UNIVERSITY OF NAIROBI

DEPARTMENT OF MECHANICAL ENGINEERING

USE OF BIOGAS FROM BREWERY WASTE WATER:

A CASE STUDY OF KENYA BREWERIES LIMITED

OWINY B. OWUOR (F56/77584/ 2015)

SUPERVISORS:

DR. KIMILU

DR. AGANDA

A Research Project Submitted in Partial Fulfilment of the Requirement for the Award of the Degree

of

Master of Science in ENERGY MANAGEMENT of the University of Nairobi

SEPTEMBER 2020

DECLARATION

This project is my original work and has not been presented for the award of a degree/diploma in any other University. No part of this project may be reproduced without the prior permission of the author/ University of Nairobi.

Signature ………………………………Date ………………………………

OWINY BERNARD OWUOR (F56/77584/ 2015)

SUPERVISORS DECLARATION

I confirm that the above student carried out this research under my supervision as University supervisor.

Signature ………………………………Date ………………………………

Dr. Aganda

Signature ………………………………Date ………………………………

Dr. Kimilu

(Department of Mechanical & Manufacturing Engineering, University of Nairobi)

ACKNOWLEGMENT

I am grateful to the following people, without whose support I would have found it difficult to complete this project to successful completion.

I would like to convey my gratitude to the project supervisors Dr. Aganda and Dr. Kimilu for their valuable challenge, guidance and advice throughout the project.

I would like to thank my family: Evelyn, Benjamin, Belyn and my friend Lawrence Mumo for being supportive throughout the process of this research. Without their advice, encouragement, and understanding this work would have never been completed.

I would also like to extend my thanks and gratitude to my employer Kenya Breweries Ltd, for their support throughout the course.

ABSTRACT

Rising global challenges of energy generation, especially green energy, sustainability and cost, has triggered immense research on alternative energy sources and technologies in the current times. Energy costs represent a significant expense in beer brewing industry, and it is in a company's best interest to minimize these costs. In the year 2015 Kenya Breweries Limited total energy cost was Ksh.1020.69Million. Kenya Breweries Limited utilizes an anaerobic waste water treatment which produces biogas as a by-product and flared up because it has no use at the moment. This project focused on estimating the volume of biogas flared up at Kenya Breweries Limited waste water treatment plant and its viability as an alternative source of fuel for boilers. Data was collected at the effluent treatment plant during waste water treatment and the boiler plant during steam production. The data was analysed using flow duration curve method. Values at 50% confidence levels were obtained and used to estimate the volume of biogas produced in a day after waste water treatment. The study revealed that at optimum conditions and 50% confidence levels, loading the UASB digester with a COD load of 19,761kg/day, an estimated biogas volume of 9,973m^3/day containing Methane gas of volume 6,383m^3/day was produced. The methane gas produced can run the boilers for only 3.4 hours per day to produce estimated steam of 57.6tonnes, while HFO can run the boilers for the next 19 hours to produce an estimated steam of 316.2tonnes. By using methane gas for 3.4 hours in a day, 4,250litres of Heavy Fuel Oil can be saved, which amounts to Ksh. 63,750,000.00 savings in one year. The study demonstrated that boiler burner modification would be the most cost-effective method of using the flared biogas. To adopt the power saving/ recovery strategy, it was observed that the existing boiler burner need to be replaced by a dual fuel rotary cup burner, preferably type SKVGD Saacke. Other system modifications would include modification of the existing bio-filter to act as a water scrubber, installation of a compressor (type GG 90 VSD (50/60 Hz) for compressing gas for storage, and installation of Varec Biogas 245Automatic Drip Tap to remove Condensate or water vapor along the gas pipes.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS ACRONYMS

No		ABBREVIATIONS ACRONYMS
1	KBL	Kenya Breweries Limited
2	COD	Chemical Oxygen Demand
3	ETP	Effluent Treatment Plant
4	HFO	Heavy Fuel Oil
5	HRT	Hydraulic Retention Time
6	SS	Suspended Solid
7	TSS	Total Suspended Solid
8	UASB	Upflow Anaerobic Sludge Blanket
9	VFA	Volatile Fatty Acids
10	UHC	Unburned Hydrocarbons
11	CHP	Combined Heat and Power

CHAPTER ONE

INTRODUCTION

1.0 Background of the Study

The increase in population has resulted into rapid increase in urbanization and industrial development, which are major sources of environmental pollution. With the increased population, the rate of use of hydrocarbon-based fuels has increased drastically due to increased rate of consumption of energy all over the world (Okonkwo et. al., 2013). However, hydrocarbon-based fuels have limited sources that might not meet future demand of energy in the world. The prospect of diminishing supplies of fossil fuels and the growing demand of energy, has led to increased development and use of renewable energy sources (Eze J.I., and Agbo K.E., 2010).

One of the technologies in renewable energy sources is biogas production from waste water treatment. Biogas has been tested and founded as a better alternative source of fuel. Biogas is produced when biodegradable materials like sewage, biomass, manure or municipal waste are subjected to anaerobic digestion. The main factors that have rekindled the interest in use of heat /electricity production from biogas are: the high cost of non-renewable fuels and pressure to shift society towards renewable energy (Agler et. al., 2010).

Effluents from brewery plants normally contain high chemical oxygen demand (COD) and suspended solids (SS) (Okonkwo et. al., 2013). The contents of COD are easily biodegradable organic compounds such as soluble starch, sugars and ethanol (Driessen and Vereijken, 2003). The biogas from anaerobic treatment is a renewable energy source alternative to fossil fuel, that can be integrated into the energy mix of the brewery. This can ultimately improve the economies of brewery. Waste water treatment processes that generate biogas deserve to be fully utilized so that the economics of the process are improved.

Kenya Breweries Limited (KBL) has an Effluent Treatment Plant (ETP) for wet waste treatment that produces biogas as a by-product. The biogas is flared up for environmental conservation, having no use at the plant. This waste heat can be recovered as a source of energy and be used to run the boilers and the generators, and hence save energy cost. Kenya Breweries Limited uses 9 Million litres of Heavy Fuel Oil (HFO) yearly at a cost of approximately Ksh. 450 Million in running the boilers to produce steam. The amount of electricity used to run the plant for the year 2015 was 35,080,440 kWh.

According to Stams et. al. (2003), the best established technology for protecting the environment through treatment of waste and waste water is by anaerobic conversion of organic material and pollutants. Despite this, excess exposure of biogas to the environment has severe effects. For instance, Hydrogen Sulphide, a component of biogas, in excess of 500ppm causes unconsciousness and can result to death in 30 minutes to 1 hour of being in contact. It also causes corrosion in engines, compressors, gas storage tanks and gas pipeline. Thus, mitigation measures have to be put in place to avoid and reduce the risks associated with each of the gas component that constitutes biogas.

In this study, brewery effluent waste water treatment and decomposition in an Up flow Anaerobic Sludge Blanket (UASB) reactor, generating biogas for alternative use was investigated. Using industrial waste to produce fuels, do provide an inexpensive source of energy as well as simplifying the disposal process.

1.1 Energy Use at Kenya Breweries Limited

Kenya Breweries Limited as a public company is engaged in production of non- alcoholic and alcoholic beverages. It was founded in 1922 by two white settlers, George and Charles Hurst. The company has four main production units namely: Utilities, Brewing, Packaging and Spirits departments. Its energy is provided via an energy mix comprising of thermal, diesel, electrical and LPG.

Table 1.1 shows the different sources of energy and amount of each energy used at Kenya Breweries Limited. The total Energy utilised in the year 2015 was recorded as 459,260,397.77 MJ. Thermal energy is widely used in the brewery than any other form of energy accounting for 72% of the total energy consumed at KBL followed by electricity at 23.4%.

Table 1.1: 2015 KBL Total Energy Usage

Energy Type	Total (MJ)	Percentage (%)
Thermal Energy	330,847,946.81	72.0
Electrical Energy	107,586,219.60	23.4
Diesel Genset	1,285,746.00	0.3
LPG	19,540,485.36	4.3
Total Energy	459,260,397.77	100

Table 1.2 shows the types of energy used at Kenya Breweries Limited and the cost incurred annually. It is evident that the use of HFO (44.09%) and electricity (55.57%) are the highest types of energy consumed hence highest in terms of energy cost at Kenya Breweries Limited. HFO is used to run the boilers for steam production, while electricity is for running the process machines. For the analysis in this study, it was assumed that the boilers ran at 300 days/year, cost of electricity was Ksh.16.17/kWh, and the cost of HFO was Ksh.50.00/litre.

Table 1.2: Energy Cost

Energy Type	Cost (KSH. M) per year	Percent Cost
Electrical	567.2	55.57%
Heavy Fuel Oil	450.0	44.09%
Diesel & LPG	3.49	0.34%
Total	1020.69	100%

Figure 1.1 shows the utilization of thermal energy per department. Packaging and spirits uses the highest thermal energy at 56%. In packaging and Spirit departments, steam is used in heating hot water and Caustic Soda for bottle washer. The hot water is also used in pasteurization of beer. Brewing department uses 32.1% of the total thermal energy.

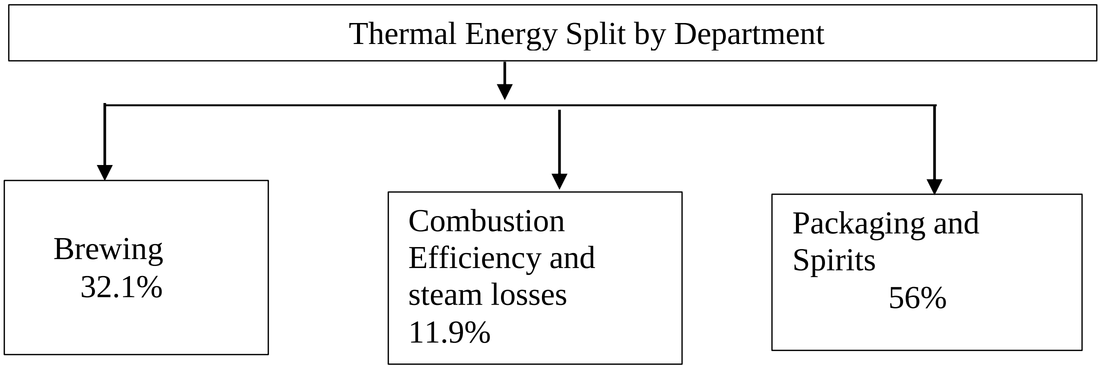


Figure 1.1: Thermal Energy Deployment

The objectives of waste water treatment are to reduce Solid wastes, Biodegradable organic matter, Pathogens level and the toxic compounds level in the waste water, and to meet regulatory standards that protect public health and the environment (Riffat Rumana, 2013). The Environment Treatment Plant (ETP) at Kenya Breweries Limited is basically for waste water treatment before being discharged to the sewer line and not intended for biogas production. The biogas produced as a by-product of the process is flared off to remove methane gas, without making use of the available energy.

Heavy Fuel Oil is the main source of fuel in steam production at KBL. The amount of heavy fuel oil (HFO) used to run the boilers for steam generation is approximately 30,000litres/day at a high cost of Ksh.1.5 Million/day (Ksh.450 Million/year). Burning HFO is a major contributor of greenhouse gases which pollute the environment, and hence lowering its consumption would result to reduced CO_2 emissions.

Biogas as a potential source of alternative energy at KBL has not yet been fully explored and is the basis for this study. The study seeks to answer the following research question;
Is the volume of flared biogas at KBL ETP plant enough to run the boilers as an alternative fuel?

1.2 Objectives of the study

The main objective of the study was to evaluate the viability of using Biogas being flared up at KBL Waste Water Treatment Plant as an alternative source of fuel for boilers.

The specific objectives of the study were:

1. To relate biogas generation to waste water flow and treatment.
2. To estimate the volume of biogas being flared.
3. To estimate the savings to be made in using methane gas as an alternative fuel for boiler
4. Redesign boiler system for biogas use.
5. Highlight the environmental impact of excess biogas exposure and propose mitigation procedures.

CHAPTER TWO
LITERATURE REVIEW

2.1 Waste Generation from Brewing Process

Beer is a millennial alcoholic beverage that permits consumers to have taste of different brands and styles, that depends on how the production process is conducted and/or raw materials used (Mathias et al., 2014). In Kenya beer is the fourth beverage mostly consumed after milk, tea and coffee.

The brewing process is based on three major biochemical changes: conversion of starch to sugars; during fermentation the conversion of sugar in presence of yeast to alcohol, carbon dioxide and heat; and maturation where beer stabilization takes place (Vrellas et.al. 2014). During beer production the raw materials passes through three biochemical and chemical reactions (mashing, boiling and fermentation) and three liquid-solid separations (wort separation, wort clarification and beer clarification) (Rao et.al, 2014). During the process of beer brewing, water consumption, wastewater and solid-liquid separation, form an economic improvement opportunity in beer brewing process.

A huge volume of waste (water) is produced together with two types of solid waste generated; spent grain and trub. The effluents discharged are found to have high organic and acidic content, which increases the chemical oxygen demand and high organic load. This is as a result of dissolved carbohydrates, alcohols, suspended solids, yeast etc, which pollute water bodies considerably (Chaitanya, K., et al., 2011).

2.2 Effluent Treatment Plant (ETP)

Waste water is a mixture that contains liquid wastes and wastes transported in water from Industries, households and commercial establishments, as well as other surface runoff and storm water (Riffat Rumana, 2013). Waste water contains both organic and inorganic contaminants. Treatment of waste water entails the removal of organic and inorganic matter, as well as soluble and insoluble materials (Arceivala et. al., 2007). Waste water treatment is usually done in a digestion plant. The first digestion plant was built at a leper colony in Bombay, India in the year 1859. By 1895, the invention had reached England, whereby through a "carefully designed" sewage treatment plant, biogas was recovered and used to fuel street lamps (Stams et. al., 2003).

2.2.1 Up- flow Anaerobic Sludge Blanket (UASB) Reactor

The world’s first full scale demonstration UASB reactor for municipal waste was built in Kanpur, India in 1989 (Arceivala et. al., 2007). Lettinga and co-workers developed the UASB process in the Netherlands (Lettinga et al., 1980). This anaerobic technology treated high strength industrial waste water.

Figure 2.1 shows a schematic diagram of organic influent pumped through distributor. The degraded organic matter settles as the sludge blanket while the effluent liquid is discharged from the top. Evolution and gas production provide enough mixing in the sludge blanket. Solids that have escaped from the UASB are collected by the liquid effluent that is passed through a settling tank. The solids that have been collected are recycled back to the reactor. The anaerobic gas is removed from the sludge blanket by either plate separation or vacuum degasification.

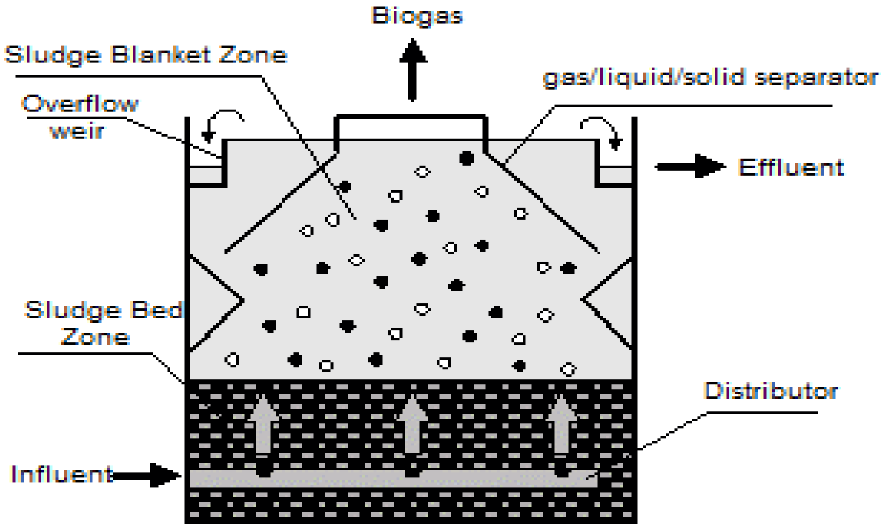


Figure 2.1: UASB

The formation of dense granulated sludge determines the success of UASB process. The concentration of solids from the bottom can range from 50 to 100g/l and from the top of the reactor between 5 to 40g/l. A high-developed sludge blanket permits the use of higher COD loading volume than other anaerobic processes (Lettinga et al, 1980). The UASB has proven to be chemically the best waste water treatment technology available, as less energy is required, volume of waste sludge produced is lower and has the potential of producing methane gas which can be used for electricity generation (Abbasi and Abbasi, 2012; Fang et al., 2011).

