ability to maintain a sufficient amount of viable sludge, thereby providing efficient and stable treatment (Sayed & de Zeeuw, 1988 cited in (Hosseiny, 2013)).

In comparison with their popularity for treating wastewater from many agro-processing industries (i.e. brewing, potato processing, etc.), the application of high-rate anaerobic systems to slaughterhouse wastewater has encountered significant problems (Stebor et al., 1990 cited in (Hosseiny, 2013).

- ***Disadvantages of high rate anaerobic process:***

- The high fat, oil and grease concentration in the wastewater cause severe problems, due to their insolubility, which slows the rate of degradation, and its tendency to form scum and coat surfaces. High-suspended solids concentrations in the feed adversely affect UASB, fluidized-bed and fixed-media anaerobic processes. Recent studies have shown that the form of pollutants (i.e., suspended, colloidal or soluble) in the influent wastewater greatly affects the performance of high-rate anaerobic systems (Sayed & de Zeeuw, 1988 cited in (Hosseiny, 2013)).
- The BOD concentration in the feed is relatively low for successful operation of high-rate anaerobic processes, which operate better at BOD_5 concentrations of 10,000 mg/l or more. This requires high hydraulic throughput.

To resolve these problems, an appropriate fat separator should be installed to prevent excessive scum layers in the reactor (Sayed et al., 1993; Manjunath et al., 2000 cited in (Hosseiny, 2013)).

2.3.5. Anaerobic Digestion Process

Anaerobic digestion (AD) is a serie of biological processes in which microorganisms break down biodegradable material in the absence of oxygen (Wu, 2012). These substrates are obtained through a serie of degradative steps that involve a variety of bacteria (DaSilva, 2010). The decomposition of bio-waste takes place into four stages as following:

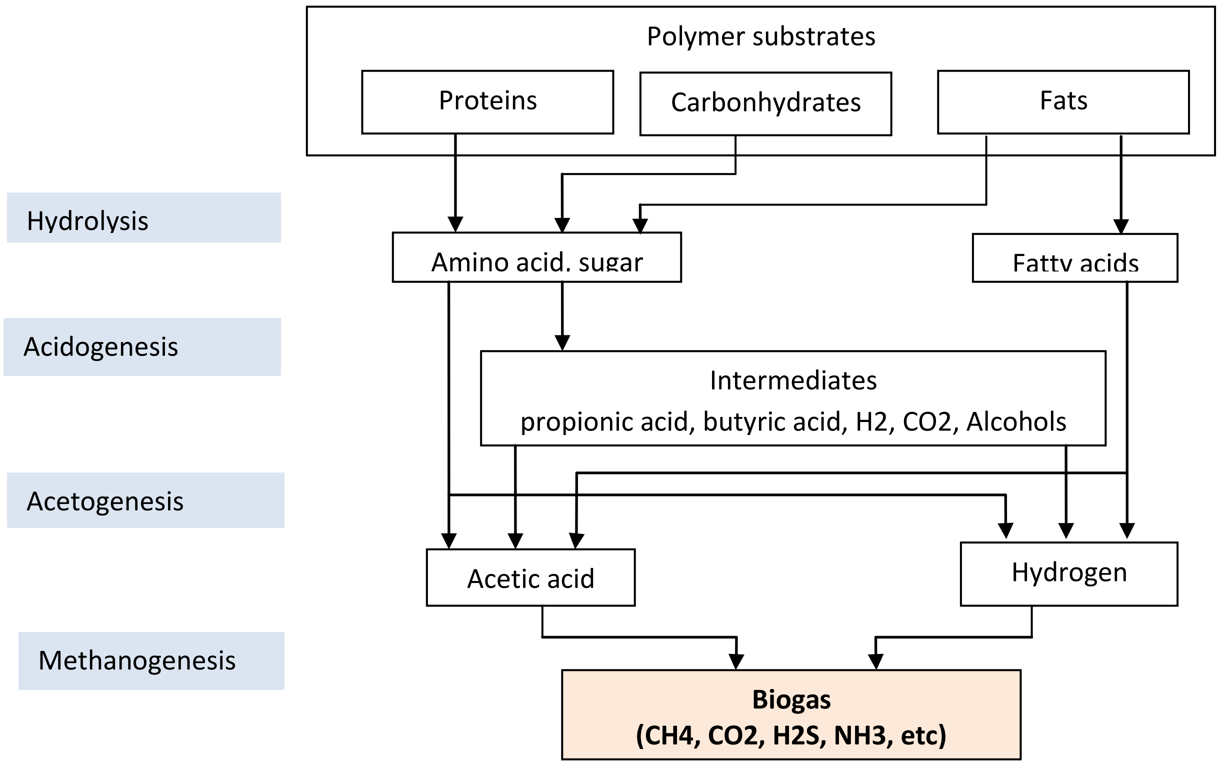


Figure 2.2: Degradation steps of anaerobic digestion process

Hydrolysis: Bacteria transform the particulate organic substrate into liquefied monomers and polymers. Carbohydrates, proteins and fats are broken down into smaller fragments such as simple sugars, glycerol, fatty acids and amino acids. Equation (1) shows an example of a hydrolysis reaction in which organic waste, in this case glucose, is broken down into a simple sugar (WtERT, 2016).

$$C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + 2H_2 \quad \textbf{(1)}$$

Acidification: In the second stage, acidogenic bacteria transform the products of the first reaction into short chain volatile acids, ketones, alcohols, hydrogen and carbon dioxide. The principal acidogenesis stage products are propionic acid (CH_3CH_2COOH), butyric acid ($CH_3CH_2CH_2COOH$), acetic acid (CH_3COOH), formic acid (HCOOH), lactic acid ($C_3H_6O_3$), ethanol (C_2H_5OH) and methanol (CH_3OH), among other. From these products, the hydrogen, carbon dioxide and acetic acid will skip the third stage, acetogenesis, and be utilized directly by the methanogenic bacteria in the final stage (WtERT, 2016).

Equations (2), (3) (Ostrem, 2004 cited in (WtERT, 2016)) and equation (4) (Bilitewski et al., 1997 cited in (WtERT, 2016)), represent three typical acidogenesis reactions where glucose is converted to ethanol, propionate and acetic acid, respectively.

$$C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH + 2CO_2 \quad \textbf{(2)}$$

$$C_6H_{12}O_6 + 2H_2 \leftrightarrow 2CH_3CH_2COOH + 2H_2O \quad \textbf{(3)}$$

$$C_6H_{12}O_6 \rightarrow 3CH_3COOH \quad \textbf{(4)}$$

Acetogenesis: Here, the rest of the acidogenesis products, i.e. the propionic acid, butyric acid and alcohols are transformed by acetogenic bacteria into hydrogen, carbon dioxide and acetic acid. Hydrogen plays an important intermediary role in this process, as the reaction will only occur if the hydrogen partial pressure is low enough to thermodynamically allow the conversion of all the acids. Such lowering of the partial pressure is carried out by hydrogen scavenging bacteria, thus the hydrogen concentration of a digester is an indicator of its health (WtERT, 2016).

Equation (5) represents the conversion of propionate to acetate, only achievable at low hydrogen pressure. Glucose and ethanol (in equation 6 and 7 respectively)) are also converted to acetate during the third stage of anaerobic fermentation (Ostrem, 2004 cited in (WtERT, 2016)).

$$CH_3CH_2COO^- + 3H_2O \leftrightarrow CH_3COO^- + H^+ + HCO^{3-} + 3H_2 \quad \textbf{(5)}$$

$$C_6H_{12}O_6 + 2H_2O \leftrightarrow 2CH_3COOH + 2CO_2 + 4H_2 \quad \textbf{(6)}$$

$$CH_3CH_2OH + 2H_2O \leftrightarrow CH_3COO^- + 2H_2 + H^+ \quad \textbf{(7)}$$

Methanogenesis: During this stage, microorganisms convert the hydrogen and acetic acid formed by the acid formers to methane gas and carbon dioxide (Equations 8, 9 and 10). The bacteria responsible for this conversion are called methanogens and are strict anaerobes. Waste stabilization is accomplished when methane gas and carbon dioxide are produced. The produced biogas contains up to 70 % methane (WtERT, 2016).

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad \textbf{(8)}$$

$$2C_2H_5OH + CO_2 \rightarrow CH_4 + 2CH_3COOH \quad \textbf{(9)}$$

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad \textbf{(10)}$$

In biogas plant, the process described above happen almost simultaneously. They are in a sensitive state of equilibrium, which is dependent on the pH and temperature. Changes may have a negative effect and drastically disrupt the total biogenic process.

Again, it is necessary that both aspects of the anaerobic digestion process - liquefaction and gasification - be well balanced. If the methane bacteria are absent, the digestion process may only succeed in liquefying the material and may render it more offensive than the original material. On the other hand, if liquefaction occurs at a faster rate than gasification, the resultant accumulation of acids may inhibit the methane bacteria and the bioconversion process as well (DaSilva, 2010).

To be able to control the process in biogas plant in order to achieve efficient control of the degradation process, physical and chemical properties should be taken into consideration. Some properties are as follow: Temperature, total solid content (TS), Redox potential, pH, acidic capacity, COD, organic acids/ fatty acids.

- **Temperature**

In biogas power plant, temperature plays a key role. Temperature of former function varies between 35 °C and 41 °C due to mesophilic and thermophilic characteristics of biogas plants. With a mesophilic flora, digestion proceeds best at 30 ºC – 40 ºC; with thermophiles, the optimum range is 50 ºC – 60 ºC. The choice of the temperature to be used is influenced by climatic considerations (DaSilva, 2010). The temperature of the fermentation process should be taken as constant as possible in order to avoid temperature fluctuation because methanogenic bacteria are extremely sensitive to temperature fluctuations. Here, the temperature constant should be within a maximum of ± 1 °C (Wiese & Ralf, May 2007).

- **Total solid content (TS)**

The total solid content (TS) or total organic solids content (TOS) in biogas plant play a role of estimating the volumetric loading of digester in order to manage the solids streams. For wet digester, the total solid content is about 8% to 10% but for special digester TS could reach up to 20%. Measuring the TS for a biogas power plant operation is very important because it helps to insure that the digester is not at high level. If the digester has too high total solid content let say (> 3 kg of TS/ (m3), there will be an overloading and the process will not function well. Therefore, in this case the input substrate has to be reduced (Wiese & Ralf, May 2007).

- **Redox potential**

The redox potential of a digester is a measure of the oxidisability or reducibility of its content. Biogas production only proceeds efficiently in an anaerobic environment, i.e. the redox potential must be less than 330 mV (Wiese & Ralf, May 2007). In general the use of oxidation promoting substrates, i.e. substrates that contain oxygen, sulphate or nitrate groups, may significantly change the redox potential and thus cause a shift in the pH. Such a negative development for the fermentation process can be triggered by, for example, a change of substrate. Continuous redox measurements give an early warning, i.e. before the shift in pH occurs.

- **Ph**

In biogas plant, just like the temperature there is more than one optimum pH value. During hydrolysis and acidification, the best pH is between 4.5 and 6.3. The optimal pH range for methane formation is the narrow window between 7.0 and 7.7 (Wiese & Ralf, May 2007). Continuous pH metering gives an early indication of any acute disruption of the process.

However, the plant cannot be controlled reliably simply on the basis of the current pH. This is especially true of plants whose digester has a high buffer capability, as an unintentionally large input of organic acids does not necessarily result in a drop in pH (Wiese & Ralf, May 2007).

- **Acidic capacity**

The acid capacity is a measure of the buffering capability of the digester. The greater the acid capacity, the less rapidly the pH can rise or fall. The acid capacity is measured in mmol/l or mg/l $CaCO_3$ (Wiese & Ralf, May 2007).

- **COD**

The chemical oxygen demand (COD) is the amount of oxygen required to oxidise the oxidisable components of the fermentation substrate. All oxidisable organic compounds are totally chemically oxidised to CO_2 and H_2O. COD is a reliable indicator of the energy potential of a fermentation substrate (Wiese & Ralf, May 2007).

- **Ammonium**

During the fermentative degradation of protein rich substrates in particular, e.g. grass silage or chicken droppings, high concentrations of ammonium ions may be generated. Ammonium exists in a pH dependent equilibrium with ammonia, which is toxic to the bacteria. If the pH increases the equilibrium shifts favouring ammonia. Regular checks of the ammonium content of the digester ensure the trouble free operation of a biogas plant (Wiese & Ralf, May 2007).

2.3.6. Anaerobic digestion of protein-rich substrate

Anaerobic digestion of organic material is a complex microbiological process requiring the combined activity of several groups of microorganisms with different metabolic capacities which need to work in a synchronized manner in order to obtain a stable biogas process (Ek, A. et al., 2011).

One type of key organisms is the methanogens, producing methane mainly from acetate or hydrogen and carbon dioxide. Protein-rich substrate, such as slaughterhouse waste, is a well-known source of sulphide formation during anaerobic degradation. The increased concentration of sulphides in the digester lead to higher concentrations of corrosive H_2S in the biogas and can further lead to sulphide inhibition of the methanogens. When the proteins in slaughterhouse waste are degraded, not only sulphides are formed but also ammonia. The released ammonia increases the pH in the digester and with a large ratio of slaughterhouse waste in the substrate mixture, the pH tends to reach over 8.0, which can be growth limiting for some volatile fatty acids (VFA) consuming methanogens (Ek, A. et al., 2011).

The above optimal pH, together with a high fermentation rate of proteins and fats in the slaughterhouse waste can lead to an accumulation of fatty acids. Thus, if the organic load to the digester is not decreased at that point, the process overload can lead to increasing concentrations of process inhibiting fatty acids, the consequential pH drop and finally to a total inhibition of methanogenesis and process collapse will follow. The released ammonia (NH_3) from protein degradation is in equilibrium with the less harmful ionized ammonium species (NH_4^+). However, the non-ionized form is itself also a source of inhibition of microorganisms, since the neutral NH_3 can easily pass through cell membranes of bacteria and archaea and upon entering the cell disrupt e.g. intra-cellular pH and concentrations of other ions (Ek, A. et al., 2011).

Thus, methods to lower ammonia levels in anaerobic digesters treating high-protein substrates are desirable and subject to active research (Ek, A. et al., 2011).Furthermore, at increased pH and temperature, the equilibrium is shifted towards the toxic ammonia, resulting in a positive correlation between toxicity effects and increasing pH and temperature.

Among the methanogens, the acetate-utilizing methanogens have been suggested to be responsible for 70-80 % of the methane produced. However, recent results suggest that an alternative methane producing pathway is activated at elevated levels of ammonia. In this pathway, acetate is converted to hydrogen and carbon dioxide by syntrophic acetate oxidizers (SAO), followed by the subsequent reduction of carbon dioxide to methane by hydrogen utilizing methanogens, i.e. by this pathway methane is produced by hydrogenotrophic methanogens only. Development of SAO has been shown to occur due to a selective inhibition of acetate-utilizing methanogens by ammonia, released e.g. during the degradation of proteins (Ek, A. et al., 2011).

2.4. Biogas Advantages and Composition

2.4.3. Benefits of biogas

All anaerobic digestion systems produce biogas, irrespective of the specific process used, and this can be used in a number of ways. For example, biogas can be used to generate electricity and heat, to produce hot water and steam, or as an energy source to provide refrigeration. By removing the carbon dioxide and other impurities, biogas can be upgraded to biomethane and injected into the gas grid for use in industry and homes (heating and cooking). Alternatively, in compressed or liquefied form, biomethane can be used as a transport fuel (ViesMann Group, 2015).

Energy generated from biogas is ultra-low carbon; producing significantly less than 50 g CO_2/kWh. Biomethane is one of the few low-carbon alternatives to natural gas, and when used as a transport fuel achieves significant environmental and cost savings compared to diesel in buses and other vehicles, while also playing an important role in improving air quality in towns and cities (ViesMann Group, 2015).

Anaerobic digestion produces biogas 24 hours a day throughout the year and so provides reliable and consistent base load energy, which can help balance the intermittency of other renewable energy sources. Furthermore, if the type of energy required changes, only the biogas treatment technology of the plant (10% to 20% of the capital investment) needs to be changed. Biogas generated from AD is, therefore, not only flexible but is also future-proofed against changing legislation and need (ViesMann Group, 2015).

2.4.4. Biogas composition

The composition and quantity of the biogas are largely determined by the feedstock and its loading rate. Biogas produced in an anaerobic digester is typically composed of 50-75% methane (CH_4) and 25-50% carbon dioxide (CO_2). Depending on the feedstock, biogas can also contain significant amounts of hydrogen sulphide (H_2S), water (H_2O) and traces of other chemical products (ViesMann Group, 2015).

Table 2.5: Typical composition of biogas from normally functioning digesters

Compound	**Chemical**	**Range %**
Methane	CH_4	50 – 75
Carbon Dioxide	CO_2	25 – 50
Nitrogen	N_2	0 – 10
Hydrogen	H_2	0.01 – 5
Oxygen	O_2	0.1 – 2
Water vapour	H_2O	0 – 10
Hydrogen Sulphide	H_2S	10 – 30,000 ppm
Ammonia		0.01 – 2.5 mg/m^3

Although pure methane is lighter than air, the specific gravity of biogas can vary from 0.8 (lighter than air) to 1.2 (heavier than air), depending on the concentrations of methane and carbon dioxide, which in turn depend on the feedstock and the stability of the digester. Digestion of fats and proteins will produce a biogas rich in methane while digestion of starches will produce a biogas with more carbon dioxide. The CO_2 concentration can also increase when a digester is overloaded, making the biogas heavier than air (ViesMann Group, 2015).

- **Methane**

Methane is highly flammable, non-toxic to mammals and insects, odourless, and colourless. It forms carbon dioxide and water on combustion. Methane is a potent greenhouse gas, around 25 times more damaging than carbon dioxide. Among other sources, methane is released from open slurry stores and the decomposition of organic matter in landfill, so the diversion from landfill and treatment of biodegradable waste via anaerobic digestion brings distinct environmental benefits (ViesMann Group, 2015).