2.3 Effluent Treatment Process

Biological treatment of sludge and waste water in absence of oxygen is referred to as anaerobic treatment. Anaerobic technology of sewage treatment process is increasingly becoming the advanced core method for resource preservation and environmental protection (Seghezzo and Zeeman, 1998). Anaerobic treatment of waste water results in organic matter stabilization, at the same time reduction in pathogens, odour and mass of solid organic matter that require further processing (Kaparaju et.al., 2011). In the end of the process in an oxygen free or anaerobic environment, organics such as carbon dioxide and methane are emitted biologically. Anaerobic treatment is simple and less expensive technology, which consumes less energy, space, and produces less residual sludge.

For this study, an anaerobic waste water treatment plant at KBL was used. The treatment process stages are as outlined below:

1. Inlet channel – at this point the PH of the effluent is determined. The PH should always be between5-12. At this point the Total Suspended Solid (TSS) is also reduced by using both coarse screen and fine screen.

2. Equalization tank- waste water from the inlet channel comes in alkaline form with a pH of around 10 due to traces of caustic. Naturally occurring extracellular enzymes lead to acidification of the water that is in the equalization tank, a process that takes an average of 8 hours. Volatile fatty acids (VFAs) are formed ultimately leading to a drop in the pH.

3. PH correction-The low pH of the effluent is not favourable for the survival of the methanogenic bacteria that is used in treating the effluent necessitating the correction of the pH to neutral levels pH 7. This is done by dosing either caustic soda or hydrochloric acid depending on the pH of the effluent emanating from the Equalization tank.

4. The Up flow Anaerobic Sludge Blanket (UASB) digester – in the digester the waste water is seeded with methanogenic bacteria and it is where treatment of the effluent takes place anaerobically. The bacteria in the digester consume the VFA, breaks down the soluble sugars and considerably reduce the COD in the effluent and in the process generate methane gas as a by-product.

5. Polishing tank-After treatment the effluent is channelled to the polishing tank which is designed to allow for settling of solids thus reducing the total suspended solids which are basically bacteria that may have escaped from the digester.

6. Outlet channel –after the treatment, the effluent is harmless to the environment hence discharged to the sewer line. Methane gas produced during this process is flared up to protect the environment from pollution.

2.4 Methane Gas Production

Gas production is the amount of biogas produced per day during anaerobic digestion. , Micro-organisms (principally bacteria) during anaerobic digestion convert organic matter into additional biomass and simple end products as the general equation (Eq. 2.1) for anaerobic biological degradation (Romero, 1999).

$$\text{Nutrients} + \text{Organic Matter} \xrightarrow{\text{Bacteria}} CH_4 + CO_2 + \text{New cells} \qquad 2.1$$

These interactions take place in the anaerobic sludge granules that are normally present or selected in an UP flow Anaerobic Sludge Blanket (UASB) system. Figure 2.2 shows the steps of methane gas formation as described below:

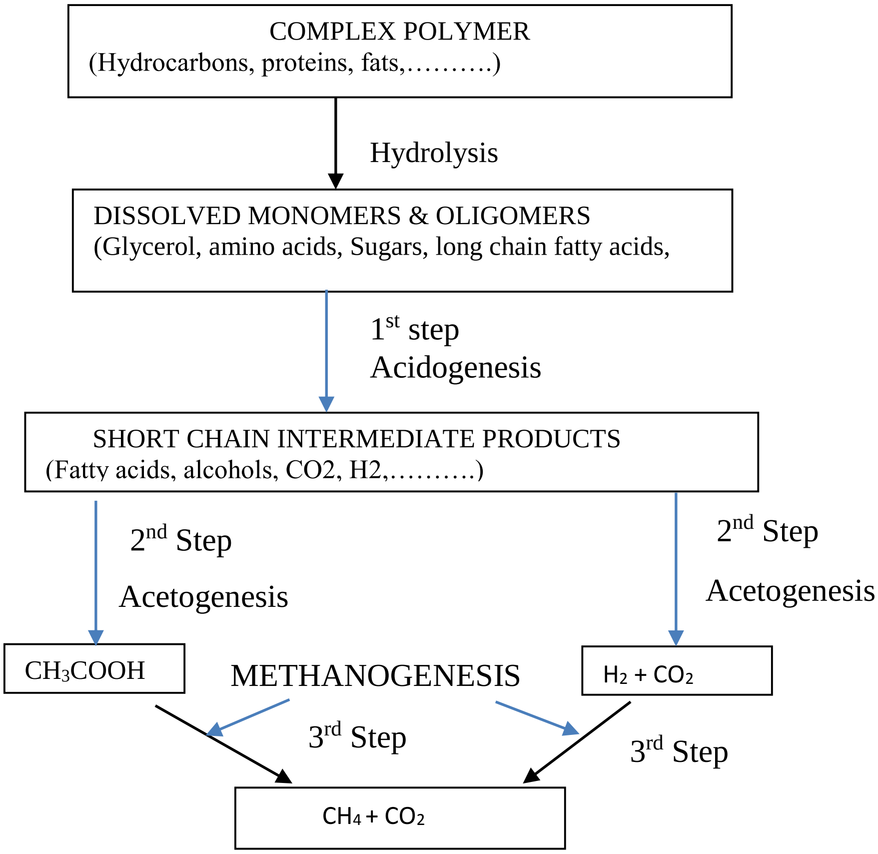


Figure 2.2: Anaerobic Biodegradation Pathway (Barik and Murugan, 2013)

Hydrolytic fermentative (Acidogenic) bacteria are the first group of organisms of anaerobic digestion. The bacteria hydrolyse the complex polymers to organic acid, sugars, alcohols, carbon dioxide and hydrogen.

The fermentative products of the previous step are converted into carbon dioxide and acetate by the second group. Methanogenic as the third group, convert simple compounds (carbon dioxide and methanol, acetic acid plus hydrogen into methane (Hutnan & Buday, 1999). The methanogenesis is the last step in the anaerobic pathway. Because of the low solubility in water of methane, it will escape as methane gas.

$$\mathrm{CH3COOH} \longrightarrow \mathrm{CO_2} + \mathrm{CH_4} \tag{2.2}$$

$$\mathrm{CO_2} + 4\mathrm{H_2} \longrightarrow \mathrm{CH_4} + 2\mathrm{H_2O} \tag{2.3}$$

2.5 Biogas Composition

The composition and amount of biogas produced depends on factors like: the amount and characteristics of feedstock used (e.g. Organic content, total solid content), Reactor type (Plug flow, mixed tank) and process used (continuous, semi-continuous, batch), and process parameters such as temperature, hydraulic retention time, organic loading rate and PH (Rasi et al., 2007). Depending on the pH value, carbon dioxide is either partially dissolved in the liquid phase as carbonic acid or converted to bicarbonates (Franco et al., 2007). Waste stabilization occurs when methanogenic bacteria converts acetic acid or acetate to methane.

Biogas composition is typically methane - CH_4 (45-70 per cent), and carbon dioxide - CO_2 (30-45 per cent) with small amount of hydrogen sulphide- H_2S (0-2000ppm) and ammonia - NH_3 (0-590ppm). Occasionally, present in the biogas are traces of hydrogen, nitrogen and carbon monoxide and saturated water vapor. High methane content with low concentration of trace compounds can be obtained in Anaerobic Digestion plants, as well as sewage treatment plants (Rasi et al., 2007).

Biogas use as a clean fuel offers solutions to current concerns touching on ecology, economics and energy such as: better source of renewable energy as the fossil deposits are declining, reduction of fossil energy dependency, exhaust gas emission and green house effects (Papacz Wladyslaw, 2011).

2.6 Biogas Treatment

Biogas purification or treatment is the conditioning of biogas to upgrade its quality prior to utilization. Without proper gas treatment, the gas utilization equipment will experience increased wear, deterioration and maintenance problems. Technologies of different types have been designed for the separation of CO_2 from biogas to increase its energy value such as cryogenic separation, CO_2 fixation by chemical or biological process, absorption by chemical solvents, physical separation and membrane separation (Agler et. al., 2010).

Other technologies of removing H_2S are also in place such as: conversion to base sulphur or low solubility metal sulphides, physical absorption on solid adsorbents and chemical absorption in aqueous solution (Arceivala et. al., 2007). Biogas impurities like CO_2 and H_2S can also be removed by water scrubbing. Rasi et al., (2007) concludes that both H_2S and CO_2 are removed simultaneously due to the difference in binding forces of the non-polar CH_4 and the polar H_2S and CO_2.

2.6.1 Water Scrubbing Method

Impurities in biogas dissolve relatively easily in water, especially under medium to high pressure. Water scrubbing is the absorption of CO_2 and H_2S using water at high pressure (Kwofie E. M and Boateng Ofori, 2009). A water scrubber compresses and introduces raw biogas at the base of a tall randomly packed vessel as compressed water is sprayed from the top of the vessel in a counter current flow. A purified methane gas stream exits out of the top of the vessel as a carbonated waste water stream exits out at the base. The upgraded biogas obtained from the dryer usually contains more than 90% methane (Hosseini and Wahid, 2014).

By removing non-combustible gases from biogas ingredients, the calorific value of biogas is increased. According to Barik Debabrata and Murgan S. (2013), the rate of CO_2 and H_2S absorption is determined by: biogas composition, water purity and water flow rate, gases flow pressure, and size of scrubbing tower.

Kapdi et al., (2005), states that water scrubbing technology is cheap, simple and the loss of CH_4 is very small (less than 2 per cent) due to the difference in solubility of CH_4 and CO_2.

2.7 Biogas Combustion

The combustion process of gaseous fuels is that in which the heat and mass transfer takes place between substances in the same phase. This process is called homogenous combustion. Parameters which are normally determined during combustion processes are:

quantity of air required for combustion, quantity of product of combustion released and enthalpy of the product of combustion.

2.7.1 Air to Fuel Ratio

Air to Fuel Ratio (A/F ratio) is the quantity of air supplied to the gas burner divided by the quantity of fuel supplied at the same time period for combustion processes. Air Fuel Ratio (AFR) being an important parameter do determines the quality of combustion. The combustion performance is majorly affected by AFR used. Too High or too Low AFR reduces the combustion efficiency (Noor et.al. 2014). The chemically correct or stoichiometric air–fuel ratio (A/F ratio) is the correct ratio necessary to burn all the carbon and hydrogen in the fuel to carbon dioxide and water, with no oxygen remaining.

Methane burns in air (O_2) as shown in Equation 2.4 giving out carbon dioxide and water. Energy content in the methane gas is released out.

$CH_4 + 2O_2 \longrightarrow CO_2 + 2\,H_2O + \text{Energy}$ 2.4

1 volume of CH_4 requires 2 volumes of oxygen to complete its combustion

Assuming air composition of a mixture of oxygen (21%) and nitrogen (79%) then:

$$Volume\ of\ Nitrogen\ =\frac{(2\ x\ 79)}{12}\ =\ 7.52\ Volume$$

$CH_4 + 2O_2 + 7.52N_2 \longrightarrow CO_2 + 2\,H_2O + 7.52N_2$ 2.5

Thus, 1 volume of CH_4 requires 9.25 volume of air, hence A/F ratio for methane is 9.25

Air contains 21% oxygen while biogas contains 60% methane, the volume ratio for stoichiometric mixture of biogas and air is a volume fraction of 17.5%. Biogas in air burns over a narrow range of mixtures from approximately 9% to 17% (Tumwesige et. al., 2014).

If the flame contains a lot of fuel (low AFR), then incomplete combustion will take place, releasing poisonous carbon monoxide and unburned hydrocarbons (UHC) or soot particles. UHC in the exhaust gas is a waste of fuel and unwanted combustion can be created at an unwanted location (Noor et. al., 2014). Therefore, the design of biogas combustion equipment should aim at maximizing the conversion of methane into carbon dioxide in order to reduce the occurrence of incomplete combustion (Tumwesige et. al., 2014).

A biogas burner mixes air and gas directing to the flame ports for combustion. Most burners are partially aerated, meaning that the gas is mixed with a fraction of primary air that is less than optimum for combustion. Secondary air that flows around the outside of the flame ports completes the combustion process (Tumwesige et. al., 2014). The jet controls the volume of gas flowing into the burner; a jet is a carefully sized hole which determines the output power of the burner. The volume of air that allows a fuel gas to burn is called the stoichiometric mix and is 5.5:1 for biogas. The gas pressure and hole size, determines the flow of gas from the jet and is given by eq.2.6

$$Q = 3.16 C_d A_0 \sqrt{\frac{p}{s}} \times 100, \text{ in } dm^3s^{-1} \quad \text{(Tumwesige et al., 2014)} \qquad 2.6$$

Where A_0 is the area of the jet (m^2), Cd is the coefficient of discharge of an orifice (jet), S is the specific gravity of the gas and P is the gas pressure (Pa). Typical ranges of C_d are between 0.7 and 0.9 depending on how well the orifice is made, and S is 0.94 for biogas.

The power (P) produced by the burner is given by

$$P = Q \times H \quad \text{(Tumwesige et al., 2014).} \qquad 2.7$$

Where H is the enthalpy of combustion and can be taken as $21.7 MJm^{-3}$**.** As the jet releases the gas, it accelerates, which minimize the pressure according to Bernoulli’s equation:

$$P + {}^{1}\!/_{2}\, \rho V^2 \quad \text{(Tumwesige et al., 2014)} \qquad 2.8$$

Where V is the gas velocity (in ms^{-1}), P is the pressure (in Pa) and ρ is the density (Kg m^{-3}). The reduced pressure draws in air, which mixes with the gas in the mixing tube.

Biogas as a renewable source generated in the anaerobic digestion, has application in heating and power generation. The Low Calorific Value (LCV) of biogas becomes one of the important bottlenecks to conversion into thermal energy or electrical. Presence of water vapour and H_2S biogas components becomes a challenge in biogas purification and utilization (Hosseini et.al, 2013). Flameless combustion can be used to eliminate the two disadvantages.

Biogas ideally contains 40-80% of CH_4 and at standard pressure and temperature the CH_4 lower heating value is about 34,300kJ/m^3, hence lower heating value of biogas is approximately 13,720- 27,440 KJ/m^3 (Hosseini et. al., 2013). Biogas is classified as a Low Calorific Value (LCV) fuel, as it contains large proportion of inert components in its composition that lower its heating value. Burning biogas conventionally, results into combustion problems related to its stability, and therefore a better technology is sought to solve these problems. Conventional combustion is affected by AFR used. Too high or too low AFR reduces the combustion efficiency. Flameless combustion technology becomes a better option for biogas as a fuel of LCV.

2.7.2 Biogas Flameless Combustions

In flameless combustion, fuel and highly diluted air burning within the furnace is above the fuel auto ignition temperature. As the furnace temperature rises above the auto ignition levels of the fuel, increasing the fuel and air jet velocity raises amount of recirculation ratio making the flame front to disappear as the furnace temperature dwindles, this zone is called instability zone. In other words, due to high Reynold number for oxidizer and low oxygen concentration, the flame structure changes, making the conventional flame to disappear. (Hosseini et. al., 2013). Audio and Visible flame is removed and the air and fuel region spread to the downstream zone of the furnace.

The flameless chamber hence contains a uniform distribution of temperature. Hot spots are eliminated and thermal NO_X formation suppressed (Hosseini et. al., 2013).

Having an alternative fuel raises the following questions:

1. What is the height of the combustion chamber should the new fuel be injected into the boiler?
2. What modifications are needed to the burner?

Flame velocity plays a very important role in the designing a burner for conventional combustion. The rate of air and fuel injection to the burner should be synchronised to the velocity of the flame to prevent blowing off (Hosseini et. al., 2013). Uniform temperature around the flameless chamber increases the stability of the refractory and auxiliary equipment. Decrease in fuel consumption, pollutant formation reduction and simplicity of the flameless burner, are the great reasons of the supremacy of biogas flameless combustion. Flameless combustion is a better option of technology due to its high efficiency and low emission and (Hosseini Seyed and Wahid Mazlan, 2013).

2.8 Biogas Utilization

The utilization of biogas as an alternative fuel is one of the sustainable ways to decrease fossil fuel dependency. Biogas can be used in either upgraded or raw state. The different biogas technologies are as follows: The production of steam and /or heat (Biogas Boiler), Electricity production with Cogeneration or Combined Heat and Power (CHP) and in its upgraded form as vehicle fuel.

2.8.1 Biogas Boiler

This is the most used technology in heat or steam generation. It is a low cost and simple operation. Some boilers are designed with dual fuel burners capable of burning either the natural gas or biogas. Typical efficiencies for heat generation in a biogas boiler are approximately 80-89 percent. The volume of available biogas must be considered and compared to the facility’s steam need and boiler capacities.

2.8.2 Cogeneration

Combined Heat and Power generation or cogeneration uses a combustion technology connected to a generator motor for electrical power production. Waste heat from the production of the power is captured for beneficial use. In cogeneration, the energy use of biogas plants involves the applications of gas turbines, micro turbines and reciprocating gas engines. CHP plants gas–powered reciprocating engines usually produce saturated steam or hot water.

Cogeneration benefits are its ability to generate two valuable energy products, accommodate varying biogas flows, handle varying heat and power demands, and utilize nearly all of the biogas generated by the treatment plant.

Figure 2.3 describes how total biogas produced from the brewery waste water can generate different types of energy as discussed below;

1. Heat Energy: Biogas can be burnt in Boilers directly for hot water and steam production. The hot water is stored in an energy storage vessel, which is used in brewing processes (Mashing , wort preheating)
2. Electricity: Burnt biogas can produce steam of high temperature and pressure. This high pressurised steam can rotate a turbine for electricity generation in a Combined Heat and Power (CHP) plant used to run utilities machines (refrigeration system, Compressed Air system and Carbon dioxide system)

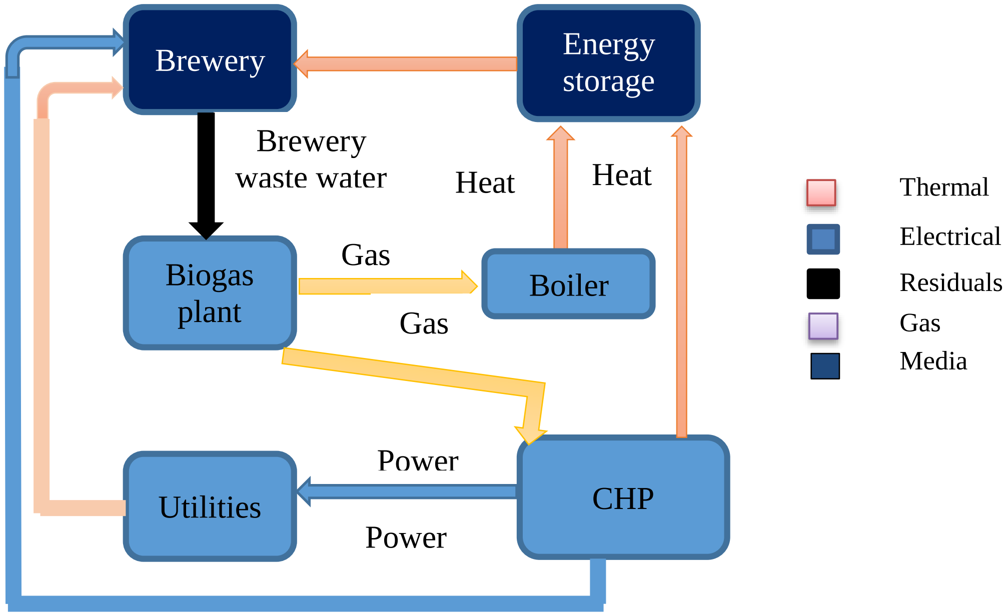


Figure 2.3: Brewing Energy Flow

2.8.3 Vehicle Fuel

Upgrading biogas to 95% methane by volume qualify the gas as a transport fuel, hence best for vehicles originally modified to run on natural gas. Vehicles fuelled by biogas can reduce carbon dioxide emissions by 75% to 200% compared to fossil fuels.

2.9 Heavy Fuel Oil

Heavy Fuel Oil (HFO) is a residual product of the fractional distillation of crude oil. It finds its use in industrial heaters, boiler, furnaces, kilns and power generators. Fossil fuels and their products are composed of mixture of organic compounds of carbon, hydrogen, oxygen, nitrogen, sulphur etc along with other inorganic matter which is identified in the residual ash after combustion. The carbon and hydrogen are of greatest importance as heat producers. The volume of the combustion air and composition of the combustion gases is determined by the fuel analysis. Impurities in fuel oil which affects its application and which are determined by analysis are: Sulphur, Sediment, Ash, Moisture, etc. This information is required for the calculation of flame temperature and during design of burners and flues. The fuel parameters checked during analysis are as discussed below:

1. Specific Gravity: It’s the ratio of the density of the substance to that of water at a specified temperature (say 60 ^{0}F for both fluid and water). It is an important property because the injection system is set to deliver a predetermined volume of oil. For classifications and quality the specific gravity of fuel oil is used as a general index. It is used as a precursor for a number of other fuel properties, such as viscosity, heating value and cetane number.

2. Viscosity: It is defined as the ratio of shearing stress in a fluid to the rate shear strain and is a measure of the resistance of the fluid to flow. It is determined by establishing the time necessary for a quantity of the fluid to escape through a standard orifice under the force of gravity. The resistance of an oil to flow is important as it determines the ease with which it can be handled and broken up into fire mist by the

burner. A temperature increase lowers the viscosity of oil and causes it to flow more readily.

3. Flash point: It is the lowest temperature at which a fuel will ignite in presence of an ignition source. Flash point provides information about handling dangers on one hand and the ease of lighting up on the other. In burning fuel oils, it is important that it be fully atomized to ensure mixing of air with oil particles.

4. Distillation test: The test measures the percentage of vaporized fuel as the temperature increases. It determines whether the fuel contains sufficient volatile substances to give good acceleration. The test also serves to show if the fuel is likely to burn completely in the engine and to leave no residue to dilute the oil in the crankcase in case of IC engines.

5. Calorific value: It is the amount of heat obtained by complete combustion of unit quantity of fuel. Major elements contributing to the calorific value are carbon, hydrogen, nitrogen, oxygen and sulphur.

Table 2.1 shows the temperature at which the different fuel oil types are heated before entering the burner. HFO requires high temperatures of 135 ^{0}C to be fully atomized and burn.

Table 2.1: Fuel Designation (Woodruff and Lammers, 1977)

FUEL OIL NO.	DESIGNATION	TEMP. AT BURNER (°C)
4	Light Industrial	66
5	Medium industrial	79
6	Heavy industrial	135

2.9.1 HFO Use in Boilers

Boilers are equipment designed to burn fuel to produce steam or heat water .Boilers are closed pressure vessel in which by application of heat transform water under pressure transformed into steam .(Woodruff and Lammers, 1984). Although boilers can be designed to burn biomass the majority of boilers use fossil fuels as source of energy. In the burning furnace, heat is generated by conversion of chemical energy in the fuel. The boiler transfers this heat to the water in the best efficient manner. Boilers mixes air with fuel to provide oxygen during the combustion process. To achieve effective combustion all fuels must be properly introduced to the flame zone, but HFO requires much more attention in the burner and combustion furnace than methane gas.

For maximum heat transfer boilers are made number of tubes. These tubes run between water collection drum at the boiler bottom to steam distribution drum at the top of the boiler. Before entering the steam distribution system steam flows from the steam drum to the super heater. With rising in fuels cost, greater innovation is being given to improve efficiency of the combustion. Boilers designed to burn multiple fuels do to take advantage of the fuel most economically available. The main use of steam from boilers is for power production, process heating, and to operate turbines (Woodruff and Lammers, 1984). The selection of the type and size of boiler depends on;

1. The output required in terms of steam per hour, working pressure and temperature.
2. The amount of fuel and water available.
3. The probable load factors.

Boilers can either be classified as fire tube or water tube. In fire tube, the product of combustion passes through tubes and heats the surrounding water to produce steam. On the other hand, in water tube boilers the product of combustion passes around tubes holding water. The tubes are interconnected to common water channel and to the steam outlet.

2.10 Flow Duration Curve

The degree of belief we have in prediction of models, will normally depend on how well they can reproduce observations. The flow duration curve is a cumulative frequency curve that indicates the percent of time specified discharges were exceeded or equalled during a given period of time. Flow duration curves represent the relationship between frequency and magnitude of flow by the definition of time proportion for which any discharge is exceeded or equalled (Vogel and Fennessey, 1994).

Flow duration curves have been in use since about 1915 (James Searcy, 1959). It combines the flow characteristics in curve throughout the discharge range without regard to the occurrence sequence. If the period upon which the curve is based represents the long-term flow, the curve may be used to predict the distribution of future flows.

Flow duration curves are used for preliminary investigations of flow sources that are not consistent, keep on fluctuating most of the time and can be depleted any time. An earliest use of the flow duration curve was for water-power studies. Some new applications of flow duration curves are: location of industrial plants, pollution studies, management of water resources and analysis of river habitats (Booker and Dunbar, 2004).

Historical discharge time-series can be used to calculate flow duration curves provided records of sufficient length are available (Booker and Snelder, 2012). The two main methods of constructing flow-duration curves are (1) the total period method and (2) the calendar-year method (Barrows, 1943). In total period method, all discharges are placed in classes according to their magnitude. The totals are cumulated, beginning with the highest class, and the percentage of the totalled time is computed for each class. In the calendar year method, the discharges for one year are ranked according to magnitude (order number 1, 2, 3, …). This process is repeated for each year of record and the discharges for each order number are averaged. The calendar year method gives lower values for the higher discharges and higher values for the low discharges than the more accurate total-period method. The data are then plotted with the time in percent of total period as the abscissa and the discharge as the ordinate (James Searcy, 1959).

CHAPTER THREE
RESEARCH METHODOLOGY

3.0 Introduction

In this chapter, the methods used and procedures followed in data collection and data analysis in the study are discussed.

3.1 Research Design

The research design used in this study provided a picture of the volume of biogas that is flared and the possible cost that can be saved when the biogas is used as an alternative source of fuel for boilers at Kenya Breweries Limited.

The research study used was longitudinal in nature. Longitudinal study is a correlation research study that involves repeated observation of the same variables over long periods of time. The variables under study were COD loads, Biogas flow and Total Suspended Solids. These variables were used to relate biogas generation to waste flow and treatment.

3.2 Data Collection

Data was collected at the Effluent Treatment Plant area during waste water treatment and boiler house during steam production. The main data collected were:

1. At the inlet to UASB the data obtained was: the volume of the daily influent flow and COD concentration. At the UASB outlet, the treated effluent data obtained was: the total suspended solid, COD concentration and the volume of biogas flared daily. This data was obtained daily by the Environmental Department, stored in a shared drive and accessible only by authorized employees. The aim of collecting the data was to relate biogas volume generated, to waste water flow and treatment.

2. The volume and cost of HFO used daily for running the boiler. This data was available at the boiler house, for the data is daily recorded against the steam consumed in a day.

3. Biogas composition which was done by SGS, a private company. A Portable Gas Analyzer probe was inserted at point where biogas flows to the flare. The analyzer upon sample collection displayed the volume of each biogas constituent's gases.

The instrument used in data collection and analysis were: For COD measurement. COD thermoreaktor – CR 3000, manufacturer – WTW G.M.b.H. For total suspended solid (TSS), DR900 Colorimeter, manufacturer HACH company. For biogas flow – CPT-01 Quantometer, Common Manufacturer.

Other Primary data which included Steam produced was obtained from daily steam generation reports at the boiler house. KBL energy used for manufacturing was obtained from the company daily production report and other literatures at Kenya Breweries Limited. Trends and key performance indicators on waste water treatment process are shown by the use of secondary data, over a period of four months to supplement analysis.

3.3 Data Analysis Methods

The data analysis process started with validation and verification of data (inlet & outlet COD load, COD removal rate, Total Suspended Solids and Biogas flow) to ascertain the correctness and accuracy of the information collected. The analysis was mainly qualitative and content analysis method has been used for the study analysis. Content analysis is an indigenous communication research in social sciences (Krippendroff, 2012). Content analysis is a method of analysing written, verbal or visual communication messages (Cole, 1988). To fulfil the objectives of the study, the following methodology was used.

3.3.1 Estimation of biogas production

UASB daily Flow volume of inlet & outlet COD load, COD removal rate, Total Suspended Solids and Biogas flow were tabulated separately. A Flow duration curve was plotted for each variable. From the Flow Duration graphs, Values at 50% confidence levels of inlet & outlet COD load, COD removal rate, Total Suspended Solids and Biogas flow curves were obtained. Calculations were done based on the confidence levels of the variable to estimate the daily biogas flow from the Effluent Treatment Plant. In doing so the relationship between the volume of biogas generated to waste water flow and treatment was ascertained.

3.3.2 Estimation of HFO use in boilers and Biogas required

Daily volume of HFO used by the boilers for steam production was tabulated. The average of the HFO used per day was obtained.

Daily volume of estimated steam consumed was tabulated. A flow duration curve of the estimated steam consumed was plotted. From the flow duration graph, estimated steam value at 50% confidence level was obtained. The estimated steam value was used to obtain the required volume of methane gas, able to run the boilers and produce the same volume of estimated steam. This was done to estimate the cost of HFO use and the savings made in using methane gas as an alternative source of fuel.

3.3.3 Equipments for the biogas system.

The estimated biogas volume was used to obtain the equipments for holding and passage of biogas. The main equipment are water scrubber, gas storage vessels, compressor and dual fuel burner.

3.3.4 The environmental impacts of excess biogas exposure.

This was done based on volume of biogas components analysis by SGS. A Portable Gas Analyzer probe was inserted at a point where the biogas flows to the gas flare. A certain volume biogas sample was siphoned into gas analyzer which recorded the percent volume and or ppm of each biogas components. Biogas samples were also collected using Tedlar bags. USEPA reference method 18 was applied to get the volume of Methane in the biogas stream. The analysis results which constitute biogas components volume were then tabulated as in Appendix 1.

3.4 Flow - Duration Curves

The flow duration curve is a cumulative frequency curve that indicates the percent of time specified discharges were exceeded or equalled during a given period. The biogas estimation flow data in Appendix 2 uses the total-period method and the discussions which follow in Chapter 4 are restricted to this method. Four Months data for COD Loads, Total Suspended Solids, and percent COD removal rate were taken. Percent Time Equalled or Exceeded was found by use of cumulative frequencies. A graph was then drawn of each data against Percent Time Equalled or Exceeded. A percentage of Confidence Level was then read using a Percent Time Equalled or Exceeded on the x-axis against the main parameter on the y- axis.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.0 Introduction

This chapter presents the results of the study. The results include: The relationship between biogas volume generated to waste water flow and treatment. The in-depth design analysis will have references on the data collected on the appendices. Analysis was done to ascertain the amount of methane gas equivalent to a litre of HFO able to burn and produce steam. Then a comparison was made in terms of cost saving when using methane gas as an alternative source of fuel.

4.1 UASB Measurements

The UASB influent and effluent parameters were gathered from June to September 2015 and tabled in Appendix 2. Data collected included :UASB inlet COD (mg/1) and UASB outlet COD (mg/1), Flow to UASB (m^3/day), UASB COD load (kgCOD/day), TSS (mg/1), COD removal volume, Biogas flow (m^3/day) and % COD removal. Each of the above parameter had varying data over the four month and an average volume of each was found using the duration curve method.

4.1.1 Inlet and Outlet COD Load

Relevant parameters include the following:

Chemical Oxygen Demand (COD) **-** This is the measure for the amount of carbon material that can be chemically oxidized. It is a measure for the amount of oxygen necessary to oxidize all the organic matter in the waste water. It represents the total amount of organic contamination.

Chemical Oxygen Demand (COD) Load is the Amount of COD that flows to the UASB per day (kg/day). This is a measure of both the amount of flow and the impurity of the waste water termed as load, entering and leaving the UASB, which is equivalent to;

$$\mathrm{COD_{Load}}=\mathrm{COD}\left(\frac{\mathrm{kg}}{m^3}\right)\times\ Flow\left(\frac{m^3}{day}\right) \qquad 4.1$$

Organic (or Volumetric) Loading (V_L) is a measure for the amount of organic matter that is treated every day per m^3 active reactor volume. It is given by;

$$V_L\left(\frac{kgCOD}{M^3.day}\right)=\frac{organic\ daily\ load\left(\frac{kgCOD}{dat}\right)}{active\ reactor\ volume}=\frac{COD_{load}}{active\ reactor\ volume} \qquad 4.2$$

Hydraulic Retention Time (HRT) - The hydraulic retention time is the time the waste water needs to pass through the complete reactor of waste water treatment plant. HRT is the average period of time that a soluble compound remains in a constructed reactor (Ramdhanie and Chakrabarti, 2014). HRT can be analysed using the equation 4.3 (Metcalf & Eddy, 2003):

$$HRT(h)=\frac{Reactor\ volume\ (m^3)}{Flow\ rate\left(\frac{m^3}{day}\ or\ \frac{m^3}{h}\right)}$$

$$HRT=\frac{V}{Q} \qquad 4.3$$

Where V is the reactor volume (m^3) and Q is the hydraulic flow rate (m^3/day, h=hours) Figure 4.1 shows the inlet COD$_{\mathrm{Load}}$ duration curve to the UASB. It shows the volume of organic matter treated per day i.e. the Organic (volumetric) Loading. The graph shows that at 50% confidence level, the COD$_{\mathrm{Load}}$ is 19,761kg/day. At 98% confidence level, the COD$_{\mathrm{Load}}$ is 10,950kg/day. The current UASB is designed to process a COD$_{\mathrm{Load}}$ of 32,280kg /day (32Tonnes of waste water) by the manufacturer. This means that the COD$_{\mathrm{Load}}$ should not exceed 32 tonnes or else if more will choke and kill the bacteria in the UASB. From Figure 4.1, it can be seen that the plant operates within capacity of the UASB design.