- **Water**

When biogas is produced it is always super-saturated with water, which condenses as the biogas moves through the pipe works. The water needs to be removed via self-sealing water traps (ViesMann Group, 2015).

- **Hydrogen sulphide**

Elemental sulphur is readily converted into hydrogen sulphide (H_2S) by bacterial action during the acidogenesis phase of anaerobic digestion. The amount of H_2S produced depends on the amount of sulphur in the feedstock and the ph of the digester. Unlike biogas, H_2S is toxic and can occur at levels up to 1,000 times the safe exposure level for humans. H_2S poses a significant risk and its reduction is, therefore, a major target for the AD operator (ViesMann Group, 2015).

- **Oxygen**

Since a simple anaerobic digester has no contact with air, oxygen levels in biogas are close to zero. However, one method of removing hydrogen sulphide (H_2S) is to inject air into the biogas to stimulate the growth of sulphur-removing bacteria, which can introduce nitrogen and up to 2% oxygen. Great care must be taken when injecting oxygen into a digestion system as methane is explosive when mixed with air (at levels of 5% to 15% methane in air). Oxygen is also toxic to anaerobic bacteria and may reduce the performance of the digestion process (ViesMann Group, 2015).

- **Ammonia**

Another (unwanted) constituent of biogas is ammonia, which in turn will be converted to nitrogen oxide (NOx) in boilers and CHP units. The amount of ammonia in the biogas will depend on the amount of nitrogen in the feed, the ph, and the temperature of the digester (ViesMann Group, 2015).

2.4.5. Variations in biogas composition

Since an anaerobic digester acts as a chemostat (maintaining temperature and retention time close to constant), most visible variations in biogas composition are due to variations in the chemistry and quantity of the feedstock. Certain feedstocks are more easily biodegradable than others. It is possible to have the same amount of volatile solids (VS) entering the digester in a given day but if the feedstock chemistry changes, the reaction of the digester can also change significantly. For instance, waste from a pickling factory would add acetate to the digester which may be consumed within 15 seconds, causing serious foaming, whereas other waste more resistant to bacterial decomposition could take several weeks (or months) to decompose. On the other hand, if high protein food waste was added to the digester there would be very rapid changes in biogas quality, particularly in increased ammonia production from the breakdown of protein (ViesMann Group, 2015).

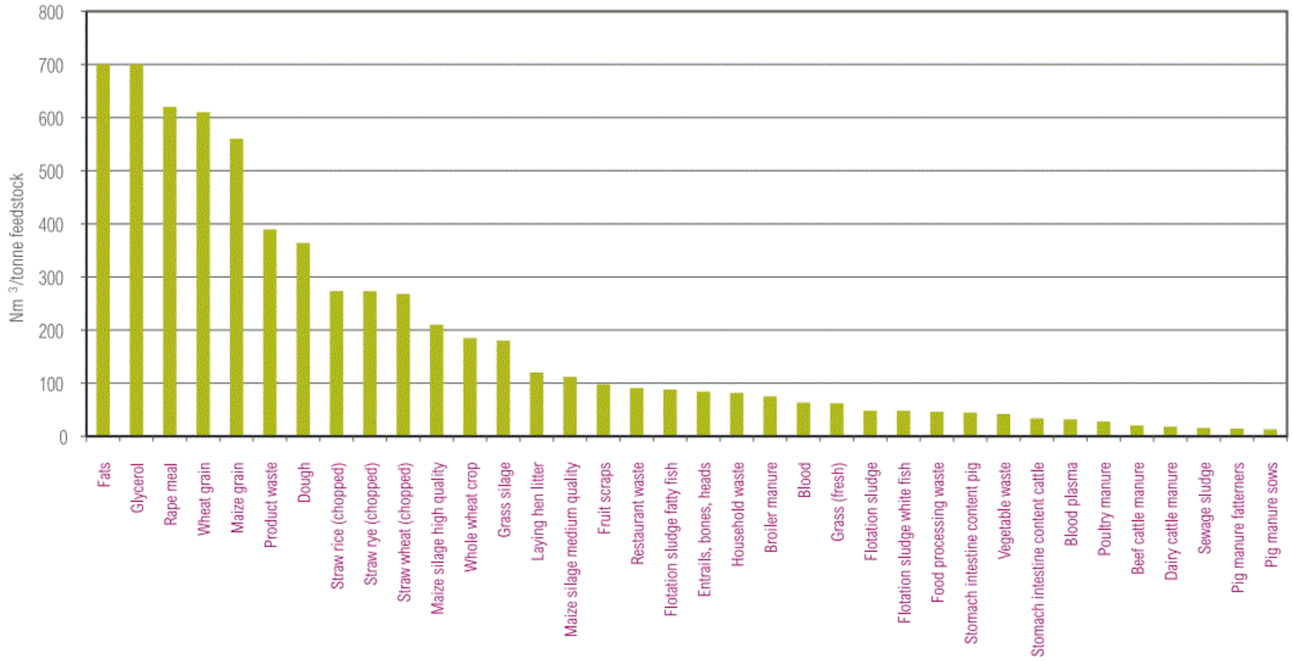


Figure 2.3. Biogas production for different feedstocks

2.4.6. Factors affecting biogas yield

Figure 2.3 indicates the relative gas production from different feedstocks. However, there can be a significant variation in yields from fresh material so it is the responsibility of the operator to assess each feedstock and load the digester, paying heed to both the amount of volatile solids (VS) loaded and the type of organic matter, and therefore its digestibility. A useful measurement for the operator is the 'half digestion time' of the organic matter, that is, the time taken for half the potential biogas to be released from a particular feedstock (ViesMann Group, 2015).

Even if a digester was fed material from a single source, there is still likely to be a variation in gas production caused by natural variation in the availability of VS. The reasons for this may include seasonal changes in plant cell wall structures, ageing of substrates, decomposition of cell walls making the contents more or less available, or changes to the lignin content of feedstock. Digestible cellulose may also be bonded to hemicellulose which can be extremely resistant to decomposition, especially if it is bonded to lignin (ViesMann Group, 2015).

Perhaps the most important characteristic of organic feedstocks is the water content. This varies due to mechanical handling and storage, as well as inherent variations in the feedstock, and is most noticeable when emptying large storage tanks. The selection of the top, centre or bottom layers of a tank of unmixed substrate over several days will provide variations in the concentration of VS from less than 1% to the limit of pumpability (ViesMann Group, 2015).

Feed tanks should be well mixed to ensure a uniformly consistent feed to the digester. Tanks can be mixed by impellers, pumps or gas injection but it is worth noting that most mixing systems do not operate at low tank levels. Therefore if a tank is almost empty the mixing process is unlikely to be effective. A stable feed for the digester can usually be achieved by blending several feedstocks from different tanks into one buffer feed tank that is always well mixed before feeding to the digester (ViesMann Group, 2015).

Where food waste substrates are stored in large tanks, the anaerobic conditions can create ‘septic’ odours, which can become a nuisance if allowed to escape. One way to prevent such odours developing is to inject air into the tank to prevent the contents from turning anaerobic. However, adding air allows the aerobic bacterial conversion of carbon to carbon dioxide (composting), reducing the amount of carbon available for subsequent biogas production. Another factor affecting the rate of digestion is the number of bacteria present or inoculated into the waste and the time available for the bacteria to consume the organic matter. Temperature is also a factor, with warmer temperatures accelerating bacterial decomposition (ViesMann Group, 2015).

Also crucial to the stability of anaerobic fermentation is the carbon to nitrogen ratio of the feedstock. High nitrogen feedstocks are generally associated with high gate fees; however they also contain protein which breaks down in the digester to form ammonia, which is toxic to methanogenic bacteria and other important bacteria groups in the digester. Ammonia can severely inhibit methane production, depending on the ph and temperature of the digester contents, with higher temperature systems being more sensitive.

It should be noted that there might be 2,000 species of bacteria present in an anaerobic digester and the assemblage may become acclimatised to a particular feedstock in time. This makes it possible to process a particular feedstock with great efficiency in one digester that might prove difficult in another. Biogas production can be controlled by the mixing of feedstocks in a buffer tank and the attentive management of the process by a competent operator (ViesMann Group, 2015).

2.5. Biogas Cleaning Prior to Use

Some of the contaminants in biogas such as hydrogen sulphide and water can cause maintenance issues with downstream equipment. When H_2S is combusted in a boiler or CHP it can result in chemical corrosion, reducing the operating life of equipment. Some simple equipment such as boilers can burn raw biogas with little pre-treatment; however if H_2S is high (typically > 500 ppm), it may need to be removed before use. It is also important to remove the water before using the biogas. Slugs of water can damage gas compressors, for example, and can also reduce the efficiency of CHP engines (ViesMann Group, 2015).

Quality requirements will vary depending on the desired use of the gas. For example, direct fire boilers will usually require no treatment; CHP may require some treatment of heavily contaminated biogas; transport use requires upgrading to biomethane; and pipeline standards require upgrading to biomethane and a final stage of polishing.

Table 2.6: Requirements to remove components depending on biogas utilisation

Application	**H2S**	**CO2**	**H2O**	**Siloxanes**
Boiler	<1000 ppm	No	No	No
Cooker	Yes	No	No	No
Stationary engine	<250 ppm	No	No	Yes
Vehicle fuel	Yes	Recommend	Yes	No
Natural gas grid	Yes	Yes	Yes	Eventually

Cleaning biogas can be achieved in a number of ways and the main techniques are briefly described below.

2.5.1. Water removal

Relative moisture of raw biogas in digester is 100% which means that it is saturated with water vapour. Removal of water mainly requires biogas received during the wet fermentation and after treatment processes using water. The drying process usually takes place during the cooling and it is possible in all production lines. Some water vapour is isolated in the form of condensate accumulated in the dephlegmators. During the process of removal of water, other undesirable components of biogas, mainly water-soluble gases and aerosols can also be removed along with water (CHEMIK, 2011).

2.5.2. Hydrogen sulphide removal

Biogas contains H_2S in concentrations from 0 to 6,000 ppm or more, depending on the feedstock composition. The odour of H_2S becomes offensive at parts per billion levels, with physiological effects starting at 3-5 ppm and becoming very noticeable above 10 ppm. H_2S is a toxic air pollutant, which means that atmospheric concentrations of 200 ppm can be lethal.

Even in low concentrations, H_2S can cause piping corrosion, gas engine pitting, and clogged piston rings. all biogas conversion and utilisation equipment can be affected by H_2S corrosion to a greater or lesser extent. Because of this, many engine manufacturers require the H_2S content of the feed biogas to be as low as 90 ppm, whilst others will accept levels as high as 1,100 ppm. The most commonly used methods to remove H_2S, namely biological desulphurisation, dry oxidation and liquid phase oxidation, are described below (ViesMann Group, 2015).

- **Biological desulphurisation**

It is possible to remove H_2S biologically using sulphur-oxidising bacteria (such as Thiobacillus denitrificans). The reaction equation is:

$$2_n(H_2S) + n(C_2O) + \text{light} \rightarrow 2_nS + n(CH_2O) + n(H_2O)$$

This reaction does not require regeneration and destroys the H_2S rather than just removing it. However, the process is highly dependent on the inhibitory effects of other biogas components. This is the simplest method of removing H_2S and the microorganisms can reduce the level by 95% to less than 50 ppm. The addition of 2-5% air into biogas allows the indigenous Thiobacilli to oxidise the H_2S to elementary sulphur which adheres to the digester surface or the digestate (ViesMann Group, 2015).

- **Dry oxidation**

Dry oxidation can be used for the removal of H_2S from gas streams by converting it either into sulphur or oxides of sulphur. This process is used where the sulphur content of the gas is relatively low and high removal efficiency is required. Some dry oxidation process methods are by absorption using iron oxide or hydroxide bed (iron sponge process), whereas others use an activated carbon sieve (pressure swing adsorption). It is important to note that these processes often have a regeneration cycle where sulphur is removed from the media by air. This process is strongly exothermic and will generate high temperatures. Care must be taken to avoid explosive mixtures of methane and air in such systems under any conditions (ViesMann Group, 2015).

- **Liquid phase oxidation**

Liquid phase oxidation is primarily used for the treatment of gases with options available to suit all ranges of H_2S concentrations, and may be either:

- Physical absorption using water; or
- Chemical absorption using iron salt solutions such as iron chloride orpolyethylene glycol (selexol).

All methods of H_2S removal by liquid phase oxidation are suitable and economically viable for large scale digesters. Although this offers one of the lowest capital cost systems, iron chloride addition will have a prohibitively high operating cost if H_2S is consistently high.

2.5.3. Siloxane (silicon – oxygen – methane) removal

Siloxanes are a group of chemicals based around a chain of oxygen and silicon atoms which are widely used in products such as detergents, water repellents, shampoos and soaps. Inside a digester they are excreted with the methane as a component of the gas. Siloxanes convert into silicon dioxide during combustion, which causes a build-up of matter on the engine surfaces.

Removal systems typically dry the gas and then absorb the silicon on a molecular sieve, a gas-porous compound that has a surface area of typically 50 hectares per kg of media.

As the siloxanes are large molecules, they become trapped on the surface of the molecular sieve. Normally there are two sieves: one is regenerated by heating to remove the siloxanes where they are captured as solid dust; and the other is used to clean the gas stream. The process can be relatively expensive to set up and the best way of avoiding the siloxane problem is to avoid putting siloxane-containing materials into the digester in the first place (ViesMann Group, 2015).

2.6. Upgrading Biogas to Biomethane

Biogas formed in the methane fermentation process contains about 50 to 60% of methane. Other ingredients such as carbon dioxide, hydrogen sulphide, water, water vapour and small amounts of nitrogen and oxygen (H_2O, H_2S, Siloxanes, Hydrocarbons, NH_3, O_2, CO and N_2) are the ballast lowers heating value of biogas. The calorific value of raw biogas is much lower than natural gas or compressed natural gas (CNG) used as motor fuel. Raw biogas most often is used for processing into electricity, heat and/or cooling. Purification of biogas for these applications is reduced mainly to remove hydrogen sulphide and water, which negatively affecting the functioning and viability of power equipment, causing them to corrode (CHEMIK, 2011).

Biogas can be upgraded to biomethane, a renewable natural gas equivalent, which can then be injected and stored in the grid or used as a transport fuel. Upgrading biogas removes all contaminants including carbon dioxide and increases the methane content to over 95%. The upgraded biogas is referred to as biomethane. Removing carbon dioxide increases the heating value of the biomethane to a similar level to natural gas, and also leads to consistency of supply from different biomethane plants.

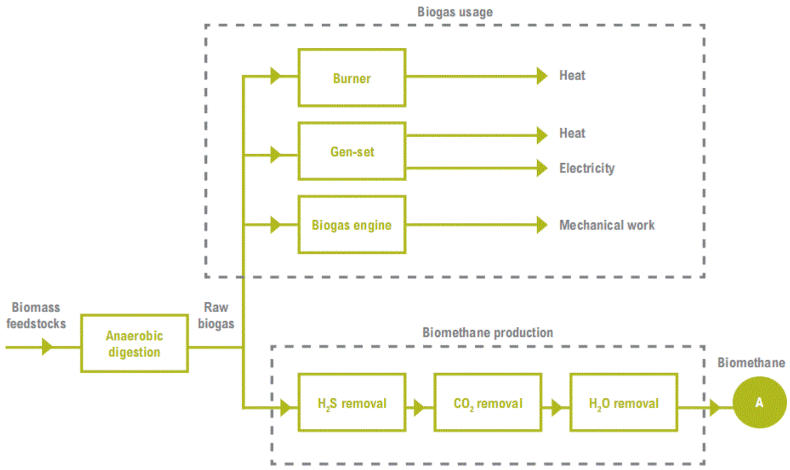


Figure 2.4. Schematic diagram of biomethane production

Source: (CALSTART White paper (2010))

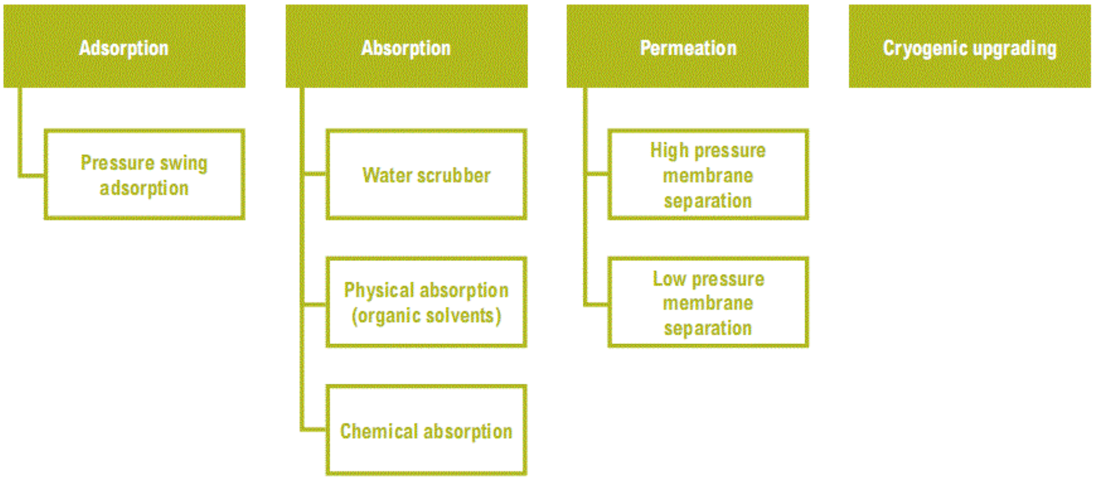


Figure 2.5. Biogas upgrading technologies

Source: Biogasmax (2009)

2.6.1. Pressure Swing Adsorption - PSA

Pressure swing adsorption is one of the most frequent techniques of biomethane production. In this technology, carbon dioxide is removed from the biogas by adsorption onto activated carbon surface or on a zeolite molecular sieve at increased pressure. Pressure swing adsorption separates some gas species from a mixture of gases under pressure. Operating at near-ambient temperatures, gases are adsorbed according to their molecular characteristics and affinity for an adsorbent material. Carbon monoxide is adsorbed by molecular sieves, whereas carbon dioxide is adsorbed by activated carbon, activated alumina or silica gel (ViesMann Group, 2015).