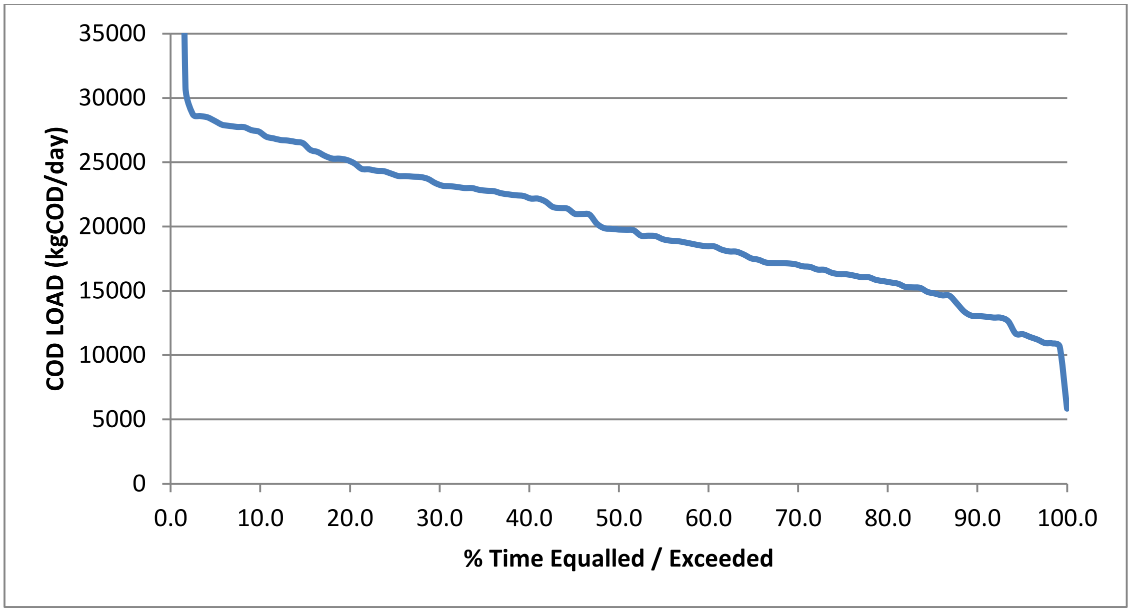


Figure 4.1: Inlet COD Load Duration Curve

4.1.2 Inlet Flow COD Duration Curve

The inlet COD represents the total amount of organic contamination. Flow to UASB (m^3/h) is independent to COD, reason being, the effluent coming from the plants has varying rate of COD. This is because of the varying, difference and intensity of activities taking place in the different plants. From Appendix 2, the COD measurement vary a lot, hence duration curve is used to get the per cent confidence value that the UASB can treat. Figure 4.2 shows the inlet purity (COD) of water to UASB before treatment. From Figure 4.2, it can be seen that at 50% confidence level the inlet COD is 6140mg/l which is higher than the UASB design value .The maximum design concentration of waste water (COD) is 4474 mg/l. COD concentration above the design specification can result in chocking and killing the bacteria. Waste water of higher COD more than the design value of 4474mg/l, is channelled to the calamity tank where it is dosed to incoming waste water of less COD to reduce the concentration to a value lower or equal to 4474 mg/l. The inlet COD is above the design value for over 80% of the time. This implies that dosing is a key procedure in the waste water treatment.

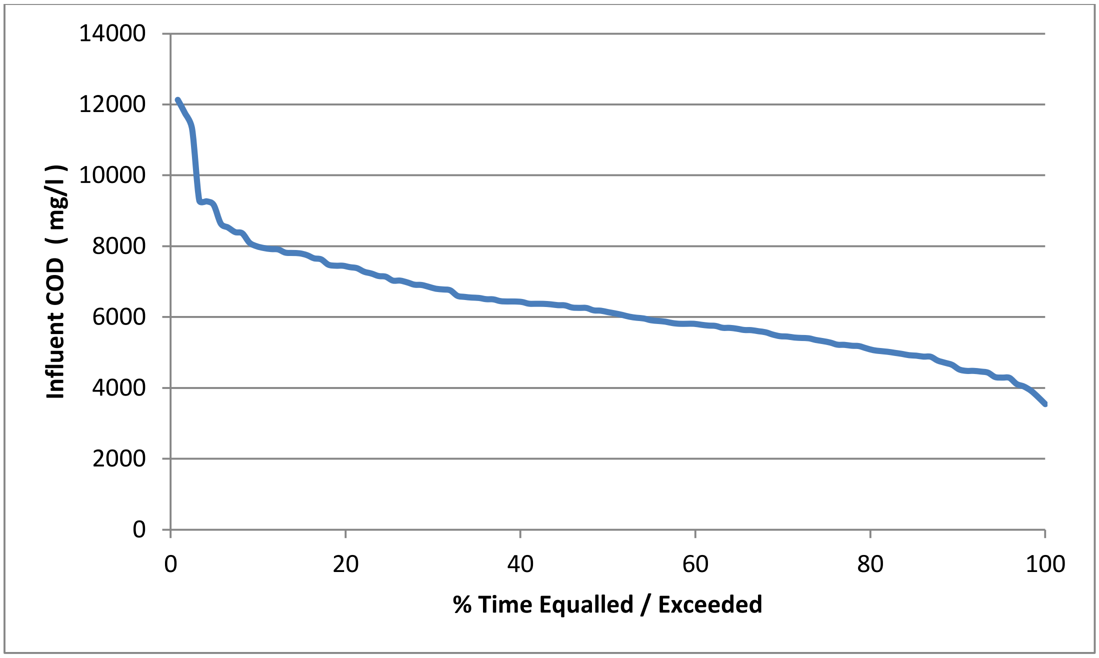


Figure 4.2: Inlet COD duration curve

4.1.3 UASB outlet COD duration curve

After treatment the effluent is measured to determine if the level of COD is below 900mg/1 that can be discharged to the sewers and not cause harm to the environment. Appendix 1 shows the data for the effluent from UASB used to come up with a duration curve. Figure 4.3 shows that at 50% confidence level the treated effluent from UASB has a COD concentration of 464mg/l which is less than 900mg/l, the design effluent COD.

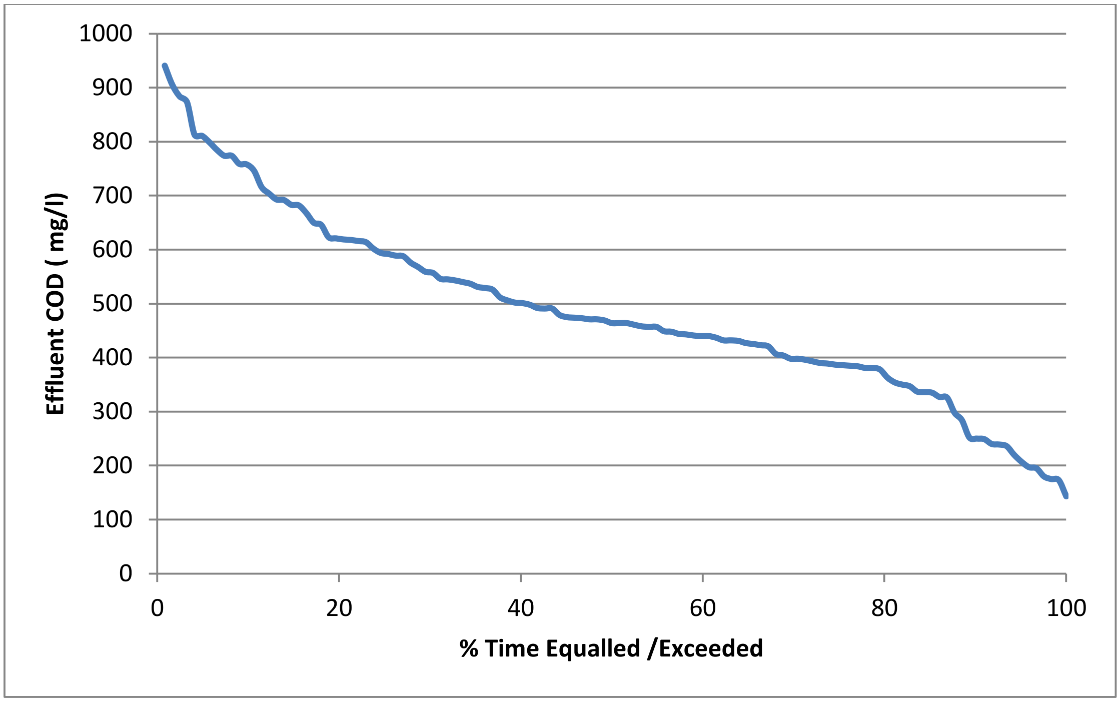


Figure 4.3: UASB outlet COD duration curve

The difference between the Inlet COD to UASB and outlet COD from the UASB gives the $COD_{removed}$ that the bacteria has consumed hence giving out biogas. This is the COD value converted to biogas .Assuming that the Influent COD concentration is diluted through dosing from 6140mg/l to 4400mg/l.

$COD_{removed}$ = Influent COD – Effluent COD (Rumana Riffat, 2013) 4.4

Assuming that the influent COD is diluted to 4400 mg/l

$COD_{removed}$ = 4400mg/1-464mg/l

$COD_{removed}$ = 3,936mg/1 which is converted to methane gas

4.1.4 Biomas Yield

Bacteria in the UASB feed on the food (substrate utilization). Some of the substrate is then converted to biomass, while part of it is converted to waste products and energy, as well as new cells. The biomass in the UASB is usually analysed in terms of concentration of Total Suspended Solids (TSS). This is the measure for the amount of solids in suspension (mg/l). TSS measures the non-filterable materials contained in a sample and contains fixed inorganic materials and organic volatile compounds (Ramadhanie and Chakrabarti, 2014). Figure 4.4 is a duration curve of the Total Suspended Solids. The graph shows that at 50% confidence level total suspended solids is 197mg/1. This is the amount of non-filterable material present in suspension.

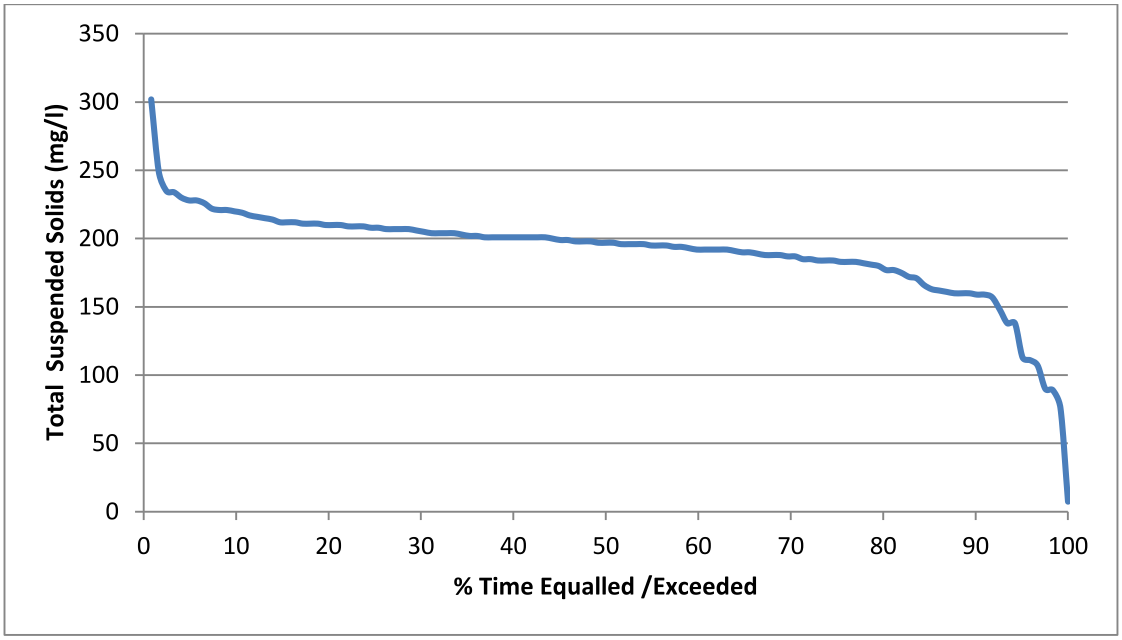


Figure 4.4: Total Suspended Solid Duration Curve

The substrate concentration can be analysed in terms of COD, hence

Biomass yield = $\frac{TSS\ produced\ mg/l}{COD\, removed\, mg/l}$ (Riffat Rumana, 2013) 4.5

Biomass yield = $\frac{197\text{mg/l}}{3936\text{mg/l}}$

Biomass yield =0.05

From Figure 4.3 the effluent COD at 50% confidence level is 464mg/l. The COD equivalent of TSS is given by;

COD equivalent of TSS = $\frac{\text{Effluent COD (mg/l)}}{\text{TSS Produced (mg/l)}}$ 4.6

COD equivalent of TSS = $\frac{464\text{mg/l}}{197\text{mg/l}}$

$COD\ equivalent\ of\ TSS = \frac{2.4mg\ COD}{mgTSS}$= 2.4mg COD / mg TSS

For every 2.4 mg COD, one mg of TSS is produced.

TSS is the analysis of non-filterable materials in the effluent waste water. The presence of suspended solids in the effluent waste water indicates a low performance of the UASB digester. The COD and total solids reduction gives a picture of the reactor performance, hence the bacteria. Higher COD greater than 900 mg/l in the effluent waste water indicates that the bacteria are not efficient; hence the performance of the UASB digester is poor.

4.1.5 Percent COD Removal

COD Removal Efficiency -The efficiency of a system is the relation between the percent amount of COD that enters the system with the raw waste water and the amount that leaves the system with the clean effluent.

The Chemical Oxygen Demand (COD) measurement is one of the important parameters used to access the bioreactors organic removal efficiency and is a measure of the waste water influent and effluent primary dilution (Ramadhanie and Chakrabarti, 2014).

$$\%COD\ removed = \frac{Influent\ COD - Effluent\ COD}{100} \qquad \text{(Speece R.E, 1996)} \qquad 4.7$$

Figure 4.5 shows the % COD removed which is a reflection of the substrate utilization in the UASB. From Figure 4.5 the graph shows that, at 50% confidence level the % COD removal is 92%, meaning the efficiency of the bacteria in substrate utilization at 50% confidence is 92%.

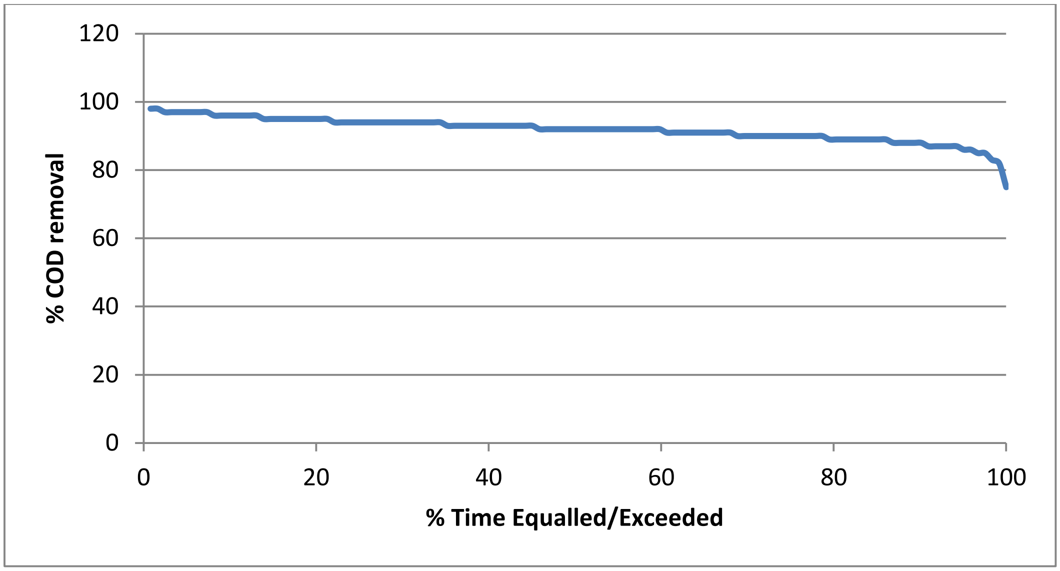


Figure 4.5: COD Removal Duration Curve

The methane COD is the volume of oxygen needed to oxidize methane completely to carbon dioxide and water as follows.