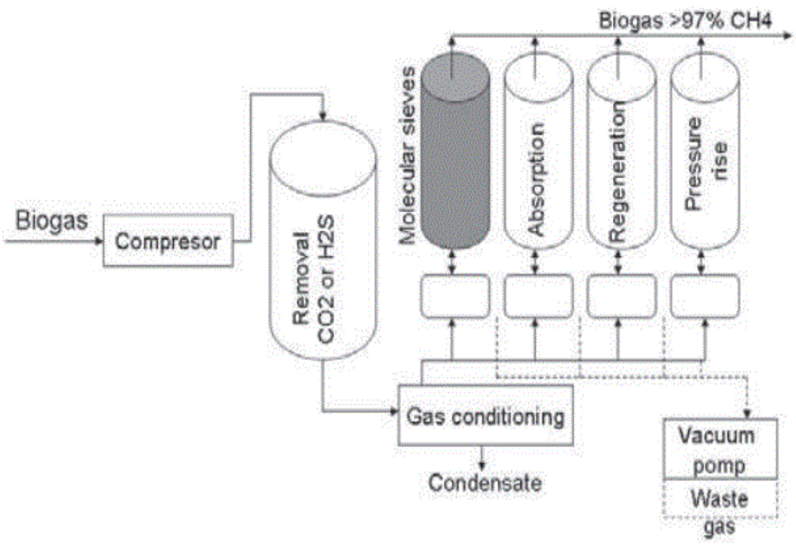


Figure 2.6. Schematic operation of the PSA system

In plants which produce biomethane and functioning on the basis of the PSA technique located in Austria, Germany and Sweden (Figure 2.5). Biogas achieves a content of methane within the limits of 96 to 97% (v/v) (CHEMIK, 2011).

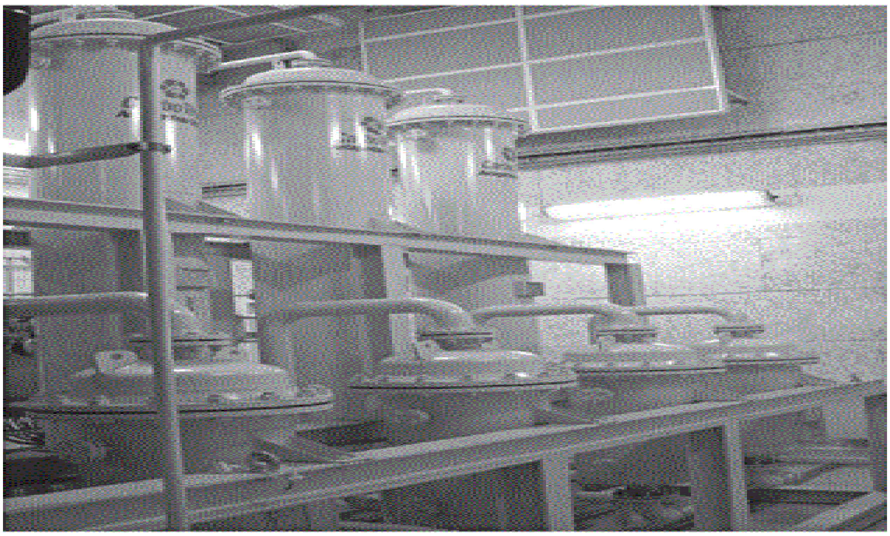


Figure 2.7. Installation for biomethane upgrading working in PSA technology, Helsingborg, Sweden

Source (CHEMIK, 2011).

2.6.2. Absorption

The absorption as a process of diffusion moving of gas particles into a liquid caused gradient difference in both phases is divided into three basic steps:

- ✓ Moving gas to the liquid surface
- ✓ Dissolution of gas in the boundary layer
- ✓ Move the gas absorbed into the liquid

Absorption processes conducted in scrubbers serve primarily to remove carbon dioxide, but with their participation hydrogen sulphide is also removed. This technology uses the phenomenon of increased solubility of carbon (CO) in water than methane. Therefore, the liquid leaving the column contain a higher concentration of carbon dioxide, but gas contains more methane (CHEMIK, 2011).

- **Water scrubbers**

Water scrubbing is used to remove carbon dioxide and hydrogen sulphide from biogas since these gases are more soluble in water than methane. This gas will be dissolved to a higher extent than methane, especially at lower temperatures. The absorption process is purely physical. Usually the biogas is pressurised and fed to the bottom of a packed column where water is fed from the top and so the absorption process operates counter-currently. In the scrubber column, carbon dioxide is dissolved in water, while methane concentration in the gas phase increases (ViesMann Group, 2015).

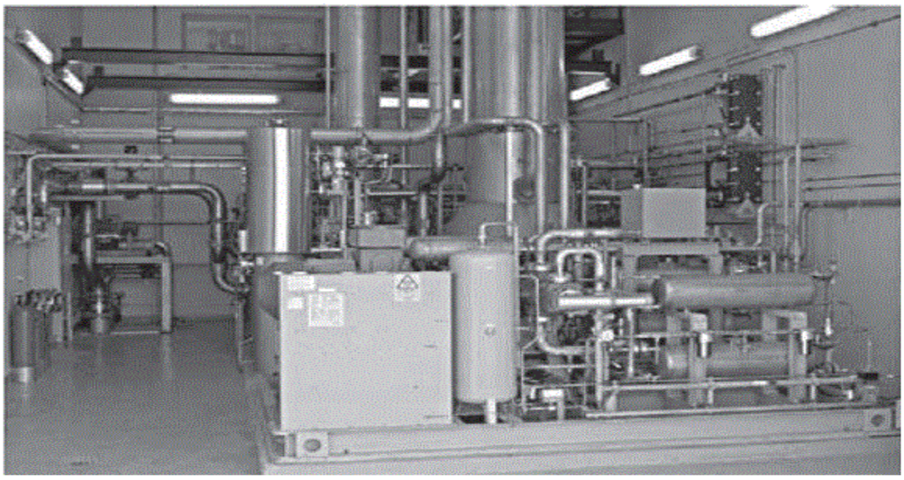


Figure 2.8. Installation of biogas purification using water scrubber technology, Stockholm, Sweden.

Sources: http://www.biogas.org.nz

- **Organic scrubbers**

Organic scrubbers work in a similar manner as the water scrubber with the difference that carbon dioxide is absorbed in an organic solvent such as polyethylene glycol, which has greater than the water solubility of CO_2. A solution of polyethylene glycol is regenerated by heating and/or a gradual reduction of pressure. Together with carbon dioxide can be removed also hydrogen sulphide, water, oxygen and nitrogen. However, they are usually removed before the purification process. Organic scrubbers are much less using than the water scrubber. Installations where this technique has been used are mainly located in Germany (Schwandorf) (CHEMIK, 2011).

- **Chemical absorption (chemical scrubber)**

Compared to physical absorption, chemical absorption processes use different absorption agents, such as organic amines. It works on the principle of chemical reaction of carbon dioxide with mono-ethanolamine (MEA) and dimethyl-ethanolamine (DMEA). Carbon dioxide binds chemically to liquid but also reacts chemically with the amine (ViesMann Group, 2015).

Amine reaction is very selective, so that methane losses are insignificant (< 0.1%). Some liquid is lost during the process due to evaporation and must be supplemented. The liquid in which carbon dioxide is chemically bound is regenerated by heating. If hydrogen sulphide is present in raw biogas, it will be absorbed in the solution contained in an amine scrubber, which means that you will need higher temperatures to regenerate this solution. Therefore, it advisable to remove hydrogen sulphide before the absorption process in the scrubber amine (CHEMIK, 2011).

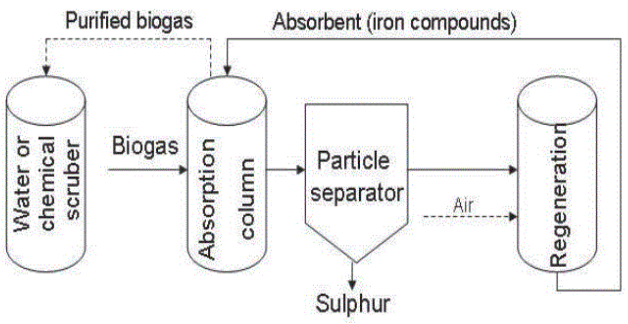


Figure 2.9. Schematic of chemical absorption of hydrogen sulphide

2.6.3. Membrane techniques

Membrane techniques allow the separation of pollutants mainly carbon dioxide and hydrogen sulphide. This processes are still relatively new but growing up very rapidly. The advancement of research in the field of membrane technology and their results indicate the technical and economic justification for their use as one of the best methods for cleaning biogas from pollutants (CHEMIK, 2011).

Membrane is a filter through which can pass without any obstacle, at least one of the components of the separated mixture, while others are stopped by it because of their size or affinity. It is associated with different permeability of the membrane. Transport through the membrane occurs thanks to an appropriate driving force, i.e. the chemical potential difference in both site of the membrane. This potential may be cause, inter alia, by difference in pressure, concentration, temperature or electrical potential occurring on both sides of the membrane (CHEMIK, 2011). There are two basic systems of gas purification with membranes: A high pressure gas separation with gas phases on both sides of the membrane; and a low pressure gas liquid absorption separation where a liquid absorbs the molecules diffusing through the membrane (ViesMann Group, 2015).

2.6.4. Cryogenic separation

In addition to the continuous improvement of already existing biogas purification technology, some new technologies are also being developed. One of them is a cryogenic purification of biogas. This process takes place under very low temperatures (about -100°C) and high pressure (40 bars). The raw biogas is cooled down to a temperature at which the carbon dioxide is condensed or sublimation, and can be separated from the biogas in liquid or solid fraction, while the methane accumulates in the gas phase. The principle of operation of cryogenic separation process is shown in Figure 2.8 (CHEMIK, 2011).

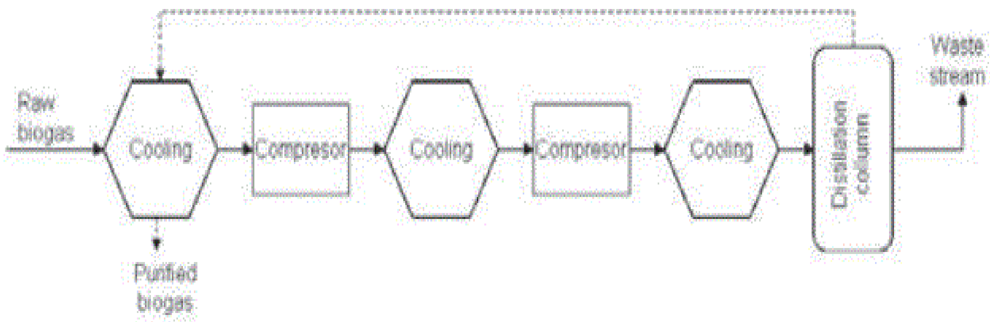


Figure 2.10. Schematic of cryogenic separation process

Cooling usually takes place in several steps in order to removal of various undesirable substances contained in the biogas, inter alia, water vapour, siloxanes, and in order to optimize energy recovery. Raw biogas stream passes through the first heat exchanger that cools the gas to a temperature of -70 °C. The next stage of the process is passing cooled biogas by a series of compressors and heat exchangers, which additionally cool the gas and cause the compression it to about 40 bar before entering the gas to the distillation column. The last step of cryogenic separation process is the separation of CH_4 from the other impurities, mainly H_2S and CO_2 (CHEMIK, 2011).

The main advantage of cryogenic separation is possible to obtain biogas with high methane content of up to 99%. The principal disadvantage is that in the upgrading process it is necessary to use many of technological equipment, especially compressors, turbines and heat exchangers. This significant demand for equipment makes cryogenic separation extremely expensive (CHEMIK, 2011).

2.7. Biogas Uses

Biogas can be used in a number of applications including the production of heat and power, injection into the gas grid and as a transport fuel. Prior to use it must be treated to achieve the gas standards of each application.

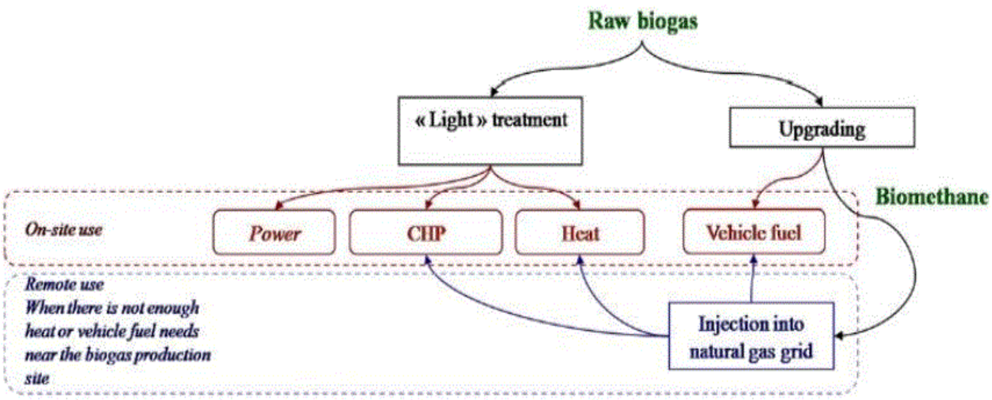


Figure 2.11. Biogas uses (on-site or injected into the natural gas grid) Combustion to generate heat

2.7.1. Combustion to burning flame

A thousand cubic feet (1000 Mcf) of processed biogas is equivalent to 600 cubic feet of natural gas, 6.4 gallons of butane, 5.2 gallons of gasoline, or 4.6 gallons of diesel oil (DaSilva, 2010). For cooking and lighting, a family of four would consume 150 cubic feet of biogas per day, an amount that is easily generated from the family's night soil and the dung of three cows. Moreover the biogas can be used directly for combustion for singeing animals in slaughterhouses as a substitute for liquefied petroleum gas (LPG) and wood fuels. Biogas by itself usually has a calorific value (CV) between 21-23 MJ/m^3 and can be burned directly in a boiler to generate hot water or steam (ViesMann Group, 2015). Biogas as produced from bio waste falls into the category of Natural gas (primarily Methane) not LPG. Methane can be converted to compressed natural gas CNG or liquefied natural gas LNG. There are two main differences in the way that LPG (Propane) and natural gas (Methane) are burnt:

- ➢ The first difference is in the energy content.

LPG has a higher calorific value, or energy content (93.2 MJ/m^3 vs. 38.7 MJ/m^3), so less gas is required to produce the same amount of heat.

- ➢ The second difference is in the oxygen to gas ratio required for proper combustion.

LPG requires oxygen to gas ratio of approximately 25 to 1; while methane requires a ratio of around 10 to 1. To achieve this difference, LPG is typically provided in a smaller quantity but at a higher pressure, drawing more oxygen with it into the combustion process.

LPG is supplied in gas bottles that are either exchanged or refilled on site by LPG tankers. There are a number of hydrocarbon gases that fall into the category of LPG. Their common characteristic is that they can be compressed into liquid at relatively low pressures. The two most common are Propane (C_3H_8) and Butane (C_4H_{10}).

Propane is the gas that is supplied to virtually all homes and most businesses. Butane is supplied to certain businesses that specify Butane, as opposed to propane. Butane has some specific applications where it has advantages over Propane. These include greenhouse applications and use as a propellant in aerosols (Hahn, 2015).

2.7.2. Combined Heat and Power from Biogas

Combined heat and power (CHP) or co-generation, is the conversion of the energy within a fuel (in this case, biogas) into heat and electricity. The efficiency of a CHP unit is often quoted to be around 40%, but this only includes the electricity generated and does not account for the energy contained in the heat. It must be noted though, that actually a CHP unit will generate as much heat (if not more) as electricity. Hence the overall efficiency of CHP can be around 85% (if all the heat is used) and the energy output can be used in a number of ways, as described below. A CHP unit in a biogas plant usually comprises a reciprocating gas engine, though small installations have utilised gas turbines (ViesMann Group, 2015).

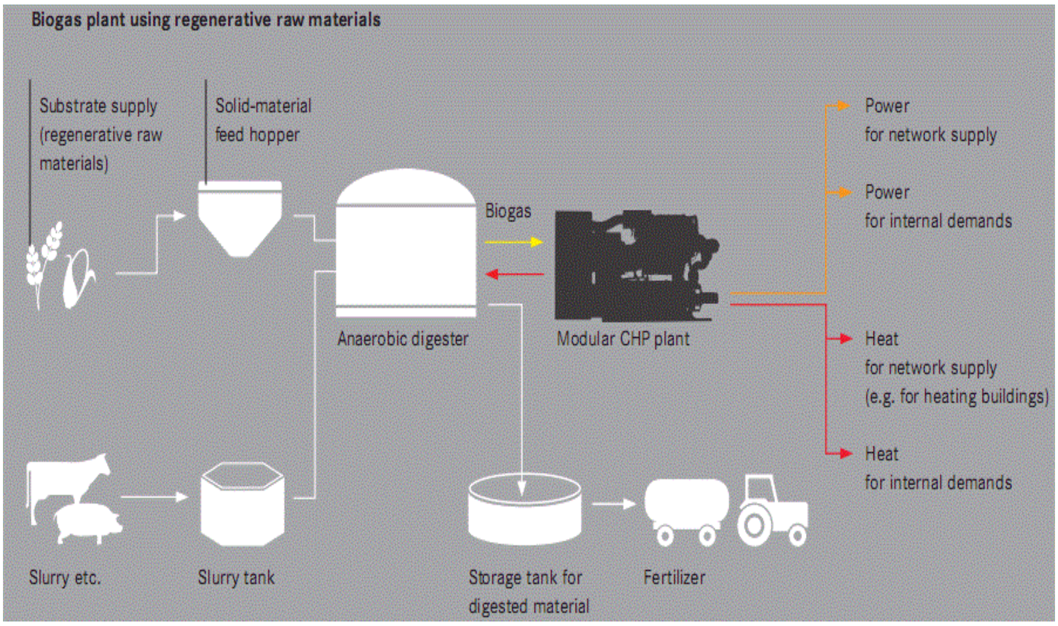


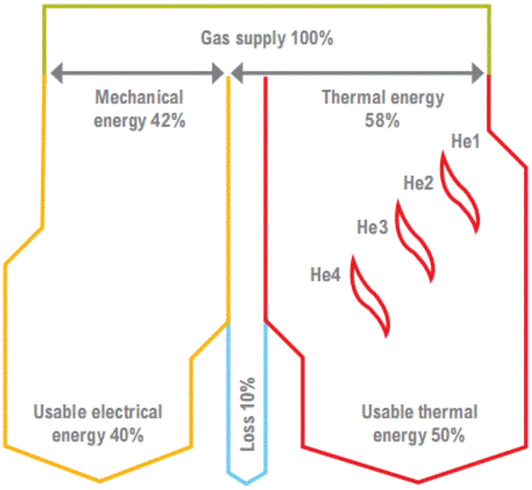
Figure 2.12. Biogas use in CHP plant

➢ Power generation

The power generating (electrical) efficiency of a CHP engine varies from supplier to supplier and with the type and size of unit. Typical electrical efficiencies for CHP will range from 36% to 43% based upon the lower heating value of the gas, and are often calculated with an assumed biogas methane content of 65% (ViesMann Group, 2015).

➢ Heat use

In addition to the electrical output, a reciprocating gas engine CHP produces heat from a number of sources (see Figure 2.14.). Most systems will generate the majority of heat from the engine cooling water (water circulated through the engine to direct cool the prime mover) and from the hot exhaust fuel gasses. Some additional heat is generated from the intercoolers on the biogas compression and from the high pressure oil system (ViesMann Group, 2015).



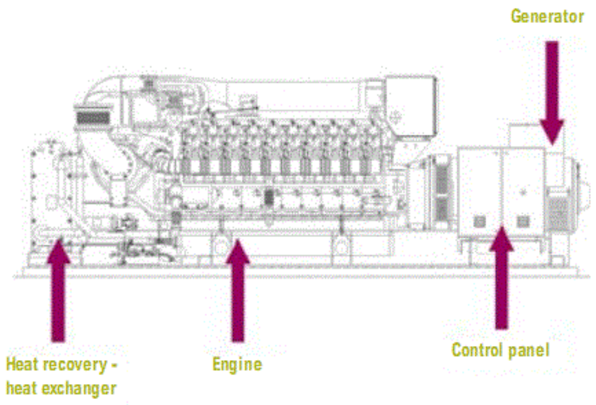


Figure 2.13. CHP energy flow **Figure 2.14. Reciprocating gas engine showing**

➢ Combined Heat, Power and Cooling (CHPC)

Using an absorption or an adsorption chiller, CHP systems can also create cooling energy with their generated heat. The approach is known as tri-generation or combined heat, power and cooling (CHPC).This functionality could be used for air conditioning in and office building, for example.

The supply of cooling energy plays an important role not only for building climate control. It can be utilized in many different areas, as well as process cooling in manufacturing, for food refrigeration or for ambient cooling in temperature-sensitive areas (e.g. data centres). The generation of cooling energy extends the possibilities of using our CHP systems in a very cost-effective way (MTU Onsite Energy, 2014).

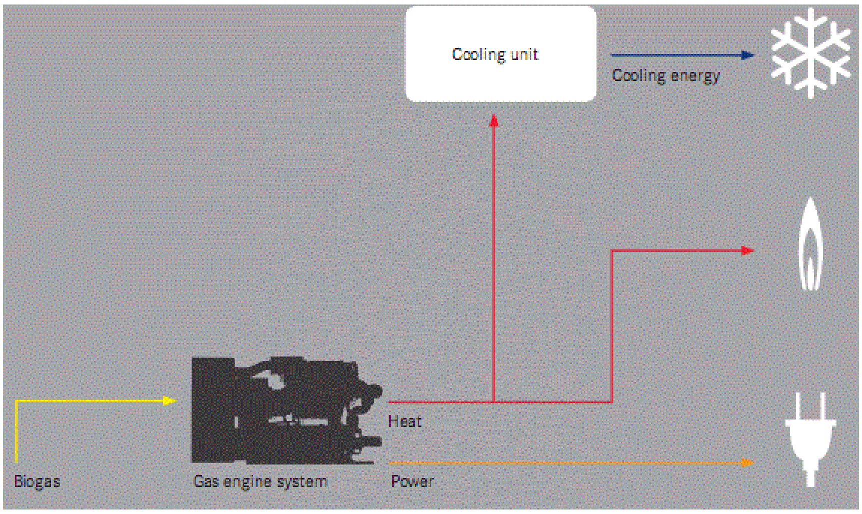


Figure 2.15. Biogas in CHPC plant

2.8. Combined Slaughterhouse-Biogas Plant across the World

The primary sources of methane emissions from agriculture are livestock enteric fermentation, livestock waste management, rice cultivation, and agricultural waste burning. Of these, livestock waste management, which represents 7% of global methane emissions, offers the most viable, near-term opportunity for methane recovery and utilization. When livestock manure and organic components in agro-industrial waste decompose, the process produces and emits methane. Capturing this methane provides an opportunity to lower the amount of methane accumulating in the global atmosphere and harness this renewable energy source (GMI Agriculture Subcommittee , 2013).

The Global Methane Initiative is an international public-private initiative with more than 40 partner countries that works to promote global methane emission reductions by focus on five sectors: agriculture, coal mines, municipal solid waste, oil and gas systems, and wastewater. Launched in 2004, GMI urges stronger international action to fight climate change while developing clean energy and stronger economies. Specifically, GMI aims to advance cost effective, near-term methane abatement and recovery, and use of methane as a clean energy source (GMI Agriculture Subcommittee , 2013). A big number of projects have successfully implemented anaerobic digesters to manage waste and produce positive financial, environmental, and social outcomes for the communities.

Facilitating the development of methane projects would increase energy security, enhance economic growth, improve local air quality, and improve industrial safety. Integrating biogas plant to slaughterhouse for methane recovery from anaerobic digestion of available slaughter waste presents a vital opportunity for the meat industry. Additionally to the environmental benefits, slaughtering facilities could enhance their energy self-sufficiency.

2.8.1. Municipal Slaughterhouse Phitsanulok, Thailand

Phitsanulok slaughterhouse presently slaughters up to 120 pigs per day. An anaerobic wastewater treatment plant has been built with a planned capacity of 400 pigs and a total wastewater quantity expected to be 60 m^3/day. Currently some 80 kg of LPG – liquefied petroleum gas – (60 kWh/d) are used for the operation of the slaughterhouse, after the planned extension the energy demand will rise up to 260 kg LPG/day (200 kWh/d) (GATE, 2001).

From a total expected suspended solids content of 80 kg/d and a concentration of 1,300 mg/l (COD total being 4,300 and BOD5 3,000 mg/l), a total biogas production of 120 m3/d, a LPG replacement of 55 kg/d and a bio-fertilizer production of 100 kg/day and 80 m3/d purified water are expected to result after treatment. The treatment plant consists of a collection tank, a 200 m^3 channel digester with gas storage of 100 m^3, an upflow anaerobic sludge blanket UASB-reactor of 60 m^3 reactor volume, a sand bed filter, a stabilisation pond, three wetland cells and a water reservoir (Gate, 2001). For a flow diagram of the fully operational system, (see figure 2.17).

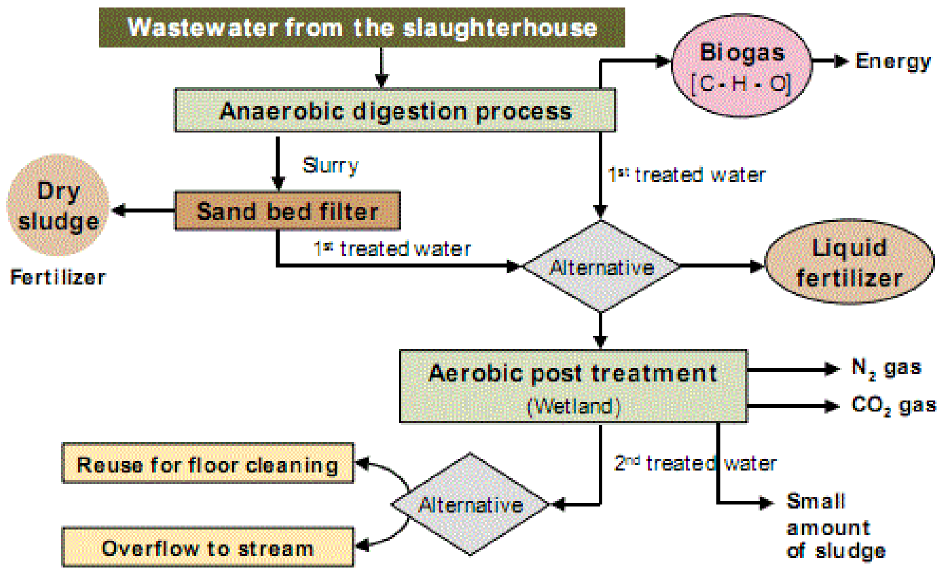


Figure 2.16. Flow diagram for wastewater treatment of Pithsanulok municipal slaughterhouse

Source: (Kiatpakdee, 2011)

Since the plant has presently only been taken into operation at 30% capacity, and bio-fertilizer and treated water are not yet used, final efficiency statements can barely be made as yet. However, the effluent water quality already achieves values exceeding the requested standards, and malodour and houseflies are substantially reduced.

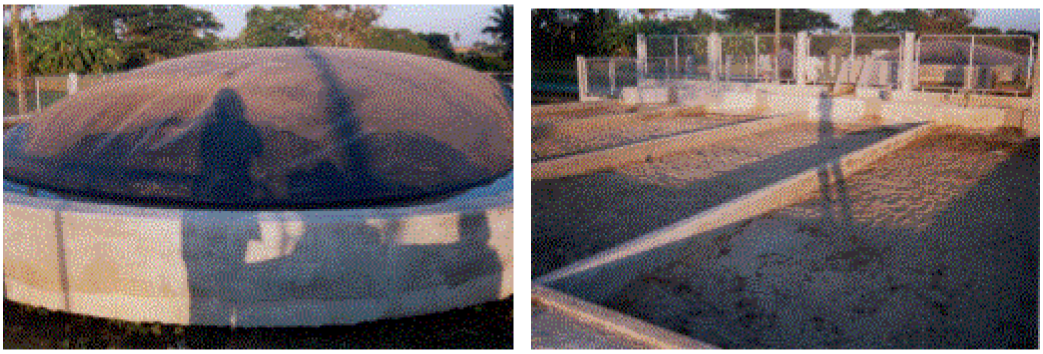


Figure 2.17: Aspects of municipal slaughter-house Phitsanulok, Thailand

Source: U. Gottschalk, GTZ)

2.8.2. Combined slaughterhouse/biogas plant located at St.Martin/Innkreis in the North-West of Austria.

Using the biogas from animal by-products (ABP) digestion, the St Martin slaughter facility can cover most of its heat demand and some of the electricity requirements. In combination with heat from a geothermal power plant, the slaughterhouse fully covers its demand on thermal energy by renewable energy (IEA Bioenergy Task 37, 2012).

Figure 2.18. Biogas plant at St. Martin

The combined slaughterhouse/biogas plant is located at St. Martin/Innkreis in the North-West of Austria. This biogas plant is processing all animal by-products which may not be further utilized such as blood, hind gut, stomach content and fat scrubber content. The electricity produced from biogas is fed into the national power grid and the heat is delivered to the slaughtering facility. The specific load profile of the slaughterhouse showed that only during 35% of time the heat produced by the CHP could directly be consumed in the slaughter-house. Therefore, a hot water storage tank serves as buffer to match the steady heat production with the heat demand of the slaughterhouse. Thus nearly all of the heat produced in the biogas plant is used in the slaughterhouse covering 80% of its energy demand (IEA Bioenergy Task 37, 2012).

- Anaerobic digestion of slaughterhouse wastes (animal by-products).
- 80% of the heat demand in the slaughterhouse is covered by the biogas driven CHP.
- A hot water storage tank uncouples heat supply from heat production.
- In combination with geothermal energy the complete heat demand of the slaughterhouse is covered by renewable energy.
- Reduction of disposal costs.
- Production of a valuable fertilizer.

2.8.3. Kenya: Biogas plant at abattoir

Dagoretti is a suburb of Nairobi well known for its slaughterhouses, which were almost shut down in 2009, due to slaughterhouse waste polluting the Nairobi River. Moreover, apart from the waste pollution they create, frequent power cuts have forced the abattoirs to use diesel generators (UNIDO Renewable Energy Unit, 2013).

- A 15 kW biogas plant was installed at the Nyongara slaughterhouse, with a high performance temperature controlled digester (using solar heating), replacing the diesel generator, and recovering waste heat to replace wood and charcoal for hot water to clean the abattoir.
- The project has cut CO_2 emissions by 108 tons per year. Economic benefits include reducing the cost of energy from US$ 0.20 to US$ 0.09 per kW. In addition, the process yields organic fertiliser as a by-product, bringing additional income to the abattoir.
- The Government of Kenya and the abattoir owners are planning to apply the lessons learned to replicate the project in other slaughterhouses around the country.
- A new project to scale up this model is under implementation.

2.8.4. "Cows to Kilowatts" abattoir-Biogas plant at Ibadan, Nigeria

"Cows to Kilowatts" is a south-south partnership committed to fighting water pollution and greenhouse gas emissions. Two NGOs and a quasi-governmental initiative in Nigeria have joined forces with a technology institute in Thailand to design, construct, and operate a bio-gas plant in the Nigerian city of Ibadan. The plant uses the waste produced by a local abattoir to produce low-cost household cooking gas and organic fertilizer. This solution won the SEED award, which is a component of the SEED Initiative, a global partnership for action on sustainable development and the green economy (Heid, 2006).

The "Cow to Kilowatts" project proposal: About 1,000 cows are slaughtered at the Bodija Market abattoir on a daily basis, which would provide 1,500 cubic metres of biogas (900 cubic metres of pure methane) per day. This, in turn, amounts to 5,400 cylinders of cooking gas per month. A sales point could be established at the Bodija Market. Cooking gas could be sold at US$ 7.50 for a 25-litre cylinder, well below the current market price for cooking gas (Note c). This low price is explained by the fact that the abattoir waste generates "almost free" raw materials for biogas production (Note d). The sludge from the biogas reactor, transformed into organic fertiliser, will be sold to the Oyo State Fertiliser Board, a governmental agency that markets fertiliser. In turn, the fertiliser could be sold to urban low-income farmers at a reduced price of US$ 1 for 10 litres, about 5 per cent of the standard price of chemical fertiliser in Nigeria (Dr.Adelegan, 2005).

2.8.5. Jan Kempdorp abattoir- anaerobic Digestion system

In South Africa, the Jan Kempdorp abattoir site uses a small-scale AD system to address cattle and bovine wastes in order to reduce GHG emissions, improve the elimination of animal by-products, reduce power grid demand by producing energy onsite, and create jobs (GMI Agriculture Subcommittee , 2013).

The Jan Kempdorp abattoir in Northern Cape concentrates on cattle and bovine products. It has a 75% production capacity and average annual energy demand of nearly 1.3 kWh. The company had an audit conducted to determine a green and economically viable proposal to improve the elimination of animal by-products. A biogas generation system was identified as a method to produce energy from the waste for electricity, heating, and cooling. The potential energy savings equal 760 MWh electricity and 1,250 MWh heat per year. The project started running on 2012 and makes actual emission reductions of 19,899 MT CO_2E (GMI, 2013).

Project details:

- Type of feed stock(s): Abattoirs wastes
- Installed cost: Approximately $1 million USD
- Investment/Interest Costs: Fully covered by electricity cost savings
- Payback period: 8 years
- System type and components: Small-scale AD, pre-treatment / digester / gas treatment / CHP engine

Project highlights:

- Improved elimination of animal by-product
- Reduced power grid demand
- Job creation
- Corporate social responsibility
- Greenhouse gas (i.e., methane, carbon dioxide) emission reductions

Figure 2.19: Jan Kempdorp abattoir- anaerobic digestion system

3

CASE STUDY OF KUMASI ABATTOIR, GHANA

3.1. Ghana Overview

3.1.1. General information about the country

Ghana is a West African country, bounded on the north by Burkina Faso, on the east by Togo, on the south by the Atlantic Ocean, and on the west by Côte d'Ivoire. The current population of Ghana in August 2016, (based on the latest United Nations estimates) is 28,097,350 habitants, and the total land area is 227,544 km^2 (87,855 sq. miles) (worldometers, 2016).

The country overall population density is 123 per square kilometre km^2 (319 people per mi square). The most densely populated parts of the country are the coastal areas, the Ashanti region, and the two principal cities, Accra and Kumasi.

Ghana's economy is strongly oriented toward agriculture, made up of five major subsectors – food crops (59.9 %), livestock (7.1%), fisheries (7.6 %), cocoa (14.3 %) and forestry (11.1%) (Ulrike, D. et al., 2014). The economy has a diverse and rich resource base, including the manufacturing and exportation of digital technology goods, automotive and ship construction and exportation, and the exportation of diverse and rich resources such as hydrocarbons and industrial minerals. These have given Ghana one of the highest gross domestic product (GDPs) per capita in Africa 1,381.4 US $ per capita (Ulrike, D. et al., 2014).

3.1.2. Abattoirs and slaughterhouses in Ghana

The Accra and Kumasi Abattoirs are the largest in Ghana and have been equipped with modern facilities. Both are supposed to have a maximum capacity to slaughter 450-480 cattle per day, 450-480 sheep and goats per day and 200 pigs per day (Ulrike, D. et al., 2014). In contrast to European habits, in Ghana slaughtering is done daily. Therefore biomass would be available daily and throughout the year on a relatively constant level with little peaks on holidays.

But apart from those two large facilities in Kumasi and Accra, there are only small to medium scale slaughterhouses or slabs in Ghana with low number of animals slaughtered:

Less than 200 large animals (cattle) per month or less than 1000 goats and sheep per month.