$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$ + Energy (Riffat Rumana, 2013) 4.8

From the above Equation 4.8 (2 × 32) or 64g oxygen are required to oxidize one mole (or 16g) of methane. The volume occupied by one mole of gas at standard temperature and pressure (STP) conditions of 0^0C and 1 atm is 22.4L so the methane equivalent of COD converted under anaerobic condition is;

$$Methane\ Volume = \frac{22.4L/mol}{64gCOD/mol}$$

$$= \frac{\frac{0.35LCH_4}{gCOD}\ or\ 0.35m^3CH_4}{kgCOD} \qquad (Riffat\ Rumana, 2013) \qquad 4.9$$

Equation 4.9 gives an estimate of the maximum volume of methane gas produced per unit of COD at STP conditions. Figure 4.6 shows the COD mass balance in the UASB. The input is the influent COD which is a measure the purity of incoming influent and contains the food to the bacteria. After bacteria feeding on food in the waste water, new cell are formed and biogas produced. The output is the treated waste water (effluent COD), which is less harmful to the environment and is discharged to the sewer lines.

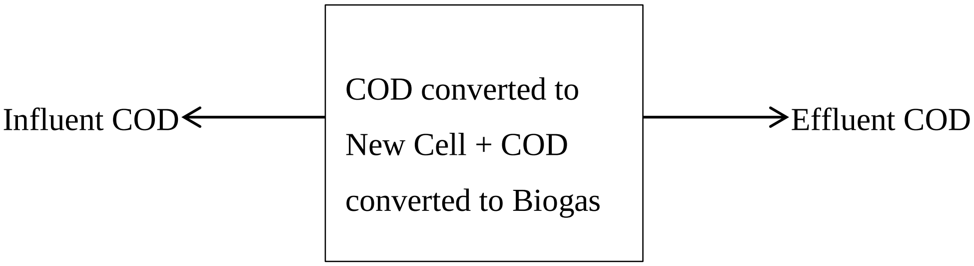


Figure 4.6: COD Mass Balance

Figure 4.6 can be summarized using equation Eq.5.0

$COD_{Removed} = COD_{New\ Cells} + COD_{Biogas}$ 5.0

Conducting a steady state mass balance for the COD in the anaerobic reactor gives;

$COD_{in} - COD_{out} - CODTSS - COD_{methane} = 0$ (Riffat Rumana,2013) 5.1

Influent COD – Effluent COD – COD converted to new cells – COD converted to Methane = for no Accumulation

During fermentation changes in COD can be accounted for by COD balancing. Instead of oxygen accounting for the changes in COD, methane production accounts for the COD loss in the reactor.

4.2 Estimation of Biogas Production

The composition of biogas produced per day at Kenya Breweries Limited contains 64% methane gas (Appendix 1), % COD removal is 92% (Figure 4.5), Biomass yield 0.05 (Equation 4.5) at 38.5^0C (Appendix 2). The total gas produced per day is computed follows;

COD Load $_{in}$=19,761kg/day at 50% as shown by Figure 4.1

COD Load$_{out}$=(1-0.92) 19,761 kg /day=1,581 kg/day

COD_{Tss}=%COD Removal × COD Load / day × biomass yield × COD equivalent of TSS (Riffat Rumana, 2013) 5.2

COD_{TSS}= 0.92 × 19,761 × 0.05 × 2.4

COD_{TSS} = 2,182kg/day

If $0=COD_{in}–COD_{out}-COD_{TSS}-COD_{methane}$

Hence

0=19,761kg /day – 1,581kg /day-2,182kg/day-$COD_{Methane}$

$COD_{Methane}$=15,998kg/day

The volume (V) occupied by 1 mole of methane gas at 38.5^{0}C.from the ideal gas law at 1 atmosphere

PV = nRT

but for 1atm

V = nRT (Riffat Rumana, 2013) 5.3

Where; n = number of moles

R = Ideal gas constant = 0.08207atm.L/mole.k

T=temperature, K

P= pressure, atm

Hence T = 273 +38.5 = 311.5K n=1 mole, p = 1 atm

$$V = \frac{1mol \times 0.082057atm.L/mol.k \times 311.5k}{1\ atm} = 25.57L$$

Calculating the methane equivalent of COD converted under anaerobic conditions

$$\frac{25.57L/mol}{64gCOD/mol} = 0.399L\frac{CH_4}{gCOD}\ or = 0.399m^3CH_4/kgCOD$$

Calculating methane gas produced

CH_4 produced = 15,998kg/day × 0.399m^3CH_4kg/COD= 6,383m^3/day

The total gas produced if 64% is methane (Appendix 1, Final Report).

$$Total\ gas = \frac{6{,}383m^3/day}{0.64} = 9{,}973m^3/day$$

Thus at 50% confidence, if UASB is loaded with 19,761kgCOD/day (19.8T) then 9,973m^3Biogas is produced with 64% (6,383m^3) Methane gas.

4.2.1 Measured Biogas Volume Flow

As per Appendix 2B, measured biogas flow data varies a lot hence the data was used to plot a biogas duration curve as shown in Figure 4.7. The variation is due to the large fluctuations, in the strength (COD concentration) of the brewery waste water. At 50% Confidence level Figure 4.7 shows that the Measured Biogas flow is 9,090 m^3/day and from 4.2, the theoretical Biogas Flow is 9,973 m^3/day. Measured biogas flow is less because of the differing pressures which depends on the variations in the waste water loading rate and the inlet COD concentration. This is attributed to the conditions at digester and the measuring device .Measured biogas flow rate is at 91.1% of the theoretical value, which is a good approximation.

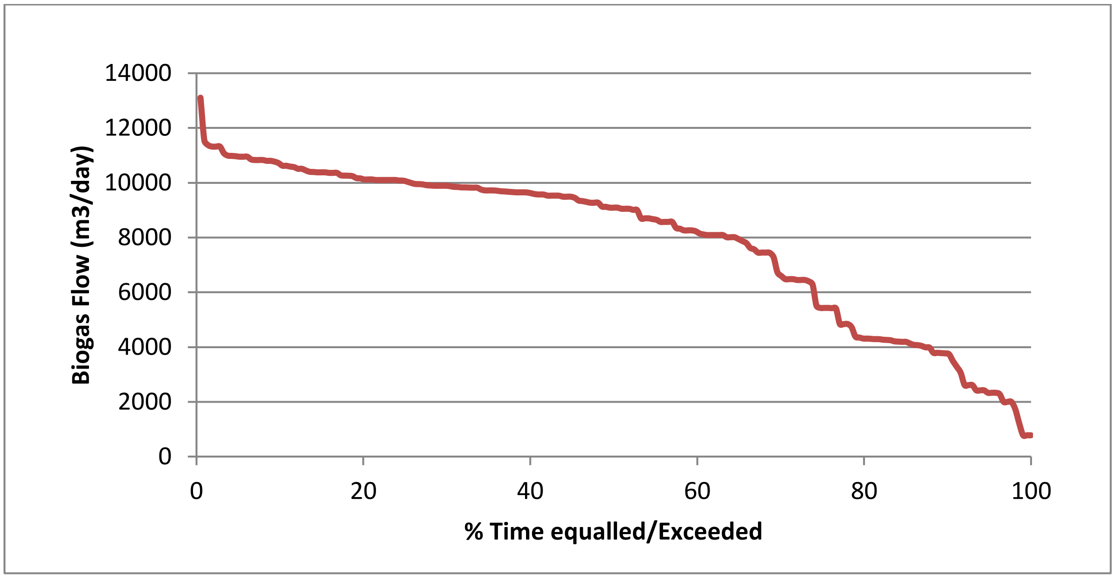


Figure 4.7: Measured biogas Flow Durative Curve

At 50% confidence level the theoretical biogas volume is more (9,973 m^3/day) while the measured at the same confidence level is 9,090m^3/day, hence a storage vessel is needed as a buffer vessel. At 98% confidence level the calculated biogas volume is less (5,527 m^3/day), hence storage is not necessarily needed as the dry gas can be burned directly as it flows from scrubber to the boilers through the dual fuel burners. In this study a storage vessel or a buffer tank is required to store the gas when HFO is in use.

4.2.2 COD Removal versus Biogas Production Profile

Figure 4.8 shows the relationship between the COD removed which is then converted to biogas and the rate of biogas flow. The higher the COD removal rate, the higher the biogas volume flow produced from the process. The importance of the UASB digester treatment efficiency is to reduce the total solids in the influent, entering the digester.

The UASB process consistently removed on average 90-92% of chemical oxygen demand (COD) in waste water containing brewery waste at 38^0C in 24hrs for loading rates up to 32tonnes/day. This higher rate of COD removal indicates a very high efficiency from the digester hence high biogas yield.

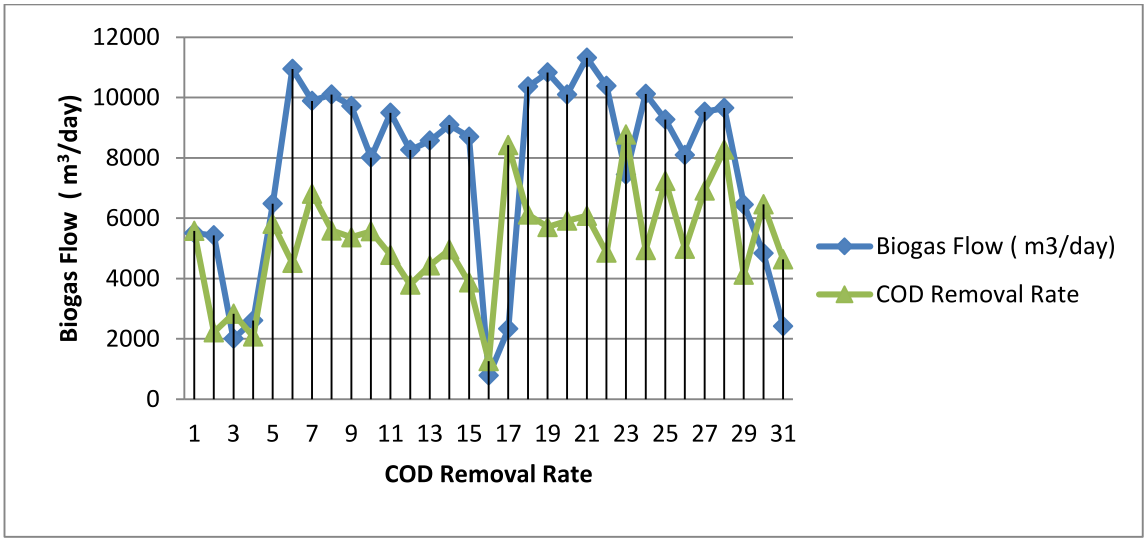


Figure 4.8: Biogas Flow Graph

4.3 Financial Analysis

Analysis was done to ascertain the amount of methane gas equivalent to a litre of HFO able to burn and produce steam. Then a comparison was made in terms of cost saving when using methane gas as an alternative source of fuel.

Data of estimated steam flow from Appendix 3 were used to come up with the estimated steam utilized duration curve. Figure 4.9 above shows that at 50% confidence level, the estimated steam utilized per day is 404.58tonnes.

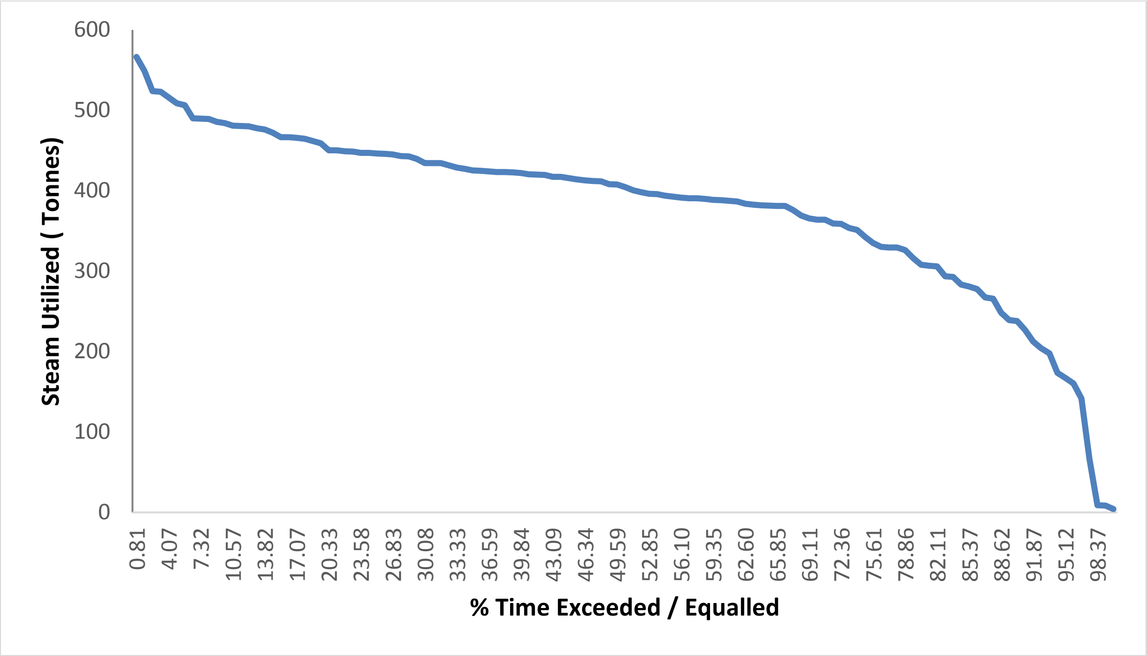


Figure 4.9: Boiler Steam Duration Curve

Data of HFO utilized from Appendix 4 was used to come up with the estimated average HFO utilized per day. On average the amount of HFO used daily is 30,000Litres.

Using 30,000litres of HFO per day to run 3 boilers alternatively, an estimated volume of steam produced and consumed is 404.58tonnes per day. Hence 1250 l/h of HFO produces 17tonnes of steam per hour.

4.3.1 HFO versus Methane Usage

3 Boilers alternatively HFO usage is 30,000Litres/day= 1250 l/h while Methane generation = 266m^3/h

At 50% confidence level COD load is 19,761Kg Estimated Methane gas produced (Section 4.2.6)

6,383m^3/ day which is 266m^3/h

38MJ = 1m^{3}natural gas

$$\frac{266m^3 \times 38MJ}{1m^3} = 10108MJ$$

1MJ=0.28Kwh

$$\frac{10108\text{MJ} \times 0.28\text{Kwh}}{1\text{MJ}} = 2830\text{Kwh}$$

1,162.2Kwh = 1ton steam per day

$$\frac{2830\text{Kwh} \times 1}{1,162.2\text{Kwh}} = 2.4\text{tonnes}$$

266m^3/h of Methane gas, when burned in boiler produces 2.4tonnes/h (2400kg/h) of steam per hour against steam consumption of 17tonnes/h. To produce 17 tonnes of steam we need 1884m^3/h of Methane gas.

The Current UASB digester is designed to process COD Load of 32000kg/day. The theoretical methane gas volume is 6,383m^3per day. The UASB inlet Load can be increased to treat more waste water and not underutilizing it. At 4% confidence level from Figure 4.1, the Volumetric Load is 30,000Kg COD/day which is still within the design range of the UASB of not more than 32,000KgCOD/day.

Calculated Biogas gas produced with a COD Load of 19,761kg/day is 9,973m^3/day, while Methane gas produced is 6,383m^3/day (266m^3/h) which produces 2.4tonnes of saturated steam per hour against consumption of 17tonnes /h.

4.3.2 Cost Analysis of HFO and Savings of Methane Gas Use as an Alternative Fuel

From Figure 4.9 the estimated steam is 404.58tonnes per day (17tonnes per hour), at 50% confidence level. Table 4.1 shows a breakdown of thermal energy needed per department with reference to estimated steam per hour (17tonnes per hour). Methane gas produces 2.4tonnes/h of steam, which is less than what is needed by individual departments.

Table 4.1: Departmental Steam Usage Vs Steam from Methane Gas

DEPARTMENT	ENERGY PERCENTAGE	THERMAL ENERGY (tonnes/h)	METHANE ENERGY (tonnes/h)
Packaging and Spirits	56%	9.52 tonnes	2.4 tonnes
Brewing	32.1%	5.45tonnes	
Combustion losses	11.9%	2.023tonnes	

Loading the UASB with COD_{Load} of 19.8tonnes gives an estimated Methane gas of 6,383m^3/day. The same volume of methane gas can produce an estimated steam of 57.6 tonnes per day against 404.58 tonnes per day of steam, which is consumed by brewing, packaging and spirits. The calculated volume (6,383 m^3/day) of methane gas can run the boilers for only 3.4hours per day, producing an estimated steam of 57.6tonnes. HFO is then used to run the boilers for the next 21hours to produce an estimated steam of 347 tonnes. Table 4.2 shows split thermal energy use hours if methane gas produced per day is used to serve one department at a time. Packaging and spirits would use the methane gas harvested in one day for 13hours alone in day, while brewing can make use of the same volume of methane gas in 17hours in a day. If all the departments are to use the same volume of methane at the same time, then the entire KBL site will run for 5hours alone on Methane gas while 19hours run will be on HFO. Immediately the volume of methane gas drops, the boiler has to switch to HFO to maintain boiler combustion. The dual fuel burner can switch automatically from one fuel to the other upon detection of zero supply of one fuel.