The slaughterhouse in Accra is significantly less frequented than the one in Kumasi; accordingly the waste streams are lower. Since there is hardly any livestock farming in this region, this slaughterhouse remains significantly under-used in the long-term. This is due to the fact that all small animals, up to the size of a goat, sheep or pig will be slaughtered at home and due to the location of the slaughtering houses and slabs mainly right in the centres of the cities, which makes them not well accessible for cattle transportation.

The Ministry of Food and Agriculture (MoFA) noted with concern that the health of the general public was in danger because of the poor sanitary conditions at some abattoirs and meat processing plants in Ghana. The system concept and the design of the abattoirs in Kumasi and Accra are quite improved. Nevertheless, the state of both abattoirs is insufficient and due to lack of waste management and effluent treatment in unhygienic conditions (Ulrike, D. et al., 2014).

Furthermore the burden of extremely high energy costs is challenging the economical situation of abattoirs, making it impossible for them to generate profit. Hence, abattoirs do not have the financial strength to consider biogas projects with high initial investments.

3.1.3. Biogas sector in Ghana

In general, agricultural industries show the greatest potential in biogas in Ghana with a relevant potential due to significant feedstock available for biogas generation, in particular, agro-industrial residues but also animal and agricultural residues. Potential clients for biogas implementation are big food processing companies that have a need to find cost-effective solutions to biodegradable waste disposal, such as oil palm mills, cocoa processing companies, fruit processors, starch production companies, breweries and abattoirs (Ulrike, D. et al., 2014).

The biggest driver for biogas installation next to sanitation aspects however is the energy recovery from biogas systems. The biogas can be used to generate different forms of energy as heat, cooling and power. At present, energy consumption at industries is a big part of the production cost. This is because there is usually significantly high consumption of fossil fuels such as diesel, Residual Fuel Oil (RFO) or even Liquefied Petroleum Gas (LPG) due to the operation of a mainly old, inefficient steam boiler, generators or high consumption of power from the grid (Ulrike, D. et al., 2014).

Table 3.1: Fuel prices in Ghana

Fuel in GHS	RFO per litre	Diesel per litre	LPG per kg	Power Load Tariff Medium Voltage			Power Non-residential Tariff			
				Capacity Charge (KVA/month)	Energy Charge (/kWh)	Service Charge (/month)	1 – 300 units	301 – 600 units	601 + units	Service Charge (/month)
2011	0.84	1.77	1.36	13.2252	0.2039	15.4294	0.2527	0.2689	0.4243	2.760
2013 (October)	1.1	2.2	2.30	23.6598	0.3648	27.6032	0.4521	0.4811	0.7591	4.929

In October 2013, the Public Utility Regulatory Commission (PURC), as the body mandated to set the tariffs for electricity and water has approved adjustments in water and electricity tariffs. The current electricity tariffs amount to an increase of up to 80% (Ulrike, D. et al., 2014). This development together with unstable line-side power supply has adverse repercussions on businesses and is challenging Ghana as a whole.

Every energy-intensive industry is facing severe problems in terms of energy costs and fears the shutdown of production. The power demand currently relies on the national power grid and diesel fired generators as well as on RFO or LPG for heat and steam production. Most of the companies will look for options to replace this high-cost energy forms and to become more independent by using renewable energy technologies.

Biogas systems can offer an optimized interplay of all energy forms through an integrated concept by combined generation of electrical power, heat and cooling. The technical circumstances allow landfill gas capturing and use in certain locations in Ghana. The organic content of the deposited waste is low, but there are sufficient gas building conditions; the water content in most of the landfills is sufficient for a stable anaerobic organic process. The old dumpsites and dumpsites in rural areas are often unusable for degasification due to small deposited waste amounts, insufficient filling period, fires at the dumpsite as well as little organic content caused by a high sorting level. There are still shortfalls in the nature and structure of the deposited waste. There are few disposal sites with sufficient waste capacity and engineered filling area to be found (Ulrike, D. et al., 2014).

The following table presents the results of landfill gas prognosis: the potential maximum electricity output is calculated with respect to the medium gas production prognosis and specific parameters of a CHP plants (e.g. degree of efficiency 37%). Taking into consideration a minimum period of energy recovery of about four years, a plant capacity to be installed in CHP units is also assumed (Ulrike, D. et al., 2014).

Table 3.2: Energy potential of specific landfills in Ghana

	Daily dumping volumes in Mt	Maximum capacity (CHP) to be installed in $kW_{electric}$	Capacity (CHP) to be installed over a period of 4 years in $kW_{electric}$
Kumasi	1,000	2,400	1,200
Secondi -Takoradi	320	700	600
Tamale	240	1,200	800
Tema	2,200	7,000	6,000

Source: (Ulrike, D. et al., 2014).

3.3. General Description of Kumasi Abattoir

3.2.1. General company information

The Kumasi Abattoir Company is a publicly owned limited liability company. It was established as a company in 1993 and started operations in 1998. Its core business is the slaughtering of cattle, small ruminants (goats, sheep) and pigs, as a service to animal owners; cold storage of meat products; and the processing of meat into sausages, bacon, cooked ham, prime cuts, etc. The company owns three shops in Kumasi and sells its products door to door with its own meat trucks.

3.2.2. Site characteristic

Kumasi Abattoir is situated just south of the Kumasi ring way, at coordinates 6°39'36.3"N 1°36'16.6"W (see Figure 3.1). It is located immediately on the Kaase Industrial Area dual carriage road, a main road that branches from lake road.

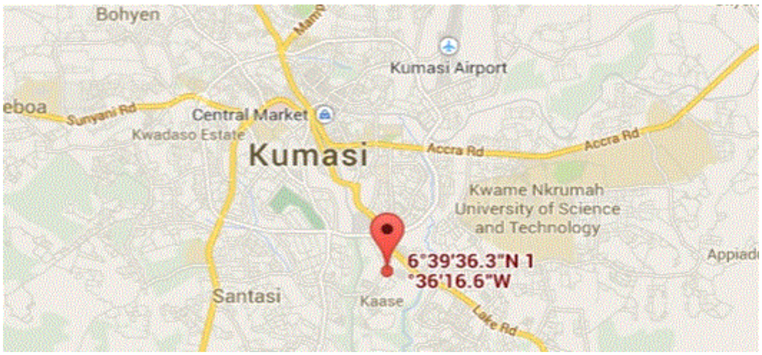


Figure 3.1 Situation of Kumasi Abattoir in town

The total area is approximately 7 hectares (17.5 acres) of which approx. half is occupied by the production area, the old wastewater treatment plant and the pond. Of the remainder, approximately half is in use as a market place and kraal, and the remainder is mostly open space of which parts are occupied by squatters, and parts are heavily littered. The production area is level but the other terrain slopes down in North-Northwest direction with an estimated slope of approximately 5%.

An area on the edge of the terrain next to the singeing plant is designated for the biogas plant (Figure 3.2). Installing the biogas plant on area nearer the production premises facilitate security and reduce the distance for transportation of wastes, effluent, gas and/or electricity.

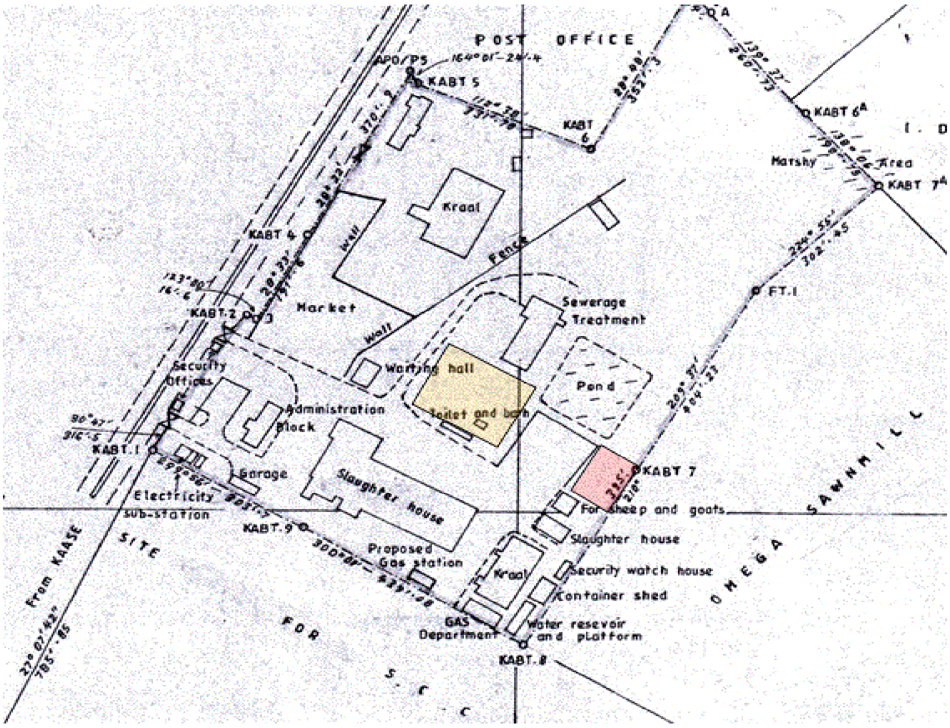


Figure 3.2 Map of Kumasi Abattoir terrain. The red area indicates the location for the biogas plant as proposed; the yellow area would be alternative location providing some more space.

Main climatic data for Kumasi is shown in Figure 3.3. The average annual temperature is 25.6°C, with monthly averages ranging between 24-27°C.

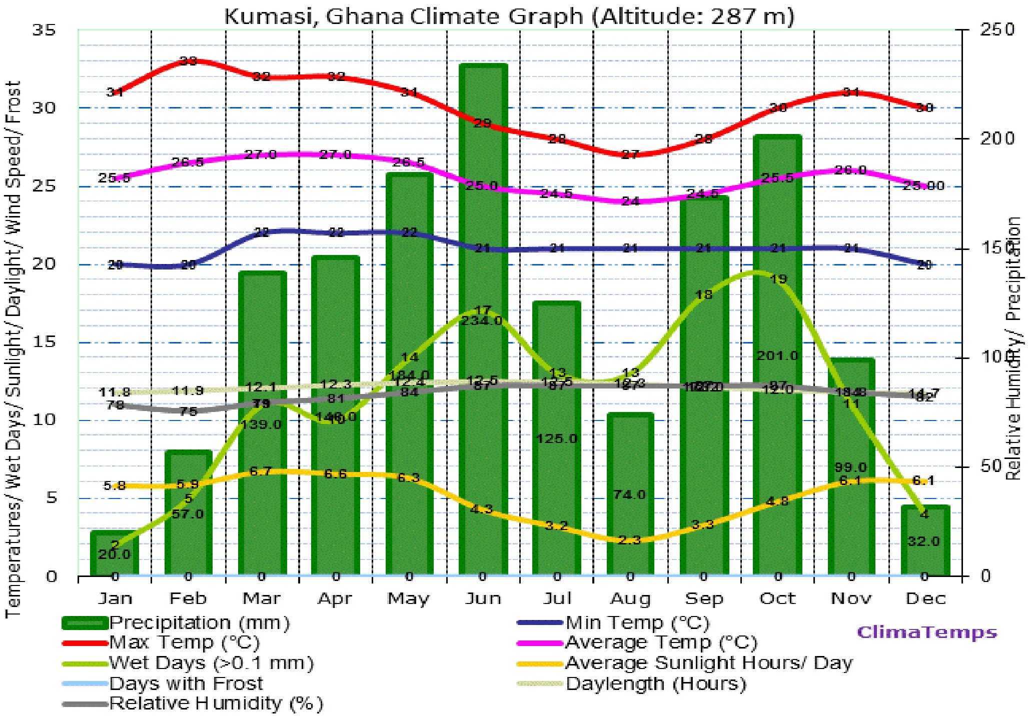


Figure 3.3 Average climatic data for Kumasi.

Source: http://www.kumasi.climatemps.com/graph.php

3.2.3. Operational characteristics

The Abattoir was originally fitted with three slaughtering lines: one for cattle, one for sheep and goats, and one for pigs. However, due to the large demand for cattle slaughtering, the sheep / goat line was transformed to a second cattle slaughtering line. The pig slaughtering line was decommissioned as the small number of pigs did not render it economical to use the line.

Figure 3.4 Cattle and Goats at Kumasi Abattoir.

Over all, the abattoir now has a slaughtering capacity of approximately 400 heads of cattle per day, 200 sheep or goats, plus 200 pigs.

Figure 3.5, below presents the actual numbers of animals slaughtered over the years 2011-2016; the data is included in Annex A.

- The abattoir slaughters on average some 241 heads of cattle per day, with an annual peak in December-January and a dip in the period March-June. This number includes more than 90% of all the cattle slaughtered in the Kumasi area, and on top of that considerable numbers from elsewhere (including Burkina Faso and Mali).
- Sheep and goats are slaughtered in considerably smaller numbers; on average some 134 heads per day. These animals are slaughtered in several other places; Kumasi Abattoir only slaughters some 20% of the animals slaughtered in the Kumasi area.
- The number of pigs slaughtered is again much smaller, on average 26 per day. Like sheep and goats, pigs are also slaughtered in other places.

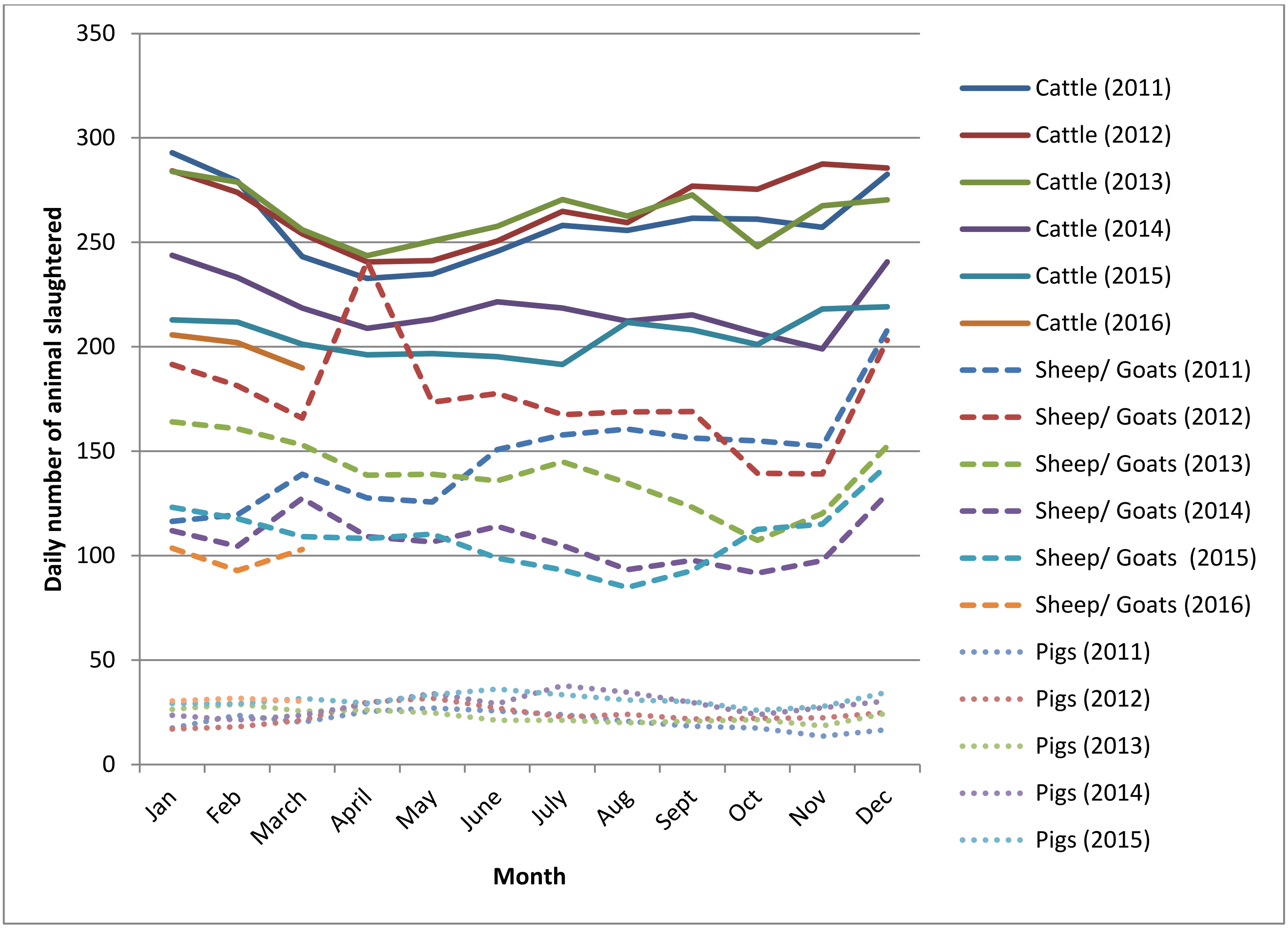


Figure 3.5 Average daily number of animals slaughtered at Kumasi Abattoir.

An analysis of daily numbers of animals slaughtered in 2013 shows that day-to-day variation is limited. Including seasonal variations, 94% of the days the number of slaughtered cattle is within +/-20% of the average. Variation is larger with pigs, goat and sheep: here some 50% of the days the numbers are within +/-20%.

Normal working hours at the Abattoir are from 06:00 to 14:00, usually 7 days per week. Note that the capacity utilisation of the Abattoir is mainly delimited by the number of animals that is offered for slaughtering each day, which has over the years been quite stable. There has been talk at the Kumasi Metropolitan Assembly of closing down the smaller slaughtering units ("slabs") in the area as a hygienic measure, which would then lead to an increase of sheep, goats and pigs offered for slaughtering at the Kumasi Abattoir. However, no concrete plans of this sort have been developed so far.

Slaughtering of cattle is done in two production lines, where the animals are subsequently stunned, slaughtered, bled, skinned, eviscerated, split and quartered. Intestines and carcasses are routinely inspected for signs of illness. The processing of a small number of cattle involves singeing as an important processing step. During this process, the hairs are burned off the hide of the slaughtered animals, using LPG burners. The animals are subsequently eviscerated and quartered. The numbers of animals singed each day varies, but most days (80%) it is within +/-20% of the average (30 cattle). See data on numbers of animals singed in Annex B; average number per month is 926 cattles. All parts of slaughtered animals are used, only blood and rumen content are rejected.

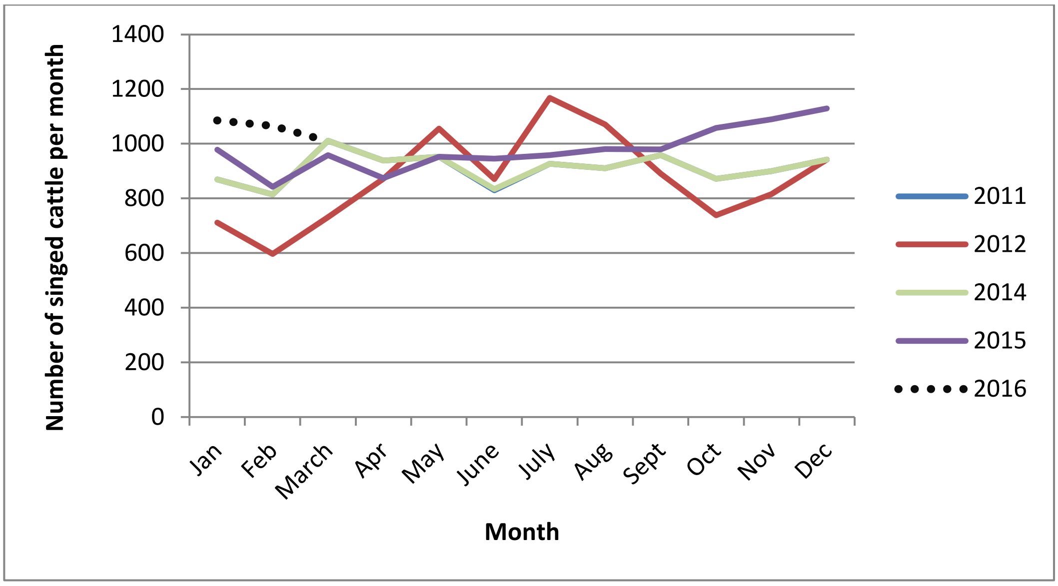


Figure 3.6 Number of monthly singed cattle

Water is not metered; it is stored in an underground water tank of 100,000 gallons (approx. 450 m^3) which is said to be sufficient for 2.5-3 days of operation. Daily water consumption thus estimated at 150-180 m^3/d. From the underground storage it is pumped into a 20,000 gallon (90 m^3) water tower and subsequently distributed over the site.

3.4. Wastes Production and Disposal

Annex C gives an overview of the main production steps and the related waste flows at the abattoir. Note that the figures are mainly based on estimates and averages, supported by spot measurements and data from literature.

3.4.1. Solid wastes

➢ ***Origin and composition***

The solid wastes produced at the abattoir comprises mainly (some 75%) of the solid rumen content of the slaughtered animals. The nature of this material varies, depending mainly on the time between grazing / drinking and slaughtering. Also, the material is different within the animal, as the material at the start of the digestive tract is more like food, and at the end more like dung. The solid waste contains furthermore smaller quantities of dung, bone dust, small meat fragments, and bile. Average moisture content is estimated at 15%, which corresponds to literature values (e.g. (Deublein & Steunhauser, 2011)). The exact composition is unknown but because of the large portion of rumen content it is likely to contain much grass like matter in various stages of decomposition.

By far most of the waste comes from cattle processing; this is due to the numbers slaughtered, but also due to the volume of the rumen content per animal. Note that (parts of) animals that are rejected by the inspection are treated separately from the other solid waste for sanitary reasons.

➢ ***Quantities***

A typical average solid waste production of 8 ton per day (8 ton /day) has been used for calculations in the biogas plant design in the UNIDO project which started in 2014 (UNIDO, 2014). This was later verified by some measurements done by (Poku, 2016), showing total quantities in the order of 6.5-7.5 ton/day at cattle production (see Annex D).

The indicated average daily volume of solid waste cross-checked with the average numbers of animals slaughtered and data on average quantities of rumen content from literature (e.g. (Janloo, et al., 1998)) show that the data can be considered consistent.

- ***Disposal***

At present, all solid waste is collected in steel containers with a capacity of approximate $6m^3$. The containers are transported to a landfill site at a distance of some 6 km from the abattoir. Typically, 2-3 trips to the landfill site are made each day, but containers may not be fully loaded. Costs for disposal, including fuel, truck maintenance and personnel, is approx. 10 GHS per tonne (2,500 GHS/month).

3.4.2. Liquid wastes

- ***Origin and composition***

Liquid waste (waste water) is produced in all the different slaughtering sections of the abattoir. It consists mainly of water, part of the blood produced, liquid rumen content, bone dust, and hair. A series of samples from the different abattoir sections, and from the combined waste water stream, have been analysed at Kwame Nkrumah University of Science and Technology (KNUST) for physiochemical properties and occurrence of pathogens (see the results in Annex E).

- ***Quantities***

According to abattoir staff, the average daily waste water production is approx.180 m^3/day. The origin is not entirely clear but it is consistent with daily water consumption (approx. 150-180 m^3/day), of which most ends up in the waste water. Note that the water which is used for cleaning after processing comprises some small quantities of soap, but lower amounts of (organic) solids. As such it could optionally be disregarded for further treatment. On the basis of the flow measurements and cleaning hours, the quantity is estimated at 15% of the total wastewater volume, or some 27 m^3. There has also been an assessment of the quantities of blood produced at the abattoir. On the basis of literature values for quantities of blood per animal, and the numbers of animals slaughtered, typical daily blood production would be in the order of 4 t/day.

- ***Disposal***

In the past, the abattoir used to operate an aerobic pond in which their waste water was treated. However, the system broke down, and as its load / energy consumption was exorbitant it has not been put back in operation. Waste water is currently dumped in a small stream at the edge of the abattoir terrain. This causes considerable environmental problems and is a major nuisance and a potential health threat to surrounding communities. As such, treating their waste water has a high priority for the abattoir.

3.5. Energy demand at Kumasi Abattoir

3.4.1. Electricity demand

➢ ***Total load and electricity consumption***

Figure 3.5 and Figure 3.6 show the monthly electricity consumption in kilowatt-hour (kWh) and maximum apparent load during the month (kVA) in the period 2011-2016.

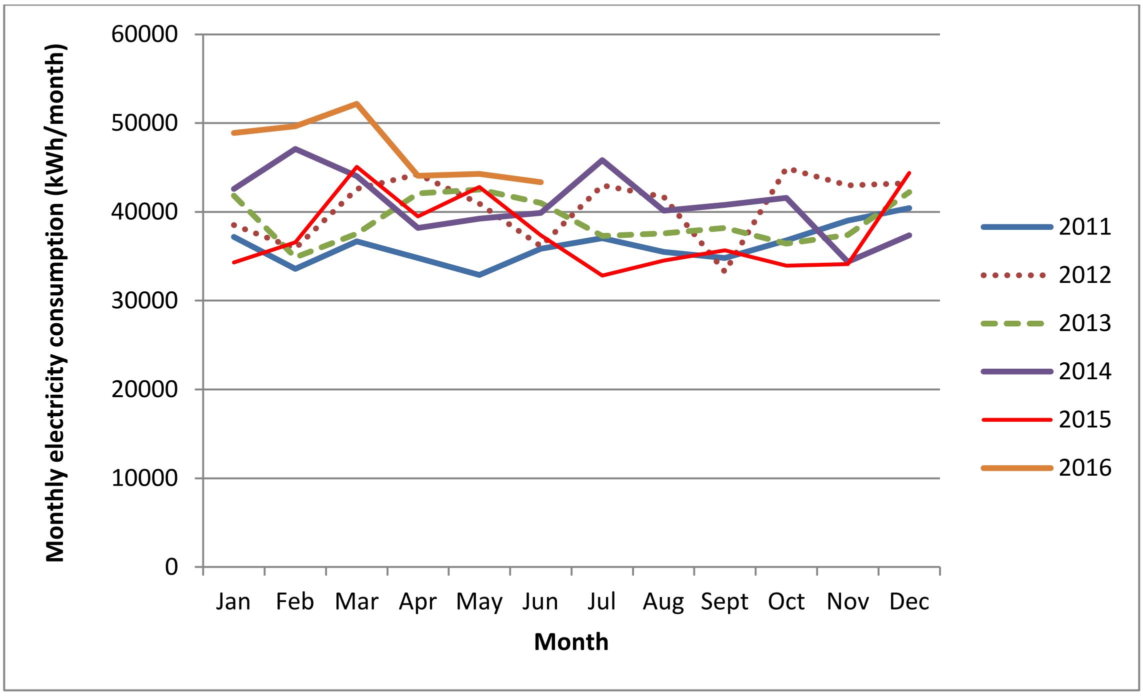


Figure 3.7 Monthly electricity consumption in each month in the period 2011-2016

Average monthly electricity consumption during this period is 39,627 kWh/month (1,321 kWh/d), varying between 32,814-52,161 kWh/month (1,094-1,739 kWh/d) (see Annex F). Note that this does not yet include electricity produced with the abattoir's backup generator, which adds approximately 16 kWh/d or (1%) to the total electricity.

Data on day-to-day variation of consumption is not available, but seen the consistent day-to-day routine of operation of the abattoir, fluctuations are expected to be limited.

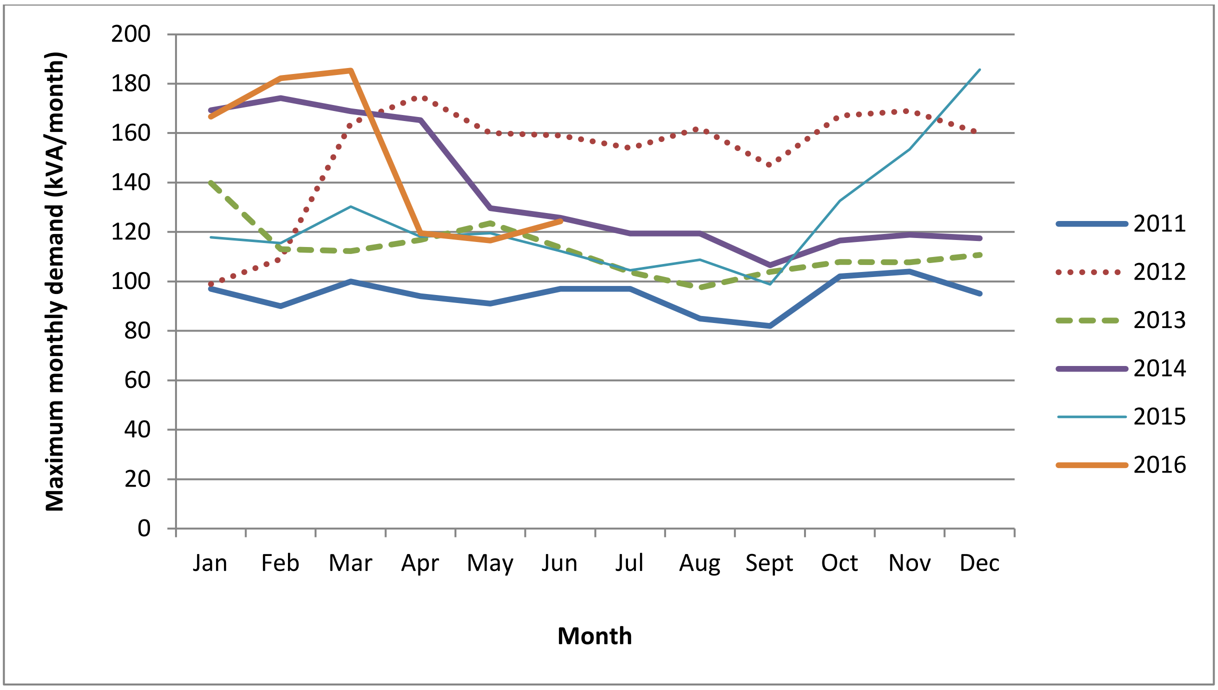


Figure 3.8 Maximum load (kVA) for each month in the period 2011-2013. Note that in the period of February 2012 – January 2013 the power factor correction equipment was not operational, which resulted in high values of maximum kVA.

Average maximum load of the abattoir is approx. 126 kVA, varying between 82 and 186 kVA. Under normal circumstances, power factor is kept above 0.95 by automatically controlled correction equipment. Figure 3.6 does not show a seasonal pattern of maximum occurring loads.

➢ ***Load and consumption of departments and installations***

Table 3.3 below shows an overview of electrical equipment in the production and administration departments, as well as estimated maximum loads and average daily consumption rates. The data is based on actual measurements and interviews with staff on rate of use of the equipment.

Table 3.3: Description of electrical loads and typical consumption per department

Unit / equipment	Description	Average daily consumption kWh/d	%	Average max demand (kVA)
Daily avg consumption	**Full abattoir**	**1,288**	**100%**	**102**
Production dept		**1,112**	**86%**	**80**
Chillers	5 units of which 4 are operational; 2 chilling rooms and 2 refrigeration rooms. One single system accounting for more than half the cooling energy	806	62%	
Water pumping	Four boreholes with submersible pumps (1.5-2kW); one water booster (15 kW)	206	16%	
Other	Hoisters, bone saws, mincers, air conditioners, lighting.	100	8%	
Administration		**178**	**14%**	**22**
Air-conditioning	10 offices with 1.5 kW air conditioners	150	12%	
Lighting and others	10 offices with fluorescent tube lighting and computers	28	2%	

Source: (UNIDO, 2014)

➢ ***Electricity supply***

Electricity is being supplied by the Electricity Company of Ghana Ltd (ECG). An 800 kVA transformer is installed on-site. During blackouts, the abattoir uses its 394 kVA diesel generator. In 2013, the generator operated for approx. 106 hours. Electricity production with the generator is not metered but on the basis of the running hours, it is assumed to be approx. 469 kWh/month or 16 kWh/d, which is just over 1% of the total electricity consumed.

- ***Electricity costs***

The tariff structure for grid connected electricity as of 01/12/2013 is as follows:

Table 3.4: Electricity rates of Electricity Company of Ghana Ltd (31/01/2014)

Charge	Rate
Unit charge	0.4002 GHS/kWh
Maximum demand charge	25.962 GHS/kVA
Power factor surcharge	2400 GHS / pf under 0.9
Value Added Tax (VAT)	12.5%
National Health Insurance Levy (NHIL)	2.5%
Public Lighting + Government Levy	0.0003 GHS/kWh
Service charge	30.29 GHS/month

Source: (UNIDO, 2014)

Note that these costs do not include costs of running the backup generator during power interruptions. These costs are approx. 3.55 GHS/kWh (1,662 GHS/month) including fuel, maintenance and repairs.

The electricity rates have been increasing rapidly over the past two years. For example, in October 2013 there was an increase of 79%, followed by another 10% increase three months later.

3.4.2. Fuel demand

- ***LPG***

The main fuel demand by far at Kumasi Abattoir is LPG which is used for singeing. Singeing is done manually with LPG burners, of which seven are currently installed. Analysis of the fuel purchases over the past 4 years shows an average daily LPG consumption of 267 kg/d (data in Annex G). There is some variation in daily numbers of animals singed, and thus in the quantities of LPG consumed; analysis of the records show that on the majority of days (approx. 80%), the consumption was higher than +/-20% from the average.

Figure 3.9 Singeing at KACL

LPG for singeing is bought in bulk. There are six LPG tanks installed, each with a capacity of 1682 kg. Price level is at this moment 3.42 GHS/kg. Prices developments over the past 14 months have been rather erratic: early 2013 it went up from 1.30 to 1.95 GHS/kg, after which it was frequently adjusted upwards. Not including the initial hike, the average annual price increase has been some 38% over the last year. At the average daily LPG consumption, the current monthly fuel bill amounts to GHS 28,422.

In addition to singeing, a small quantity of LPG is used at the marketing department for heating water for cooking ham. The quantity used is approx. 50 kg/month.

- ***Diesel***

Some limited quantities of diesel are used in the Abattoir's backup generator. In 2013 it concerned a volume of some 5,400 litres for the production of an estimated 5,625 kWh[1]. The extent to which this fuel can be replaced depends on the chosen (main) biogas application:

If electricity would be produced at a rate where the Abattoir would be autonomous of the grid, there would normally not be a need for a backup generator. All diesel fuel would then be replaced.

[1] This is some 1.04 kWh/l consumed, which is extremely inefficient

If electricity would be produced at a lower rate (e.g. covering base load only), the Abattoir would still be using grid power, which would require regular use of the diesel generator during blackouts. In this case biogas could be used to reduce the diesel consumption (dual fuel mode).

If the biogas would be used for LPG substitution, the biogas could be used in the generator during blackouts, reducing diesel consumption. However, this would then reduce the amount of gas available for singeing which would then increase LPG consumption.

The diesel price is approx. 3.40 GHS/l (July 2016). Prices of diesel in GHS have increased with approx. 16% over the past 9 months, which corresponds to an annual growth of 22%. Note that the prices in USD have been rather stable, or even slightly reducing, over this period.

- ***Other fuels***

Small quantities of fuelwood are used for smoking sausages at the marketing department. As the wood smoke is crucial, this fuel source cannot be replaced with biogas and was therefore disregarded.

3.4.3. Heat demand

There is at the moment virtually no heat demand other than the heat for singeing which is considered above (in LPG demand). There is limited use of heat for cooking of ham, which currently consumes less than 2 kg of LPG per day.

The Abattoir’s decommissioned hog line does feature a hot water bath (60 °C) for the removal of hair. No information was available on its energy usage.

Future potential use of (waste) heat in an absorption cooling system could be an option, for example in combination with the waste heat from a generator. However, due to the low temperature of this heat (typically some 60-70 °C) its efficiency might be limited. The economics would have to be assessed before recommending such a system.

4

RESEARCH METHODOLOGY

4.1. Data Collection

The investigative approach to data collection was adopted in combination with desk research (secondary data collection) and other strategies. The main abattoir in Kumasi was selected for this study.