Table 4.2: Split Thermal use hours per department

DEPARTMENT	METHANE GAS USE HOURS	HFO USE HOURS
Packaging and Spirits	13hours	11hours
Brewing	17hours	7hours
KBL Plant (Boilers)	3.4hours	20.6 hours

Using methane gas for 3.4hours in a day saves 4,250litres of HFO. Methane gas produced from the ETP per day can only run the boilers alternating for 5hours only supplying steam to the entire KBL plant. Table 4.3 illustrates the annual savings that can be achieved from the entire KBL plant upon using methane gas as an alternative source of fuel. The savings amount to Ksh.63,750,000.00 per annum. If a dedicated methane gas boiler is used to supply individual departments separately e.g. Brewing department, then HFO will be used in another boiler simultaneously for supplying steam to Packaging and Spirit department and vice versa.

Table 4.3: Savings from using Methane Gas

Section	HFO saved in a day for 3.4hours (1,250Litres/h)	Cost of HFO saved in a day (@Ksh.50.00 per litre	Savings in one year 300 days (Ksh)
KBL Plant	4,250	KSH.212,500.00	KSH.63,750,000.00

CHAPTER FIVE

BIOGAS EQUIPMENTS SELECTION

5.0 Equipments Selection

The methane gas produced at the ETP is enough to run the boiler for 3.4hours hence redesigning the boiler system for biogas use is necessary. Equipment were sized to enable use of biogas. Additional equipment are to be included to the existing ones, to be able to clean and store the biogas rather than flaring alone. The proposed plant layout as in Figure 5.1 is made of: Water scrubber Unit, Compressor, Gas storage vessel and Dual Fuel burner. Biogas as byproduct from the UASB digester flows to the water scrubber. The biogas is cleaned at the water scrubber producing methane gas. The methane gas is compressed by the compressor and channeled to the gas storage tank. An automatic drip trap is to be installed in several piping points. The drip trap is developed for continuous collection and removing safely of condensate from low points in gas piping. The boiler burns the methane gas through the dual fuel burner. The rotary dual fuel burner is able to accommodate both the methane gas and HFO. The burner is able to switch from one fuel to another depending on the alternative fuel availability. In the event the gas level dwindles in the storage tank, HFO is automatic siphoned into the burner. In the event the whole plant is on shut down and the methane storage tank is full, any excess gas produced will be flared up but an additional methane storage vessel can be added to collect gas rather than flaring.

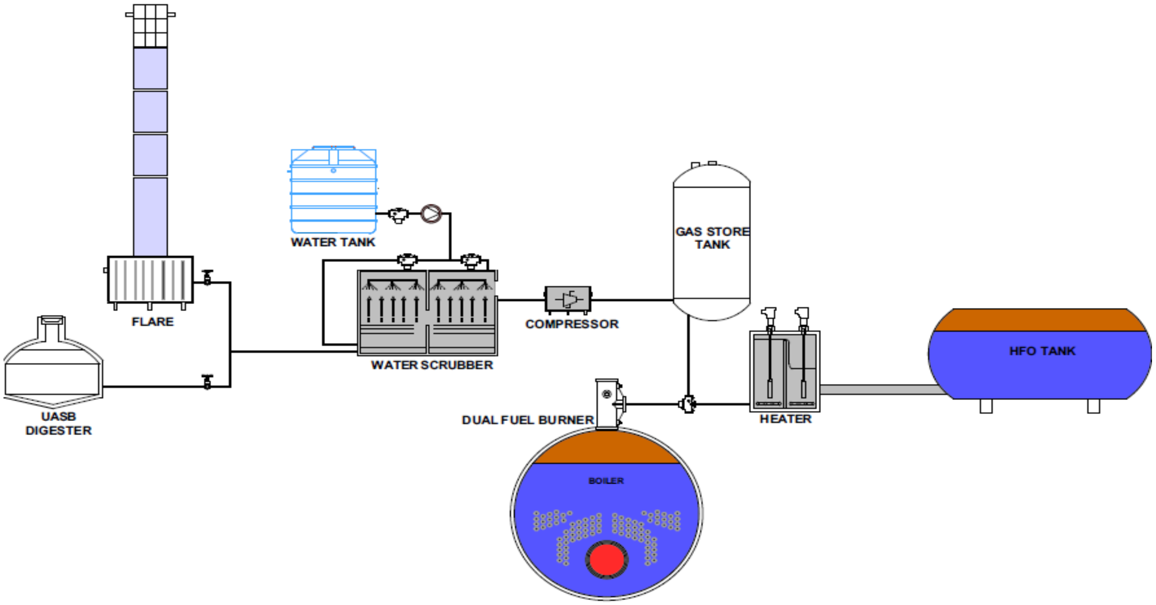


Figure: 5.1: Biogas Plant Layout

Condensate (Drip Trap) installed after the UASB removes water vapour before it cools and condenses in the piping. Varec Biogas 245Automatic Drip Tap removes Condensate or water vapour before being compressed .Removal of water vapour prevents corrosion and firing issues in the boiler duel fuel burner, ensuring that maintenance and reliability are optimized. According to Ryckebosch et al., (2011), excess water vapour from biogas can be removed through sensible pipe walls, which condense and remove the moisture as water. Moisture traps, water traps, demisters or cyclone separators are physical separation methods which can be used to remove the condensed water.

5.1 Pressure Developed in the UASB Reactor

According to Dalton’s law, the pressure of a gas mixture is equal to the sum of the pressure each gas would exert if it existed alone at the mixture temperature & volume. The partial pressure of a gas is the pressure exerted by a particular component of a mixture of gases.

$P_iV_i=n\ RT$

Where, P_i = Partial Pressure each constituent

V_i= Volume of a gas component

T = Mixture Temperature in Kelvin

R =Ideal gas constant=0.082057 atm.L/mole.k

n = Component number of moles

The maximum gas pressure developed in the digester dome can easily be determined based on the biogas volume produced in a day. Biogas is a composition of different gases and so calculating the volume and molar number of the constituent gases is possible. SGS Company did analysis of the constituent of biogas. Table 5.1 shows the concentration of individual gases of biogas as shown in Appendix 2.Table 5.2 shows the percentage composition of the gases that make up biogas.

Table 5.1: Gaseous Concentration Result (Biogas Analysis as Appendix 2)

Parameter	CH_4	SO_2	H_2S	NO_x	CO	CO_2	O_2	Moisture content
Units	ppm	ppm	ppm	ppm	ppm	%v/v	%v/v	%v/v
Methane plant	635000	103	201.5	101	1037	38.33	1	15.5
Temperature	38.5^0C							

Table 5.2: Biogas Composition

Biogas Composition	%Concentration by mass
Methane	64
Carbon Monoxide	0.0002
Carbon dioxide	15
Hydrogen Sulphide	0.065
Nitrogen Oxide	0.0004
Sulphur Dioxide	0.0103
Oxygen	1
Moisture	15.5
Hydrogen	0.0064

The volume of each gas constituent in the mixture can be determined according to each composition.

Gas Volume = % Gas Composition x Biogas Volume

Calculated gas volumes are shown in Appendix 4

Density is given by:

$$\text{Density} = \frac{Mass}{Volume} \tag{5.4}$$

Mass and Mole of gases is at Appendix 5

The partial pressures of gas:

$$Partial\ pressure = \frac{number\ of\ mole \times gas\ constant\ \times temperature}{biogas\ volume} \tag{5.5}$$

$$= \frac{n_i RT}{V}$$

Partial pressure of gases are found in Appendix 4

The biogas saturates with water vapor hence the total pressure inside the digester is the sum of water vapor and 6 pressures of the dry gases .

At 38.5℃ temperatures vapor pressure is 53.5mmHg.

Total pressure developed in UASB is given by:

$P_{\text{Total}}=P_{\text{Methane}}+ P_{\text{Carbon dioxide}} + P_{\text{Carbon monoxide}} + P_{\text{HydrogenSulphide}}+P_{\text{WaterVapour}} +P_{\text{Sulphure dioxide}} + P_{\text{Nitric oxide}} + P_{\text{Hyrogen}}$ 5.6

= 0.105 + 0.006 +0.02+ 0.003 +53.5 +0.002+ 0.002+0.002+ 0.001

UASB Partial pressure of biogas (P_{Total}) = **53.64KPa (0.54bar)**

5.2 Compressor sizing and selection

The compressor will be used to draw methane gas off from UASB through the water scrubber and boost the pressure to feed the boilers. Raw methane gas from UASB will vary through the 24hours but on average the methane gas volume will be 266m^3/h.

The ratio of discharge pressure to suction pressure is the Compression ratio (R):

$$R = \frac{P_d}{P_s} \quad (P_d \& P_s \; must \; be \text{ "absolute" } values) \qquad 5.7$$

Table 5.3 shows the different R- value and the representation or equivalent of stages. A single R value represents a single stage compressor.

Table 5.3: Compression ratio (R) Vs number of stages

R-Value	Number of Stages
1-3	Single Stage
3-5	Normally single Stage, Occasionally two-Stage
5-7	Normally two Stage, Occasionally single-Stage
7-10	Two stage
10-15	Usually two-Stage, Occasionally three-Stage
15+	Three Stage

Comparing Single Stage and two-Stage Compressors when both are installed to do the same application (same capacity, gas and pressure). Single and two stage compressors are differentiated by the number of times that the gas get compressed between the valves at the inlet and the nozzles at the burner. In a single stage compressor, the gas is compressed one time while in two stage compressor; the gas is compressed twice for double the pressure.

In this research project, the compressor that fulfills the following criteria is selected from the catalogue for compression purpose.

1. The handled gas is Methane gas
2. Methane flow rate = 266m^3/hr or 4.4m^3/minute
3. From the catalogue on Appendix 5 compressor type GG 90 VSD of maximum flow rate capacity of 900Nm^3/hour was chosen
4. Sunction pressure: Inlet compressor pressure expressed as P_s= 0.54bar
5. Discharge pressure: Discharge compressor pressure expressed as P_d=16bar max working pressure for VSD machines (Appendix 5, Technical specifications)

P_s= 0.54bar + 1.013bar= 1.553bar-a

P_d=16bar + 1.013bar=17.013bar-a 5.8

$$R = \frac{P_d}{P_a} = \frac{17.013}{1.553} = 10.95$$

The R value is 10.95 from the Tables 5.4 it shows that a Two Stage compressor is suitable. Table 5.4 explains the difference between single stage and two stage compressors. Two stage compressors have lower discharge temperature and have a lower BHP. The lower BHP means the work done during compression is reduced thus saving power. For this research project a two stage compressor is suitable.

Table 5.4: Single & two stage compressor comparison

Parameter	Single Stage	Two Stage
Discharge Temperature	Higher	Lower
BHP	Higher	Lower
Initial Cost	Lower	Higher
Overall System Complexity	Lower	Higher

Biogas Compressor

According to James L. Waish et al., (1988), a gas compressor suitable for flammable gases is better for biogas compression. This type of compressor differs from regular compressors in several aspects:

1. The cylinder is located further from the crankcase.
2. Absence of non-ferrous metals
3. Controls Condensate
4. The suction side used to wash out condensate
5. Gas leaks and from the crankcase and explosion are prevented by the provision of passage ways that vent out.
6. Contaminants pass through the designed inlet and exhaust ports instead of collecting in the compressor.

From Appendix 6 compressor catalogue, Technical specifications Atlas Copco GG 90 VSD. Compressor type (with Variable Speed Drive) from the Atlas Copco is selected for this process.

5.3 Water scrubber design

Figure 5.2 shows a schematic diagram of a water scrubber. The raw biogas is pumped from below and passes through the scrubbing vanes as water is sprayed from the top of the scrubber. Methane gas is harvested from the top of the scrubber.

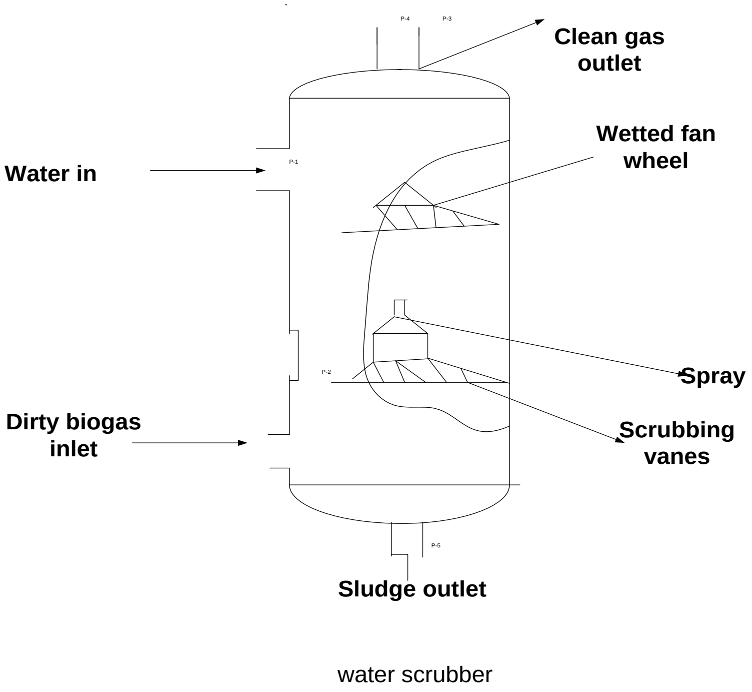


Figure 5.2: Water Scrubber

The calculated biogas volume $(V_{gc})$is given as;

(V_{gc})=9,973m^3/day (section 4.2)

Since the scrubber works for 24hr/d

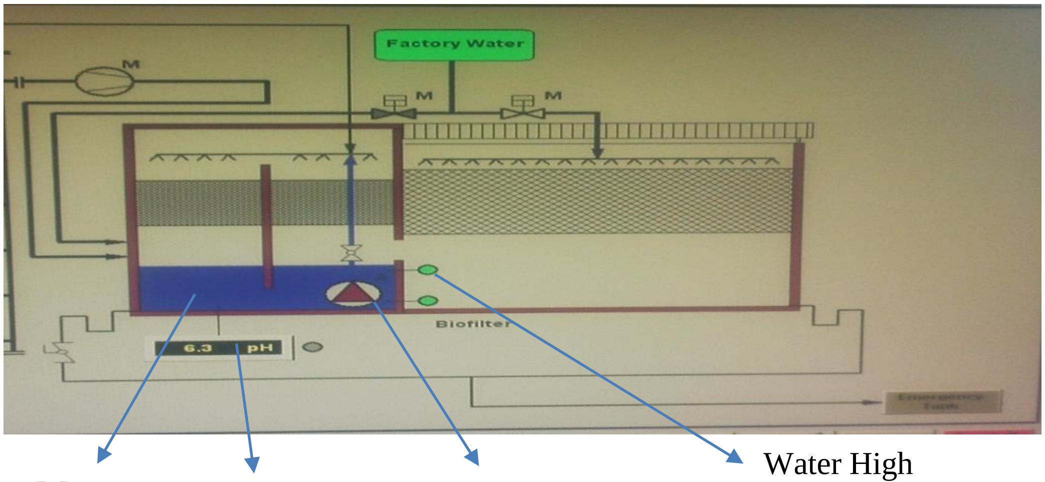
$$V_{gc} = \frac{9{,}973}{24m^3/d}$$

=416m^3/h

Allowing for Volume Safety allowance of 40%, we have a gas volume of 582 m^3/h

Existing Biofilter

Figure 5.3 shows the existing biofilter which is currently being used to absorb off gases that cannot be flared. The biofilter has a water tank of capacity 60m^3. Water of PH 5 is put in the tank to the high level probe .Biogas from the UASB passes through the biofilter and sprayed with water in a counter clockwise direction. The passenger gases are dissolved in the water, leaving methane gas to escape. Since the water keep on recirculating as biogas passes, the PH increases. The water is changed when the PH is above 6.2 which takes around 4 days .The existing biofilter can be modified to a water scrubber hence dispel bad odour as it cleans the raw biogas.



Water

PH Meter

Water Pump

Water High Level Probe

Figure 5.3: Existing biofilter

Figure 5.4 shows a schematic representation of a modified biofilter to a water scrubber. Raw Biogas can be passed in it for cleaning and channelled to the compressor.

Water pump sprays water from the top as raw biogas fed from the bottom of the scrubber flow up. During the counter flow of water and biogas, the water strips off passenger gases from the biogas and insoluble methane gas flows out of the scrubber.

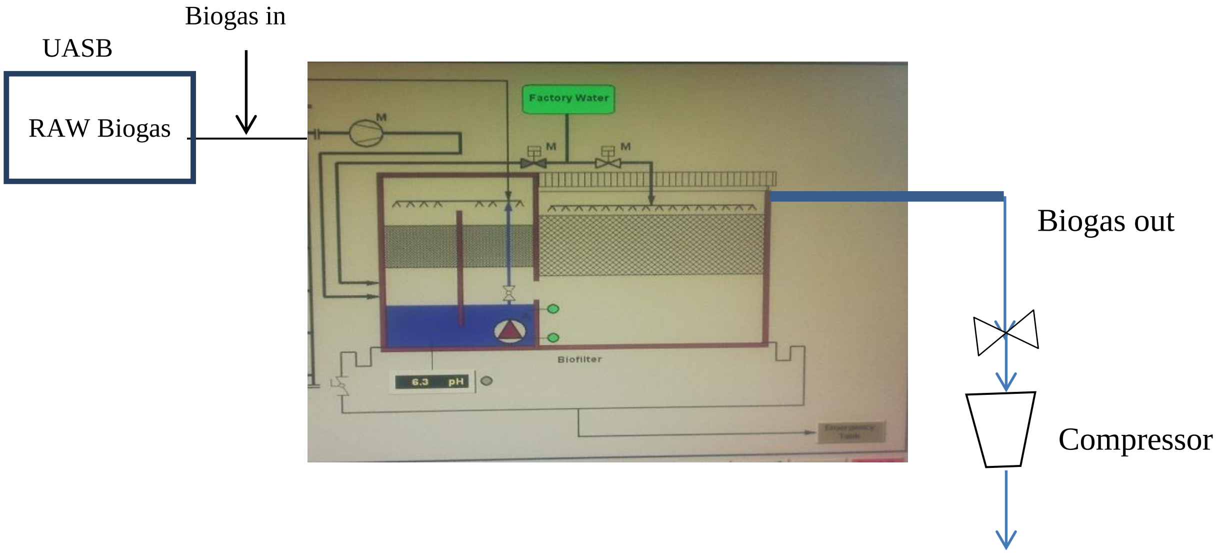


Figure 5.4 Modified Biofilter

5.4 Methane Gas Storage Tank Design

Methane gas flowrate =266kg/h

Methane gas density = 0.668kg/m^3

$$Volume\ of\ methane\ gas = \frac{Methane\ gas\ flowrate}{Methane\ gas\ density} \qquad 5.9$$

$$= \frac{266kg/h}{0.668kg/m^3}$$

= 398 m^3/h

Volume of methane gas =266 m^3/h= 6383m^3/day

$$P_l = \frac{nRT}{V}$$

$$= \frac{(398 \times 8.314 \times 311.5)}{9552}$$

= 107.9N/m^2

P_1 = 0.1kPa

Choosing a compression ratio of 1:10 (Sinnot, 2004)

i.e.$\frac{P2}{P_1}$ = 10

Therefore, P_2 = 1kPa

For the compression of methane gas

$$P_1V_1 = P_2V_2 \qquad 6.0$$

Therefore, the compressed volume of methane gas V_2 is;

$$V_2 = \frac{P_1V_1}{P_2}$$

$$V_2 = \frac{(0.1 \times 9973)}{1} = \quad 997.1\text{m}^3$$

V_2=997.1m^3

Allowing for 20% Volume safety allowance

$$V_2 = \frac{997.1}{0.8}$$

V_2= 1246m^3/day

Storage Volume and Energy Density

Compressing methane gas to higher pressures reduces its mass to a smaller volume. The increase in methane gas compression costs is as a result of higher compression ratio. For adiabatic compression, with no heat transfer across the system boundary (Q=0), thermodynamic relation by (Sinnot, 2004)

$$P_1V_1^k = P_2V_2^k \qquad 6.1$$

Where k = Adiabatic ratio C_p/C_v = 1.3 for methane gas

V_1 = Initial volume of methane that the plant produces per day

P_2 = Compressed raw biogas pressure (16bar) as compressor output is selected

V_2 = Compressed volume

Substituting the values

V_1=6,383m^3/day, P_1 = 0.1Kpa, P_2 = 16Kpa, V_2 = ? , k=1.3 for methane gas

$P_1V_1^k = P_2V_2^k$

$0.1 \times 6{,}383^{1.3} = 16V_2^{1.3}$

$V_2=128.7m^3$

Allowing for 20% Volume safety allowance

$$V_2 = \frac{128.7}{0.8}$$

$V_2=160.9m^3$

Compressed methane gas is first stored in storage vessel of capacity $160.9m^3$ hence channeled to the dual fuel burner. This forms a steady supply of the gas.

5.5 Methane Gas Piping and Instrumentation

Figure 5.5 shows the proposed biogas plant pieces of equipment and their interconnections for biogas collection, treatment and final use in the boilers. Piping and Instrumentation diagram (P and I diagram or PID) is an Engineering Line diagram that shows the engineering details of machines, fittings and valves, piping instruments and their arrangements (Sinnot, 2005). Throughout the plant the piping system parameters are similar and differ only on the pipe length, due to different functions of the plant layout.

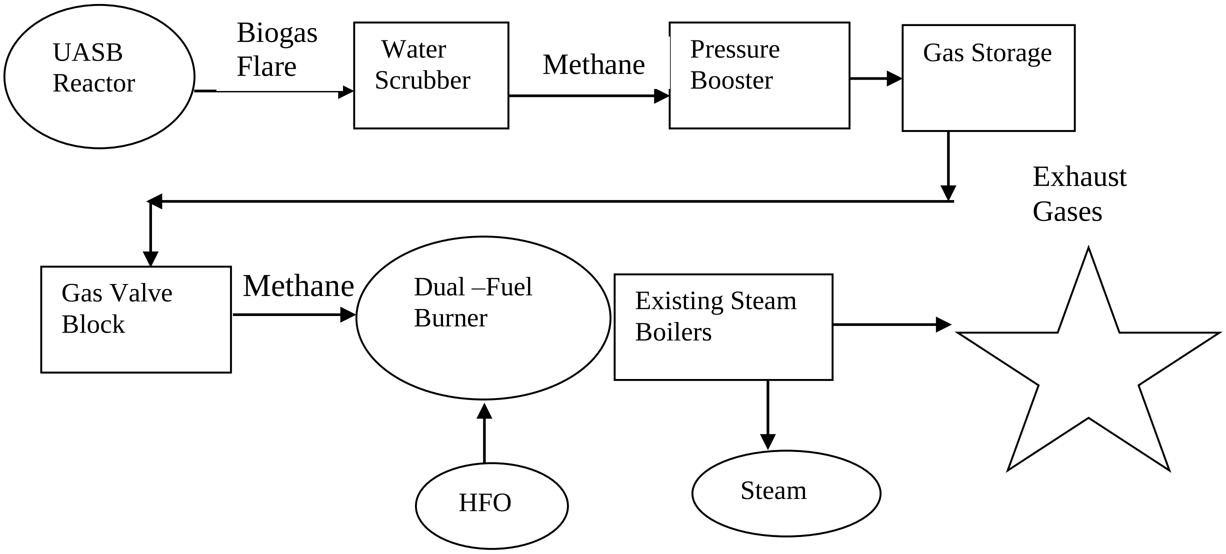


Figure 5.5: Biogas Collection Flow Diagram

5.5.1 Estimation of Pipe Diameters

The British Standard 5500 formula for pipe thickness (Sinnot, 2004):

$$t = \frac{pd}{20S_d + P} \qquad 6.2$$

Where: t = pipe thickness (mm)

P = internal pressure (bar)

d= pipe diameter (mm)

S_d= design stress at working temperature (N/mm^2)

Taking the internal pressure to be the pressure of the material in the pipe and using equation 6.5.

$$P_{internal} = \frac{Mass\,flow\,rate \times volumetric\ flowrate}{\left(Cross\,section\,area\,of\,pipe\ (\pi d/4)\right)^2} \qquad 6.3$$

Schedule number is used to specify pipes (based on the thin cylinder formula).
The schedule number is defined by:

$$Schedule\ number = \frac{P_s \times 1000}{S_s} \qquad 6.4$$

Where,

P_s= safe working pressure, 1b/in^2 (or N/mm^2),

S_2= safe working stress, 1b/in^2 (or N/mm^2)

Schedule 40 pipe is mainly for general purposes.

Sinnot (2004) established that for carbon steel, the safe working stress for butt welded steel pipe is 41.4N/mm^2

Methane density =0.668kg/m^3

$$\text{Mass flow rate} = \frac{270\text{ kg/h}}{3600\text{s}}$$

Mass flow rate = 0.08 kg/s Raw gas

$$Volumetric\ flow\ rate$$

$$= \frac{Mass\ flow\ rate}{Density} \qquad 6.5$$

$$= \frac{0.08kg/s}{0.668kg/m^3}$$

Volumetric flow rate = 0.11 m^3/s

Pipe Diameters Calculation

For carbon steel pipe (Sinnot, 2004):

d, optimum = 293 $G^{0.53}\rho^{-0.37}$ 6.6

where G = mass flow rate

ρ = density

thus, using carbon steel pipe with schedule number 40:

d, optimum = 293 $\times 0.08^{0.53} 0.668^{-0.37}$

d, optimum= 69.3mm

Cross sectional Area = $\frac{\pi}{4} \times d$ 6.7

$= \frac{3.14}{4} \times 69.3 \times 10^{-3}$

Area = 0.05m^2

5.6 Sizing of Dual Fuel Burner

The fossil fuels seem unbeatable and irreplaceable in the near future, so mixing two fuels appears to be the best alternative solution to reduce environment harm and preserve hydrocarbon resources (Nasr, 1997). Dual fuel technology includes liquids as well as gas alternatives (Noguchi et al., 1996). In the dual fuel version, the burner can combust either gas or oil with identical control ranges, which makes firing especially flexible. According to Barik et al., (2013), biogas is useful in a dual fuel engine and cannot be directly used in IC engine, because the gas has a high self-ignition temperature.

The gas pressure drives the gas and air in the burner force in the pipeline. Gas pressure to flow equation is summarized by Bernoulli’s theorem (Assuming incompressible flow)

$$\frac{p}{\rho}+\frac{v^2}{2g}+Z=constant \qquad 6.8$$

P is the pressure of gas (Nm^{-2})

ρ is the gas density (Kgm^{-3})

v is the velocity of gas (ms^{-1})

g is the acceleration due to gravity ($9.8m^{-2}$)

Z is the gas head (z) head in (m)

Bernoulli’s theorem essentially states that for an ideal gas flow, the potential energy due to the pressure, plus the kinetic energy due to the velocity of the flow is constant. Practically, with gas flowing through a pipe, Bernoulli’s theorem can be modified. An extra term can then be added to allow for energy loss due to friction in the pipe, hence

$$\frac{p}{\rho}+\frac{v^2}{2g}-f(losses)=constant \qquad 6.9$$

Figure 5.6 shows dual fuel burners from Saacke. They can be used for both biogas and heavy fuel oil. Appendix 6 shows the technical specifications of the Saacke dual fuel burners

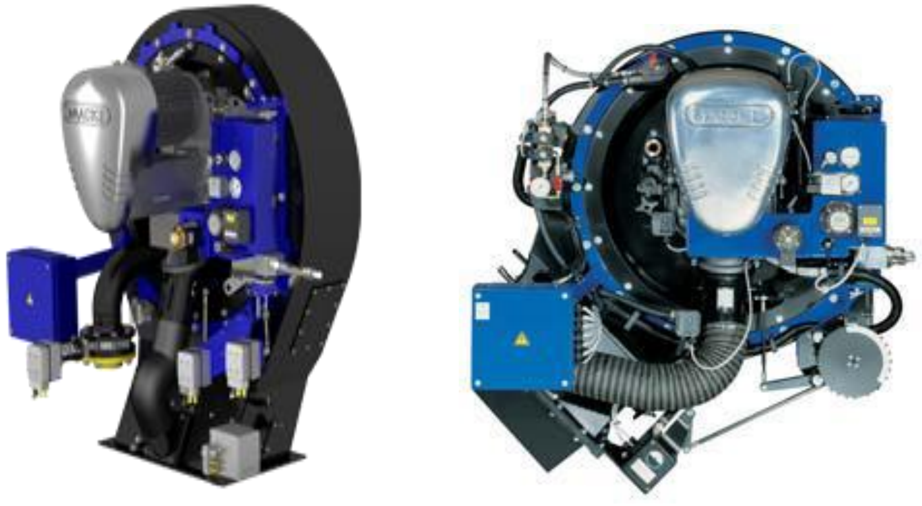


Figure 5.6 Saacke Dual Fuel Burner (Saacke, 2017)

HFO is used to ignite the mixture while the majority of fuel burned is fuel gas. According to Barik et al., (2013) due to high octane number, the fuel and air mixture doesn't auto ignite. Pilot fuel which is a small amount of diesel is injected for promoting combustion. This allows retention of the HFO efficiency while burning cheap and clean fuel gas. During changeover, the fuel is slowly replaced by gas. If the gas supply is interrupted, the engines changes from gas to fuel oil operation at any load automatically and instantaneously. This flexibility of operation gives the dual-fuel system an advantage over others. A gas valve unit supplies the fuel gas to the engine, where gas is filtered and gas pressure is controlled. Shut-off and venting valves are included in the system to ensure safe and trouble free low pressure gas supply. The advantages of a dual – fuel engine are Fuel flexibility, Low exhaust gas emission and Fuel economy.

Kenya Breweries Limited boilers use SAAKE type burners for HFO only as shown in Appendix 7. To save cost, a new dual fuel rotary cap burner of the same make can be installed, replacing the old model burners which are singly designed for HFO only. From the catalogue in Appendix 6, Saacke burner type SKVG-A compact burner based on rotary cup atomizer technology is proposed. Figure5.7 shows an improved boiler installed, using the saacke dual burner. Figure 5.7 is an improved version of existing boiler in Appendix 7.

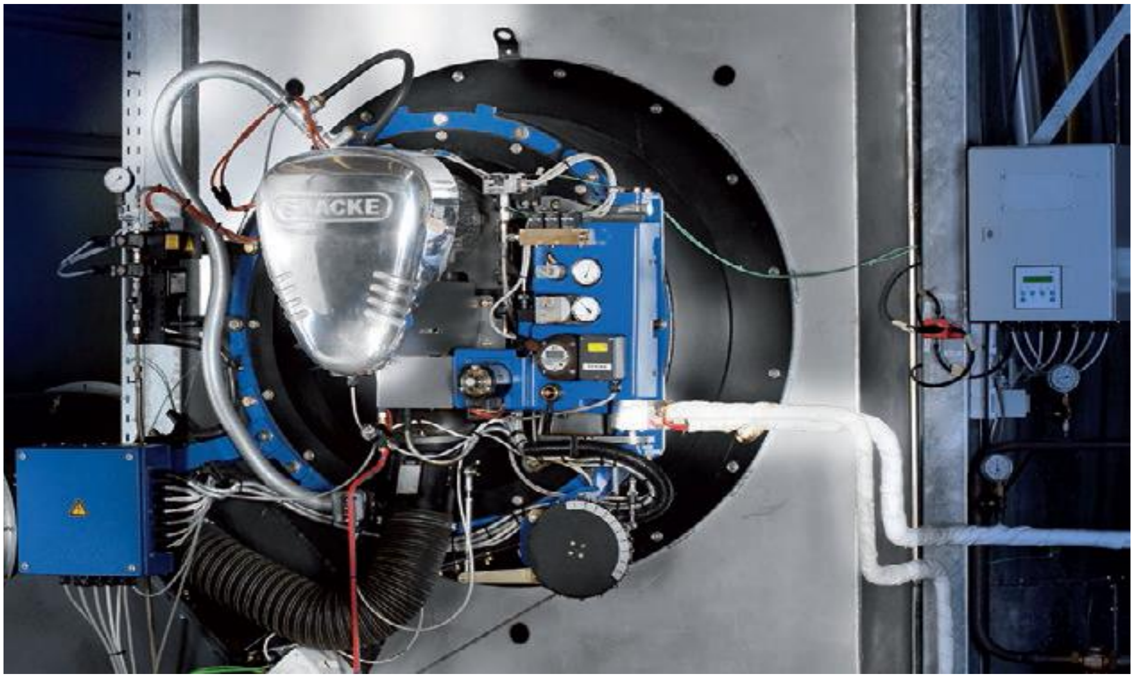


Figure 5.7 Improved Boiler with Dual Fuel Burner (Saacke, 2017)

5.7 Instrumentation and Process Control

The biogas plant was designed with controllers to enable automatic running and shutting down of the plant.