- **Number of animal slaughtered**

Data on the number of ruminants (cattle, goats and sheep) slaughtered daily was obtained from records on abattoir operations between 2013 and 2016.

- **Energy demand**

The Kumasi Abattoir has a dashboard on the Electricity Company Ghana (ECG) website dedicated to access to the automatic meter readings. Data on electrical consumption were extracted from this source. Data on LPG gas consumption was obtained from records over 2013 to 2016.

Additional information was collected through interviews with key informants (engineering department) using interview schedule.

- **Waste production**

Data on waste produced daily from slaughtering (cattle, goats and sheep) was collected (through participant observation) within 3 days. This was backed with data obtained from estimations from the literature.

4.2. Data Reliability

Data on energy demand may be considered reliable as it is based on actual consumption records (electricity bills, LPG bills) and supported by measurements during field work. Only day-to-day variations in electricity demand could not be confirmed, but this is expected to be limited due to the consistency of day-to-day production at the abattoir.

Data on waste quantities and bioenergy production may be subject to a limited certainty because of estimations.

4.3. Determination of Slaughterhouse Wastes Quantities at KACL

The slaughtering waste streams considered for this study were solid rumen content (paunch) and blood produced from slaughtered livestock at the Kumasi Abattoir. Bone dust, hair were not included due to their low biodegradability. They are usually avoided in the digestion as they may cause clogging, and does not add to biogas production.

Waste material generated from abattoir operations was estimated based on calculations (Table 4.1) by Ulrike et al. (2009).

Table 4.1: Data for estimating abattoir effluent.

City / area	Type of animal	Content per animal	
		Paunch kg	Blood kg
Kumasi Abattoir	Cattle	12	15,8
	Sheep	1,6	2,1
	Goats	1,6	2,1
	Pigs	4,4	5,8

Source: Ulrike et al. (2009).

4.4. Determination of Potential Methane Yield

Average data for biogas yields are defined as 60 m^3/t paunch content with 55% methane and 37 m^3/t blood with 60% methane given by Ulrike, et al. (2014). These authors calculated this theoretical biogas potential according to:

- ✓ Total annual amounts of available organic material (feedstock in t/a) based on production figures of the abattoir material statistics and other figures from the Ghanaian Ministry of Food and Agriculture (MoFA)
- ✓ Biogas potential for the substrate (m^3/t VS) based on dry matter (DM) content of the residue (% fresh matter, FM) and volatile solids (VS) content (% DM)
- ✓ Methane content in the biogas (%)

$$\text{Total daily CH4 produced from Paunch } (m^3/\text{ day}) = \text{ Total paunch } (t/\text{ day}) \text{ X } 60m^3/t \text{ X } 55\%$$

$$\text{Total daily CH4 produced from Blood } (m^3/\text{ day}) = \text{ Total blood } (t/\text{ day}) \text{ X } 37m^3/t \text{ X } 60\%$$

Neither of the energy potentials calculated considers the fact that future biogas plants use part of the energy produced. The energy potentials are given as total energy producible by conversion of produced methane taking into account the energy content of methane. The further conversion efficiency from methane into heat and electricity is depending on the technical specifications of the CHP generation (in the present study; 41% for electricity and 49% for heat).

The equivalent amount of LPG obtained from the daily Methane production is calculated based on the conversion factor from literature (Ministry of Finance Tax Information Sheet, 2013) in the following Table 4.10.

Table 4.2: Conversion factor for gas

CH4	Petroleum Coke	Propane
1 gigajoule (GJ) = 26.137 cubic meters (m^3)		1 litre = 0.02559 gigajoules (GJ) = 1.12 pounds
1 kilogram (kg) = 1.406 cubic meters (m^3)	1 tonne = 833.75 litres	1 pound = 0.8929 litres
1 gigajoule (GJ) = 26,137 litres		1 cubic meter (m^3) = 1,000 litres
		1 gigajoule (GJ)= 39.071657 litres

Source: (Ministry of Finance Tax Information Sheet, 2013)

4.5. Net Energy Analysis Methodology

The potential energy recovery within the confines of the full scale abattoir is determined through a net energy analysis. A net energy analysis is the examination of how much energy is available for utilisation after correcting for how much of that potential energy is exhausted in generating a unit of the energy in question. The principal aims are to determine the energy input for the production of biogas from the slaughterhouse waste stream, and determine the level of energy recovery within the abattoir through the combustion of the raw biogas into electricity and/or its direct use to replace the LPG consumption for singeing slaughtered animals.

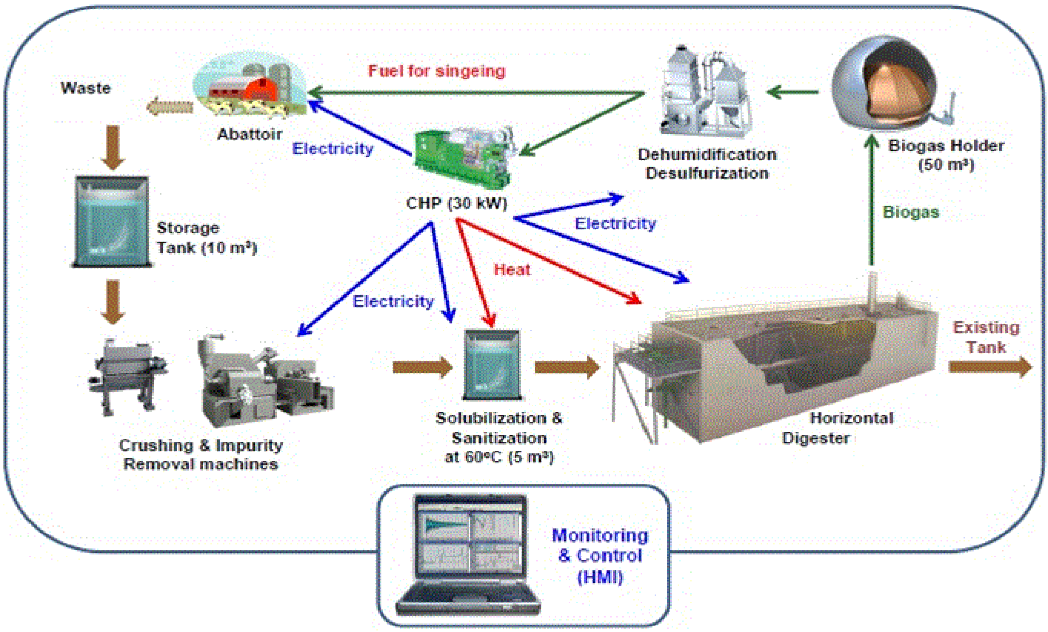


Figure 4.1 Process flow scheme for the biogas plant

Source: (UNIDO, 2014)

4.5.1. Energy input for biogas production

On exiting the slaughtering facility the organic waste streams typically exist in a state that is non-conforming to efficient biogas production i.e. large solid particles, high heterogeneity, etc. As such the initial step in the system analysed is the feedstock crusher and separator of the waste streams. The crusher unit is based on a heavy duty grinder, suitable for bulk reduction and proven successful in the maceration and reduction of organic waste particle size, to offer a more homogeneous mixture in active biogas facilities.

The proposed plant by UNIDO has the following main components:

- ✓ Feedstock crusher and separator and feedstock storage
- ✓ Feedstock solubilisation and sanitation unit.
- ✓ Main digester unit.
- ✓ Biogas purification unit
- ✓ Biogas storage unit
- ✓ Generator set

Energy consumption of the biogas plant concerns mainly electricity for agitators (39%), for crushing and separation (26%) and for biogas treatment (29%). The total energy is estimated at 180 kWh/day, according to the UNIDO's final report of proposed biogas plant (UNIDO, 2014).

4.5.2. Energy demand at KACL

The energy consumption of slaughtering facilities vary depending on the technologies utilised, energy/waste saving schemes employed, scale as well as the level of processing i.e. whole carcass chilled/frozen, finer cuts deboned chilled/frozen. Within the Kumasi Abattoir, the collected data over 2011-2016 allow the calculation of the average energy demand per day:

- **Average daily electricity demand at KACL**

The electricity bills give the total amount of Kilowatt-hours consumed in every single month from 2011 up to June 2016. By dividing the total consumption of the month by the number of days in that month, it gives the average electricity consumed per day in that month (kWh/day). After getting all the average consumptions per day from January 2011 to June 2016, it is then possible to calculate the average daily electricity demand at the Kumasi Abattoir using Excel function.

$$\text{Average electricity consumed per day in each month} = \frac{\textit{Monthly electricity consumption}\ (\text{kWh})}{\text{Number of } \textit{days in that month}\ (\text{days})}$$

Average daily electricity demand = Mean funct. ∫ (all average electricity consumed per day

- **Mean daily LPG demand at KACL**

The mean daily LPG demand at KACL is calculated by following the same approach used for calculating the mean daily electricity demand.

$$\text{Average LPG consumed per day in each month} = \frac{\textit{Monthly LPG consumption}\ (\text{kg})}{\text{Number of } \textit{days in that month}\ (\text{days})}$$

Average daily LPG demand = Mean funct. ∫ (all average LPG consumed per day)

RESULTS AND DISCUSSION

5.1. Determination of Slaughterhouse Wastes Quantities at KACL

The computations based on the waste production per head of animal given by Ulrike et al. (2014) give a total daily waste production estimated nearly 7 t/day, at Kumasi Abattoir.

Table 5.1: Daily waste produced at KACL from cattle and Sheep/goats slaughtering

	Average number slaughtered per day	**Paunch kg**	**Blood kg**
Cow	241	2,892	3,808
Goat/sheep	134	214	281
Pigs	26	114.4	150.8
	Waste produced ton / day	3 t/day	4 t/day
	Total daily waste produced	**7 t/day**	

5.2 Determination of Possible Energy production from Waste at KACL

From the Average data for biogas yields defined as 60 m^3/t paunch content with 55% methane and 37 m^3/t blood with 60% methane given by Ulrike, et al. (2014), the following Table 5.2 shows the biogas and methane possible production per day from the plant.

Table 5.2: Daily produced methane at KACL

	Methane from Paunch	Methane from Blood	Total potential energy per day
CH4 (m^3/day)	106	94	200

The theoretical biogas potential from Ulrike, et al. (2014) leads to a total daily methane production of 200 m^3 of CH4; which is close to 202 m^3 of CH4 from the UNIDO estimated daily methane production. The UNIDO report on the designed biogas plant gives that estimate, based on the results of fermentation analysis and physicochemical properties of the abattoir sample (Annex H).

- **Daily corresponding possible electricity production**

The utilisation pathway consisted of the combustion of the raw biogas with a Lower Heating Value (LHV) of 37 MJ/m^3 CH4 in a CHP unit with a total net efficiency of 90%, 41% generated as electricity and 49% as heat. The recovered electrical energy is then fed back into the abattoir and the biogas plant, while thermal energy supplies the biogas plant heat need; as showed in the process flow scheme for the biogas plant (Figure 4.1).

Table 5.3: Daily electricity possible production

	Result	Unit
Daily Methane (CH4) production	200.41	m^3/day
Corresponding energy per day (at Lower Heating Value LHV equals to 37 MJ /m^3 CH4)	7,415	MJ/day
	2,060	KWh/day
Electricity production potential per day (After 41% of CHP Operation)	845	KWh_{Elect}/day
Heat production potential per day (After 49% of CHP Operation)	1,009	KWh_{Therm}/day

➢ **Daily corresponding equivalent LPG production**

From the daily Methane production, conversion to equivalent amount of LPG production gives 213 kg/day.

Table 5.4: Possible corresponding daily LPG production

	Result	Unit
Daily Methane (CH4) production	200.41	m^3/day
Equivalent CH4 in kilograms	143	kg/day
LPG production per day	213	kg/day

5.2. Energy demand at KACL

➢ The average daily electricity demand, calculated from monthly records, is equal to 1305 kWh/day.

➢ The average daily LPG consumed is equal to 456 kg/day.

5.3. Net Energy Analysis

By converting the total methane produced into electricity to supply the slaughtering facility a self sufficiency degree of 57% (possible percentage of replacement) could be attained in term of electricity need.

Whereas when using the total methane produced to supply the gas need for singeing at the slaughtering facility, a self-sufficiency degree of 47% (possible percentage of replacement) could be attained in term of electricity need.

Table 5.5: Net energy analysis of biogas produced from annual available feedstock from slaughtering facility combusted in a CHP unit.

Gross energy production	**200.41 m^3/day (CH4)**
Corresponding equivalent LPG produced	**213 kg/day**
Net energy production from CHP unit	
Electricity @ 41% efficiency	845 kWh_{elec}
Thermal @ 49% efficiency	1,009 kWh_{therm}
External electricity input at biogas facility	**180 kWh/day**
Energy demand of Abattoir	
Electricity consumed at abattoir	**1,305 kWh/day**
LPG consumed at abattoir	**456 kg/day**
Potential energy substitution	
Potential electricity substitution (Amount left to be supplied by the public grid is [(1,305 + 180) - 845] = 640 $kWh_{elec/}$day = 43%)	**57%**
Potential LPG substitution (Amount left to be purchased is (456 - 213) = 243 kg/day = 53%)	**47%**

5.4. Cost Saved from Energy Recovery

The bills of electricity and LPG consumption at Kumasi Abattoir indicate that an average cost of 0.305 GHS/kWh of electricity and 1.889 GHS/kg of LPG is spent by the abattoir every day. This leads to 398 GHS/day for electricity and 861 GHS/day for LPG. Besides, the Kumasi Abattoir spends 32 GHS/day as cost for waste paunch disposal (10 GHS/kg).

This result to a total amount of 1,291 GHS/day spent by the abattoir for daily energy expenses and waste disposal.

- By recovery of electricity from the biogas plant, a saving of 18% of the total daily expense can be made (new daily expense equal to 1056 GHS/day).
- By recovery of methane from the biogas plant for use in singeing, a saving of 29% of the total daily expense can be made (new daily expense equal to 911 GHS/day).
- The biogas plant allows cancelling the waste disposal cost and even can lead to some more income generation if the effluents fertilizer is sold to farmers.

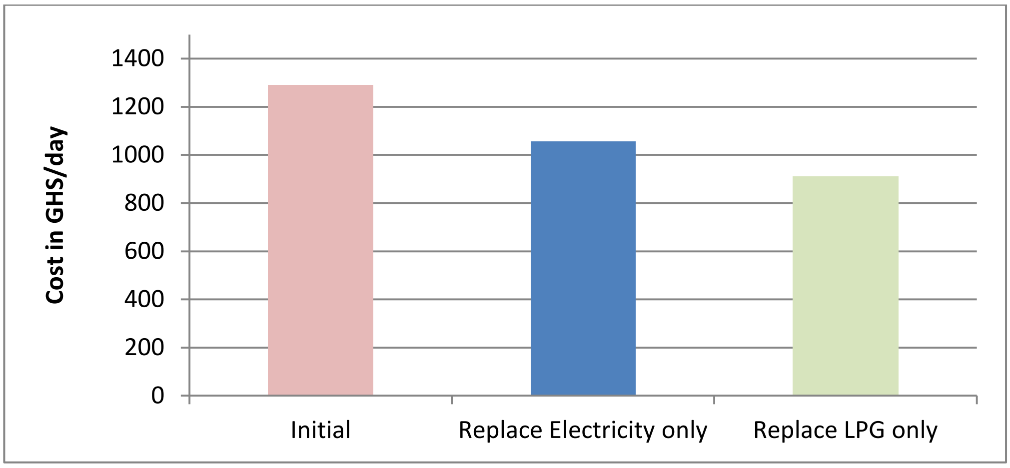


Figure 5.1 Daily cost expense at KACL after energy recovery

6

RECOMMENDATION

Considering the results in the energy recovery from the future biogas plant (currently under construction) at Kumasi Abattoir, a first recommendation would be to use the generated methane for singeing the animals as the resulting daily expense would be less compared to that of replacing with electricity. There will be a need for adaptation or replacement of the burners used for singeing, as the gas flow and the ratio of gas to combustion air is different for LPG and biogas. It is recommended to keep the existing burners operational, and install 6-8 burners using biogas.

The following recommendations are strongly suggested towards better energy self-sufficiency at the Kumasi Abattoir.

6.1. Use of solid waste at KACL

As seen in the result of potential methane yield from the waste, the solid waste paunch gives more methane yield than blood. Therefore it is recommended to focus on using the solid waste components as much as possible, as this will maximise biogas production.

There is a holding pen for keeping the animals before slaughter, which holds about three days slaughter capacity. Even though the cattle are normally sent out to graze and brought back again, substantial amount of dung is always available to be added as feedstock for the digester.

6.2. Energy Efficiency Measures

Adequate energy efficiency measures and practices are the driving force to attain the minimum energy utilization.

- **Efficient Electrical Appliances Installation**

Currently, the buildings (administration and slaughter building) at Kumasi Abattoir are powered by old incandescent bulbs and high energy consuming air-conditioners. It is recommended to replace the bulbs by new fluorescent (CFL) bulbs which are much more efficient and long lasting. Air-conditioners should be replaced by more efficient ones.

- **Power factor correction**

Although not strictly an energy efficiency measure, power factor correction will result in considerable cost savings. There is power factor correction equipment present at the abattoir, which broke down in December 2013. It is highly recommended to give high priority to its repair. On a typical electricity bill this would be GHS 2,147 (plus GHS 185 VAT), a reduction of 12%.

- **Cooling systems**

As indicated above, cooling systems account for more than 60% of total electricity consumption, so any improvements here could have a great impact on total electricity consumption. As a low-investment measure, it is recommended to refurbish the insulation of all coolant pipes, as it is missing or damaged on most of the pipes that are visible on the outside. A further step could be to replace compressors, as most are more than 20 years old. This should start with the compressor that drives the main cold room (compressor 40), which in itself accounts for more some 35% of the total electricity consumption of the Abattoir.

It is difficult to quantify the potential savings of these measures, as most benchmarks are based on European or American systems, which limits their applicability in tropical areas. These systems have typical consumption of 30-50 kWh/m^3 cold space/year, against some 250 $kWh/m^3/a$ at Kumasi Abattoir. Further, attributing the losses and potential savings to the different parts in the system would require further study.

- **Diesel backup system**

The fuel consumption of the diesel generator is extremely high (approx. 1.04 kWh/l, corresponding to an efficiency of 9%), even for a generator running at some 15-25% of its rated capacity. A newer, smaller set (e.g. 160-200 kVA) would consume 2-3 times less fuel. Especially now that blackouts occur more frequently, it may be worthwhile to consider investing in a new generator.

- **Monitoring**

It is recommended to start monitoring the energy consumption at the abattoir, as this generally leads to more rational energy usage, identifying efficiency opportunities, and provides a means of verifying energy saving measures.

- As it is now, there is only monthly consumption and maximum load demand data available from electricity bills. Meters are not accessible by Abattoir staff. It is recommended to install meters recording total consumption, administration building, water pumping / boosting, marketing department and cooling systems; in all six meters. The data should be recorded daily, and could be used for monitoring, dividing costs among the relevant production units, and possibly for setting consumption targets for the different units.
- Also, LPG consumption could be metered daily, and related to the daily number of animals singed.

6.3. Treatment of Waste Water

Regarding the physico-chemical properties of the wastewater and its considerable amount (8 tons) produced daily at the Kumasi Abattoir; it is recommended to incorporate a covered lagoon anaerobic waste water treatment system, to harness the energy potential of the waste water.

7

CONCLUSION

Operations at the Kumasi abattoir contribute significantly to meat supply in the big metropolitan city of Kumasi. However, there are serious problems with the waste disposal to the environment. The daily expenditure of the abattoir is increased by additional waste disposal cost and huge energy consumption due to poor energy efficiency measures. But for the wrong approach to waste management, the volume of effluent generated at the abattoir is a potential resource that can be utilised to enhance operations as well as serve other sectors of the economy.

For these reasons, UNIDO, Korean and Ghanaian governments have put efforts together to set up at the Kumasi Abattoir a high-tech biogas plant under the project “Supporting Green Industrial Development in Ghana: Biogas Technology and Business for Sustainable Growth”.

Anaerobic digestion of livestock solid waste by-products allows to supply heat and gas to the abattoir and to reduce the disposal-costs of the inevitable waste produced daily. The organic waste (paunch and blood) streams from the slaughtering facility proved to have high potential for energy recovery when treated as a single waste stream. By using the biogas from livestock by-products digestion, Kumasi Abattoir facility can cover most of its heat demand and LPG requirements.

The net energy analysis indicated that:

- ✓ Either 57% of the electrical demand (through combustion of the biogas in a CHP unit with electrical and thermal efficiencies of 41% and 49% respectively) of the abattoir could be met from the total energy generated by the biogas plant.
- ✓ Or 47% of the LPG demand of the abattoir could be met by direct use of the total produced gas from the biogas plant.

The replacement of LPG was recommended as this option led to higher return on daily expenditure.

Biogas is a viable alternative to fossil fuel based energy. Although the installation of combined heat and power plants (CHP units) are usually related to higher investment, they will replace high-cost fossil energy forms through the optimized interplay of all energy forms: power, heat and cooling energy.

Thus, viable biogas projects are mainly derived from sustainable and efficient energy production concepts that take into account all energy demands: steam, heat, cooling and power and find ways for economic fossil fuel substitution and enable better return on investment.

However in Ghana, there are barriers that limit the biogas sector. So far no suitable financing is available for biogas projects. Furthermore the lack of biogas specific technical, operational and management expertise is delaying the implementation and demonstration of successful biomass utilization for biogas plants on a large scale.

The Ghanaian entire animal production and meat processing system should build-up the scientific and technical knowledge so they can effectively implement best practices at all levels. The whole meat industry should have a strong interest to establish combined slaughter facility-biogas plant and not miss the opportunities to generate additional revenues by anaerobic digestion gas capture and energy recovery.

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ANNEX

Annex A: Animals slaughtered (from Kumasi Abattoir production records)

		Monthly animals slaughtered			Avg daily animals slaughtered		
		CATTLE	SHEEP/ GOATS	PIGS	CATTLE	SHEEP/ GOATS	PIGS
2011	Jan	9081	3607	539	293	116	17
	Feb	7822	3347	660	279	120	24
	March	7539	4308	627	243	139	20
	April	6983	3827	762	233	128	25
	May	7277	3896	836	235	126	27
	June	7371	4522	767	246	151	26
	July	8001	4889	737	258	158	24
	Aug	7926	4980	640	256	161	21
	Sept	7844	4690	549	261	156	18
	Oct	8094	4802	539	261	155	17
	Nov	7716	4573	408	257	152	14
	Dec	8759	6447	519	283	208	17
2012	Jan	8810	5937	526	284	192	17
	Feb	7942	5079	503	274	181	18
	March	7874	5142	655	254	166	21
	April	7219	7229	895	241	241	30
	May	7477	5378	986	241	173	32
	June	7521	5330	809	251	178	27
	July	8210	5193	706	265	168	23

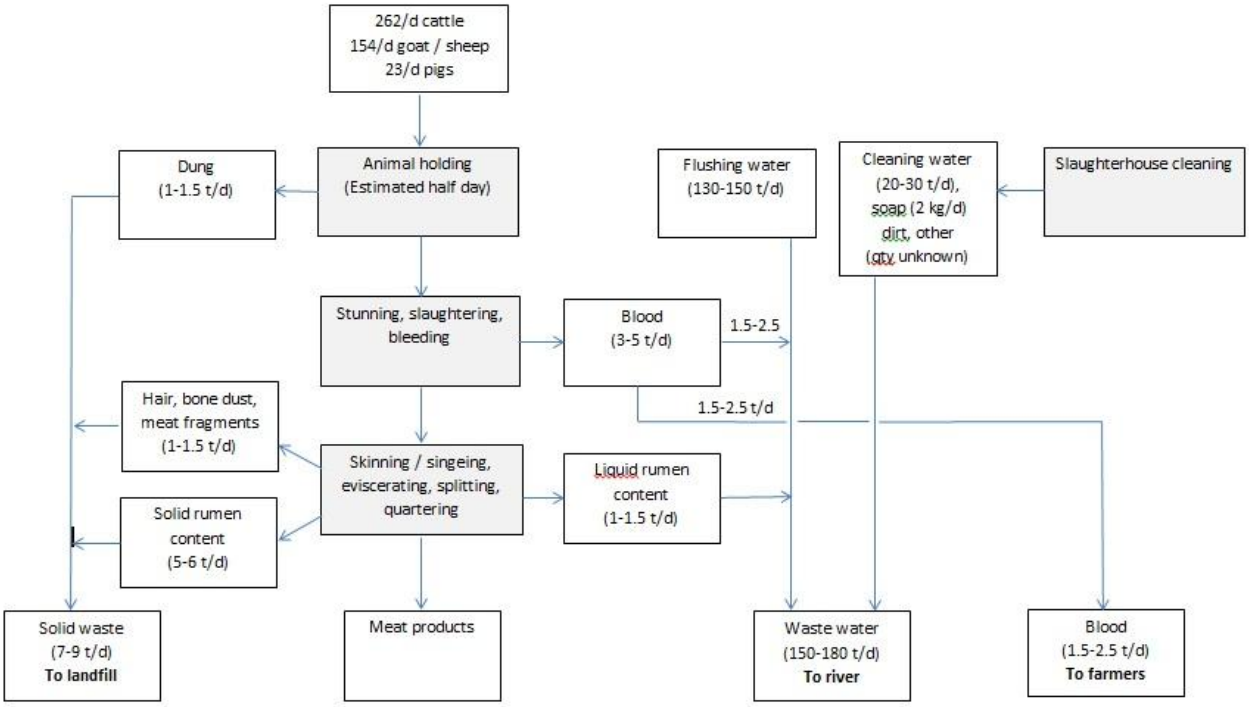
	Aug	8044	5235	743	259	169	24
	Sept	8306	5067	653	277	169	22
	Oct	8540	4320	683	275	139	22
	Nov	8625	4175	672	288	139	22
	Dec	8852	6297	773	286	203	25
2013	Jan	8802	5086	820	284	164	26
	Feb	7809	4503	811	279	161	29
	March	7935	4741	788	256	153	25
	April	7308	4154	783	244	138	26
	May	7771	4307	765	251	139	25
	June	7728	4076	636	258	136	21
	July	8385	4494	655	270	145	21
	Aug	8140	4177	618	263	135	20
	Sept	8180	3692	621	273	123	21
	Oct	7686	3328	667	248	107	22
	Nov	8024	3606	555	267	120	19
	Dec	8380	4723	764	270	152	25
2014	Jan	7557	3472	732	244	112	24
	Feb	6528	2927	597	233	105	21
	March	6774	3953	731	219	128	24
	April	6263	3275	872	209	109	29
	May	6608	3305	1055	213	107	34
	June	6644	3422	871	221	114	29
	July	6775	3251	1168	219	105	38
	Aug	6579	2891	1071	212	93	35

	Sept	6458	2934	891	215	98	30
	Oct	6400	2839	738	206	92	24
	Nov	5969	2927	816	199	98	27
	Dec	7462	4018	942	241	130	30
2015	Jan	6599	3817	905	213	123	29
	Feb	5929	3298	813	212	118	29
	March	6237	3384	981	201	109	32
	April	5885	3244	880	196	108	29
	May	6097	3418	1035	197	110	33
	June	5858	2962	1084	195	99	36
	July	5937	2887	1036	192	93	33
	Aug	6560	2629	956	212	85	31
	Sept	6242	2783	903	208	93	30
	Oct	6231	3487	803	201	112	26
	Nov	6543	3454	830	218	115	28
	Dec	6793	4441	1073	219	143	35
2016	Jan	6375	3212	942	206	104	30
	Feb	5655	2597	889	202	93	32
	March	5886	3193	940	190	103	30
		Monthly animals slaughtered			**Daily animals slaughtered**		
Minimum		5655	2597	408	190	85	14
AVERAGE		**7315**	**4082**	**781**	**241**	**134**	**26**
MAXIMUM		9081	7229	1168	293	241	38

Annex B: Animals singed (from Kumasi Abattoir production records)

	Number of Singed Cattle					
	2011	**2012**	**2013**	**2014**	**2015**	**2016**
January	869	712	No available data	869	978	1085
Feburary	814	597		814	843	1066
March	1011	731		1011	958	1009
April	938	872		938	874	
May	952	1055		952	953	
June	830	871		835	946	
July	927	1168		927	959	
August	911	1071		911	981	
September	959	891		959	980	
October	872	738		872	1058	
November	900	816		900	1090	
December	942	942		942	1129	
TOTAL	**10925**	**10464**		**10930**	**11749**	**3160**

Annex C: Main process steps and waste production at Kumasi Abattoir by the UNIDO report



Annex D: Daily Average Volume of Blood and Rumen content Produced at KACL by (Poku, 2016).

Date	Total CRC Produced per day (ton/d)	Total CB Produced per day (ton/d)	Number of Cattle Slaughtered per Day	Daily CRC per Cattle (L/c)	Daily CB per Cattle (L/c)	CB/CRC
9/6/2016	5.250	1.050	209	25.12	5.02	0.20
10/6/2016	5.850	1.155	232	25.22	4.98	0.20
11/6/2016	6	1.200	239	25.1	5.02	0.20
Average Value	5.7	1.135	227	25.15	5.01	0.20
Standard Deviation	397	77	16	0.10	0.02	0.00

Annex E: Physiochemical properties of mixed abattoir wastewater

Parameter	Unit	Range	Mean
pH[a]	-	8.4 - 9.4	9.03
Total Solids	g/L	23.61 - 24.25	24.01
Total Suspended Solids	g/L	14.84 - 15.53	15.25
Volatile Solids	g/L	11.96 - 12.36	12.16
COD[a]	mg/L	9,200 - 9,400	9,367
BOD[a]	mg/L	950 - 1,200	1,083
Protein	%	16.81 - 18.19	17.59
Lipids	%	2.18 - 2.37	2.28
Carbohydrates	%	12.11 - 14.06	12.96
Ash	%	1.36 - 1.64	1.53
Total Nitrogen	%	2.69 - 2.91	2.81
Total Carbon[a]	%	53 – 79	66.60
Total Dissolved Solids	mg/L	8.66 - 8.97	8.76

[a]Data originate from the original tests

Annex F: Electricity consumption of Kumasi Abattoir production

	Monthly electricity consumption (kWh/month)					
	2011	2012	2013	2014	2015	2016
Jan	37167	38525	41825	42603	34317	48895
Feb	33568	35886	34862	47087	36574	49641
Mar	36684	42601	37539	44022	45059	52161
Apr	34817	44240	42072	38205	39490	44057
May	32890	40917	42506	39244	42802	44273
Jun	35865	36143	41006	39869	37367	43341
Jul	37041	42972	37276	45819	32814	
Aug	35505	41686	37575	40120	34521	
Sept	34803	33270	38177	40800	35671	
Oct	36801	44930	36425	41568	33958	
Nov	39020	42972	37397	34370	34116	
Dec	40439	43232	42218	37378	44401	

	Monthly electricity consumption (kVA/month)					
	2011	2012	2013	2014	2015	2016
Jan	97	99	140	169	118	167
Feb	90	109	113	174	116	182
Mar	100	164	112	169	130	185
Apr	94	175	117	165	118	120
May	91	160	124	130	120	116
Jun	97	159	114	126	112	124
Jul	97	154	104	119	105	
Aug	85	162	97	119	109	
Sept	82	147	104	107	99	
Oct	102	167	108	117	133	
Nov	104	169	108	119	153	
Dec	95	160	111	117	186	

Annex G: LPG consumption at Kumasi Abattoir production

	Monthly LPG Gas consumption (kg/month)		
	2013	2014	2016
Jan	11774	9700	7160
Feb	10092	8280	6160
Mar	15226	7960	
Apr	8941	10480	
May	14669		
Jun	7690	6480	5040
Jul	9130	6370	9620
Aug	8890	8920	7060
Sept	9100	11140	
Oct	9820	8860	6480
Nov	9200	10380	4280
Dec	8820		8900

Date	Qty delivered kg	Price GHS/kg	Total bill GHS	Avg daily cons kg/d
14-12-12	3,364	1.3000	4,373	
21-12-12	6,374	1.3000	8,286	911
01-01-13	5,046	1.3000	6,560	459
16-01-13	6,728	1.3000	8,746	449
01-02-13	5,046	1.3000	6,560	315
14-02-13	5,046	1.3000	6,560	388
03-03-13	5,931	1.9500	11,565	349
14-03-13	5,046	1.9500	9,840	459
27-03-13	4,249	1.9500	8,286	327
17-04-13	3,364	1.9500	6,560	160
28-04-13	5,577	1.9500	10,875	507
03-05-13	3,060	1.8517	5,666	612
07-05-13	3,364	1.9500	6,560	841
14-05-13	1,682	1.9500	3,280	240

24-05-13	1,682	1.9500	3,280	168
26-05-13	4,881	1.8517	9,038	2,441
22-06-13	7,690	1.9032	14,636	285
18-07-13	9,130	2.0267	18,504	351
15-08-13	8,890	2.0988	18,658	318
23-09-13	9,100	2.2602	20,568	233
24-10-13	9,820	2.1524	21,137	317
05-11-13	9,200	2.1799	20,055	767
18-12-13	8,820	2.4232	21,373	205
13-01-14	9,700	2.4232	23,505	373
13-02-14	8,280	2.6432	21,886	267

Annex H1: Physicochemical Properties of Abattoir Sample (Mixed Streams)

Parameter	Unit	Range	Mean
pH	-	8.4 - 9.4	9.03
Temperature	°C	27.4 - 28.9	28.30
Alkalinity	mg/L	108 - 184	152.20
Total Solids	mg/L	22.8 - 24.0	23.54
Total Suspended Solids	mg/L	12.1 - 19.0	14.89
Volatile Solids	mg/L	5.4 - 6.52	5.82
COD	mg/L	9,200 - 9,400	9,366.67
BOD	mg/L	950 - 1,200	1,083.33
Protein	%	13.4 - 15.7	14.77
Lipids	%	3.6 - 4.0	3.87
Carbohydrates	%	23.9 - 25.4	24.75
Ash	%	2.4 - 3.6	3.03
Total Nitrogen	%	2.1 - 2.9	2.42
Total Carbon	%	53 - 79	66.60
Phosphate	mg/L	142 - 150	146.00
Nitrates	mg/L	10.4 - 26.5	20.37
Chlorides	mg/L	0.6 - 6.2	3.57
Potassium	mg/L	2.6 - 4.1	3.40
Calcium	mg/L	7.1 -9.2	8.19
Total Dissolved Solids	mg/L	7.5 - 8.7	8.07

Annex H2: Physicochemical Properties of Abattoir Samples (Individual Streams)

Parameters	Unit	Goat	Cattle	Blood	Rumen
pH	-	8.16	8.29	8.87	9.08
Temperature	°C	28.2	27.8	28.6	28.4
Alkalinity	mg/L	103	107	123	119
Total Solids	mg/L	22.01	22.11	20.81	23.02
Total Suspended Solids	mg/L	11.39	11.14	10.71	15.14
Volatile Solids	mg/L	4.46	4.74	3.96	5.52
COD	mg/L	2,600	7,600	13,300	34,000
BOD	mg/L	900	950	9,310	18,800
Protein	%	16.26	16.58	11.74	9.86
Lipids	%	3.06	3.26	2.94	2.23
Carbohydrates	%	22.37	22.91	25.59	27.46
Ash	%	2.46	2.64	2.11	3.29
Total Nitrogen	%	2.6	2.65	1.89	1.58
Total Carbon	%	53	51	61	57
Phosphate	mg/L	109.0	78.0	268.0	123.0
Nitrates	mg/L	13.44	12.4	10.55	11.52
Chlorides	mg/L	1.64	1.85	0.79	0.59
Potassium	mg/L	2.1	1.8	1.4	2.5
Calcium	mg/L	7.2	7.34	6.2	5.49
Total Dissolved Solids	mg/L	6.56	6.84	5.01	5.24