5.7.1 Compressor Controller

Figure 5.8 shows the compressor controller fitted with flow control valves and pressure transmitters for control purposes.

- **Control objectives:** To control the reaction temperature and flow rate and also to monitor temperature and pressure.
- Therefore in designing the compressor controller the following are considered:
- Measurement: temperature, pressure and methane flow rate.
- Variable: temperature, pressure and methane gas flow rate.

Control Principle

The compressor compresses the gas volume and delivers the gas to the storage tank. High level of gas in the tank will stop the compressor after a duration of time.

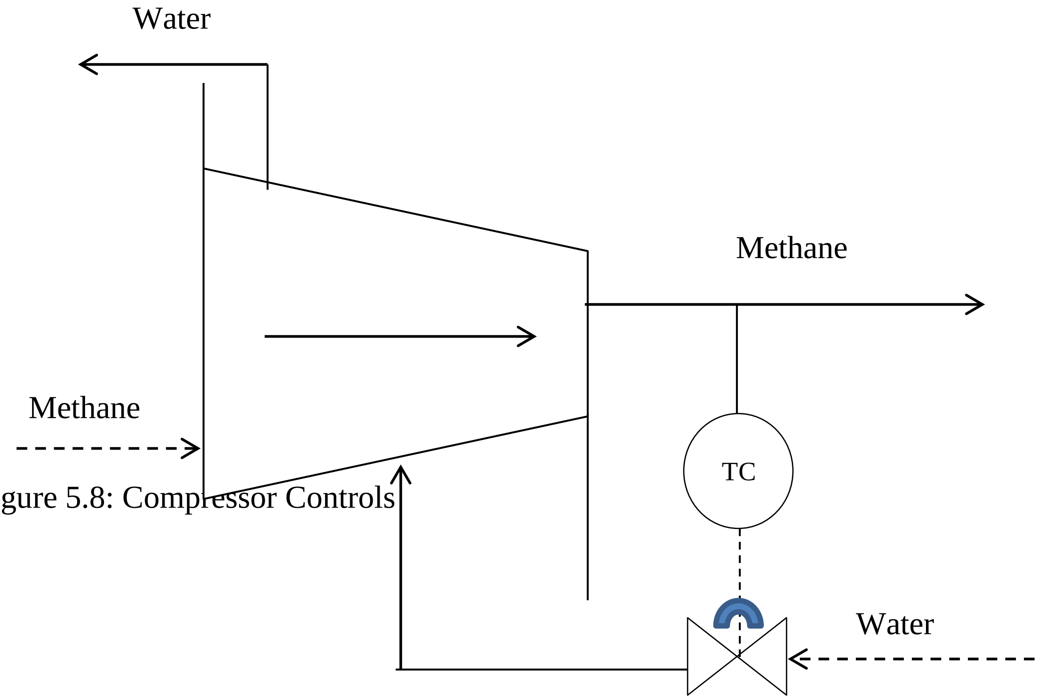


Figure 5.8: Compressor Controls

5.7.2 Methane Gas Storage Tank

Figure 5.9 shows the methane gas storage tank fitted with flow control valves, level transmitters and pressure transmitters for control purposes.

- Control objectives: To control the tank pressure, flow rate and level of the methane gas in the tank. If the capacity of the gas in the storage vessel is achieved, then the compressor stops filling the storage vessel and the excess gas is channeled to the burner to be flared off.
- Designing the methane gas storage tank controller the following are considered:
- Measurement: pressure, height and flow rate.
- Variable: pressure, height and flow rate.

Control Principle

When the storage tank is full to a certain level, the level control valve will slowly shut off, after the compressor stops. The level control valve will open slowly to allow biomethane gas in, as the level of the gas goes down in the gas storage tank. The plant is designed such that the compressor transports the methane gas (due to pressure buildup) to the gas storage tank.

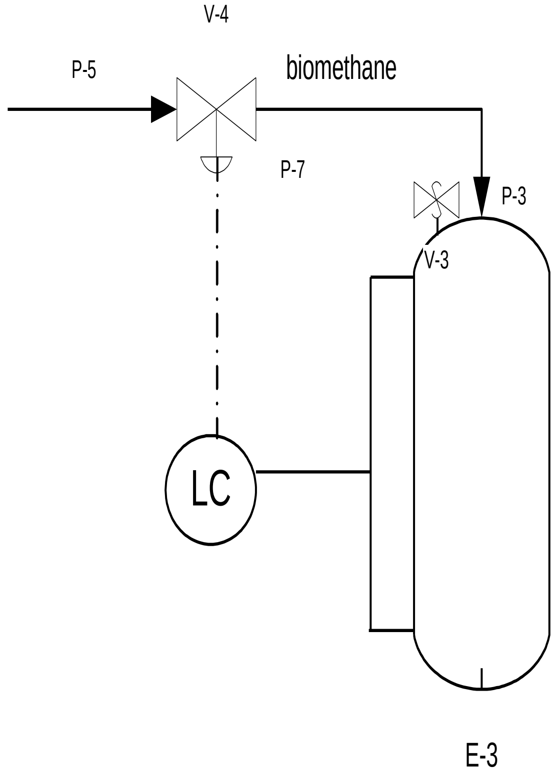


Figure 5.9: The Methane Gas Storage Tank Controls

Table 5.5 shows the summary of the equipment needed for the plant. The capacity and dimension of the equipment are tabulated.

Table 5.5: Summary of Plant Design

Equipment	Specifications	Remarks
Dual Fuel Burner	Saacke	
Gas Storage Vessel		
Biogas compressor	P_s=0bar P_d=16bar	Atlas Copco GG 90 VSD
Biogas Pipings	D=69.3mm 600m length	Carbon steel-Low Pressure Pipings
Methane gas storage tank	1212m^3/day	Carbon steel
Level Transmitter	0-4bar	Endress + Hauser
Control Valves		Alpha Laval
Atlas Copco Drain Condensate	Verac Biogas 245 Drip Tap	

5.8 Financial Analysis

Projects are assumed to be economically viable if the Net Present value (NPV) is positive, the Internal Rate of Return (IRR) is >20% and the simple payback period is of < 5 years. Table 5.6 shows the cost of each equipment necessary for setting up the plant.

Table 5.6: Estimated Plant Cost

No	Requirement	Quantity	Unit Price Ksh.	Total Price
1	Dual Fuel burner	1	7,000,000.00	7,000,000.00
2	Gas Storage Vessel	1	4,000,000.00	4,000,000.00
3	Biogas Compressor	1	10,000,000.00	10,000,000.00
4	Gas valves	4	30,000.00	120,000.00
5	Biogas Pipings	600m ½”	550.00	330,000.00
6	Drip Tap	2	105,000.00	210,000.00
7	Level transmitter	1	70,000.00	70,000.00
8	Electricals (Cables, Pannels)		5,000,000.00	5,000,000
	EX-Work Total			**26,730,000.00**
	Packaging Free on Board	1%	267,300.00	267,300.00
	Shipping	10%	2,673,000.00	2,673,000.00
	Sub Total Cost Insurance & Freight (CIF)			2,940,300.00
	Duty	10% CIF		294,030.00
	Clearing & Forwarding	2% CIF		58,806.00
	Local Transport	3 Containers	50,000.00	150,000.00
	Installation Cost	20% CIF		588,060.00
	Minor Civil Work			2,000,000.00
	Trainings	5% CIF		147,015.00
	Total			**32,908,211.00**
	Contingency	15%		4,936,231.65
	Estimated Plant Cost			**37,844,443.00**

5.8.1 Simple Payback Period

Simple payback period is time or period expected to recover the original investment used for building of a plant. It is the sum of years in which the investment is supposed to pay for itself. It is given by:

$SSP=I_C/A_S$

Where, SPP= Simple Payback Period
I_C= Initial cost
A_S= Annual Savings
Initial cost =Ksh. 37,844,443.00

Annual Savings= Ksh.63,750,000.00

Simple Payback = $\frac{37,844,443}{63750000}$= 0.59 years

Simple Payback = 6 Months

5.9 Environmental Impact Assessment of Excess Biogas Exposure at KBL

Impact assessment is the formal process of identifying, assessing and evaluating the health and environmental impact that may be associated with a hazard. Biotechnology has very minimal or no effect to the environmental. It is also referred to as Green Energy Technology.

The purpose of this section of the report is to provide an overview of the impact and safety aspects that need to be put into consideration during production and handling of biogas. Raw biogas has a composition of hydrogen sulphide, ammonia, carbon dioxide which needs to be cleaned using the water scrubber and remain with methane gas. Excesses of each of the constituent gases of biogas have negative effect to both human and environment. The most common risks are:

1. Flammability
2. Poisoning (mainly H_2S)
3. Suffocation
4. Risk caused by high pressure
5. Thermal injuries

Table 5.9 shows the different effects of Hydrogen Sulphide to human beings, under different levels of concentration. H_2S has an effect on the ozone layer too. According to the gas analysis report in Appendix 2, the concentration of H_2S is 197ppm. Which is high and hence the concentration is dangerous after one hour exposure.

Table 5.7: Effects of Hydrogen Sulphide (Mohammed, 2010)

CONCENTRATION	EFFECTS
100ppm	Smell loss, coughing, irritation in eyes after 2-5 minutes
200ppm	Irritation of the respiratory track and eyes marked even after one hour of exposure
500ppm	Consciousness loss resulting to death in 30 minutes to 1 hour
700ppm	Very fast unconsciousness with early breathing stoppage resulting to death.
7000ppm	Unconsciousness resulting to breathing stoppages. Death can occurs after few minutes even when taken to fresh air environment.

The upgraded biogas density is lower than air; hence any gas leaking will rise upward. The upgraded biogas (methane gas) has a higher ignition temperature than both petrol and diesel. This means that the risk of fire or explosion is smaller for upgraded biogas than for petrol or diesel. Typically biogas cleaning and upgrading may contain several unit operations which remove different contaminants. The Table 5.11 below shows various contaminants found in biogas and their effect downstream.

Table 5.8: Biogas Impact on Environment (Ryckebosch et al., 2011)

Contaminant	Possible impact
Dust, foam and solid particles	Clogging of gas pipelines, compressor, gas vessel
Water	Gas pipelines corrosion, compressor, gas storage vessels and engines as result of reaction with CO_2 and H_2S forming acids, high pressure causing accumulation of water in pipes condensation and / or freezing due .
H_2S	Corrosion in compressors, gas storage tanks and engines. Toxic concentration of H_2S (>5cm^{3}m^{-3}) remain in biogas SO_2 and SO_3 are formed due to combustion, which are more toxic than H_2S and cause corrosion with water.
Carbon dioxide	Low calorific value
Hydrocarbons	Combustion causing corrosion in engines

Appendix 8 indicates the piping route for methane gas to the boilers. The route has steam pipes, compressed air pipes, cooling towers with electrical connections which are potential hazards.

During methane transportation through stainless steel pipe, in case of any methane gas leakage, an explosion is likely to take off if the following potential ignition sources are present: Electric sparks and arcs, mechanically produced sparks (hammering metal with metal), hot surface, Electrostatic charges and lighting striking. As mitigation rules hot work permit will always be needed when working along or near the methane lines in order to isolate the area and possibly stop gas flow to mitigate the possible hazards. The boilers can be relocated near the ETP plant where there is a wide space away from the process plant hence reducing the risk associated with the biogas production and handling.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The research was conducted to ascertain the volume of biogas available from the Kenya Breweries limited, ETP plant. It was established that there was a potential of biogas production from brewery waste water. The study revealed that at optimum conditions and 50% confidence levels, loading the UASB digester with a COD load of 19,761kg/day, an estimated biogas volume 9,973 m^3/day containing Methane gas of 6,383m^3/day was produced. This amount of methane could produce an estimated steam of 88.4tonnes per day, against a demand of 404.58 tonnes per day.

Methane gas produced (6,383m^3/day) can run the boilers for only 3.4 hours per day to produce estimated steam of 57.6tonnes while HFO can run the boilers for the next 20.6 hours to produce an estimated steam of 357tonnes.

Using methane gas as boiler fuel for 3.4 hours only in a day can save 4,250litres of HFO fuel daily. The amount realized as saving from using methane gas for 3.4 hours is KSH. 63,750,000.00 in one year.

On equipment's design or selection, the study established that a Compressor type GG 90 VSD was suitable for compressing the methane gas for storage. A dual-fuel Saacke (type SKVG-A) compact burner based on rotary cup atomizer technology, could replace the existing Saacke burners which use for HFO only as fuel. Improving the existing Biofilter in to a Water scrubber is a cheap process for biogas cleaning hence reducing the impact to the environment by dissolving CO_2 and H_2S. Methane gas being highly flammable, possess a risk of explosion in case of an ignition source during transportation to the boilers.

6.2 Recommendations

Due to the methane explosion risk, the study found that the boilers can be re-routed to the open space near the biogas source i.e. ETP plant.

The biogas can also be upgraded and used to run the forklift at the packaging plant.

REFERENCES

Abbasi L.T. and Abbasi S.A. (2012). “Formation and Impact of granules in fostering clean energy production and waste water in upflow anaerobic sludge blanket reactors “Journal of renewable and sustainable energy reviews pp 1-7

Agler T. Mathew and Beers, R. Allen, (2010). “Anaerobic Digestion of Brewery Primary Sludge to Enhance Bioenergy Generation: A Comparison between Low and High rate solids Treatment and different Temperatures “Journal of Bioresource Technology, pp1.

Arceivala J. Soli, Asolekar R. Shyam (2007). “Waste Water Treatment for pollution Control and Reuse.” 3rd edition, McGraw-Hill, New Delhi, pp173.

Barik D. and Murugan S. (2013). “Biogas Production and Storage for Fuelling Internal Combustion Engines”. International Journal of Emerging Technology and Advanced Engineering, Volume 3, p, 193-202.

Boateng C.O. and Kwofie E.M. (2009). “Scrubbing: A better Option for Biogas Purification for Effective Storage” World Applied Sciences Journal 5 (Special issue for Environment)

Booker D.J. and Dunbar M.J. (2004). “Application of Physical Habitat Simulation (PHABSIM) Modeling to Modified Urban River Channels”, Journal of River Research and Applications. Applic.20: pp.167-183

Booker D.J. and Snelder T.H. (2012). “Comparing Methods for Estimating Flow Duration Curves at ungagged sites”, National Institute of water and Atmospheric Research, P.O box 8602, Riccarton, Christchurch, New Zealand. Journal of hydrology pp.2,3.

Chaitanya Kumar Desitti, Unissa A. Syeda, Rao Bhupatthi and Kumar V. (2011). Efficiency Assessment of Combined Treatment Technologies. A Case Study of Charminar Brewery Waste Water Treatment Plant”. Indian Journal of Fundamental and Applied Life Science, Vol 1 ,pp 138-140

Cole F.L. (1988). Content Analysis: Process and Application. Journal of Clinical Nurse Specialist. Vol 2, pp 53-57

Driessen W. and Vereijken T. (2003). “Recent Developments in Biological Treatment of Brewery Effluent” Journal of the Institution and Guild of Brewing Convention, Livingstone, Zambia. Pp 2-3

Eze I.J. and Agbo K.E. (2010). “Maximizing the Potentials of Biogas through Upgrading”. American Journal of Scientific and Industrial Research, pp 604-609.

Fang Cheng, O-Thong Sompong, Boe Kanokwan (2011). “Comparison of UASB and EGSB Reactors Performance, for Treatment of Raw and Deoiled Palm Oil Effluent (POME) “Journal of Hazardous Materials 189, pp229-234.

Franco A., Mosquera A., Campos J.L, Roca E. (2007). “Learning to Operate Anaerobic Bioreactor” Journal of Communicating Current Research and Educational Topics and Trends in Applied Microbiology, pp618-624

Hosseini S.E, and Wahid M.A. (2014). “Development of Biogas Combustion in Combined Heat and Power Generation” Journal of Renewable and Sustainable Energy Reviews, pp 868-875.

Hosseini S.E. Wahid M.A, Abuelnuor A. A. (2013). “Biogas Flameless Combustion” a Review. Journal of Applied Mechanics and Material Volume 388, pp 273-279

Hutnan M., Dirtil M., Buday J. (1999). “Comparison of Startup and Anaerobic Waste water Treatment in UASB, hybrid and Baffled reactor” Journal of Bioprocess Engineering, Vol 21, Issue5, pp 439-445

James L. Waish, Jr., P.E.Charles C. Ross, P.E., Michael S. Smith, Stephen R. Harper and W. Allen Wilkins (1988). Handbook on biogas utilization.

Kaparaju P., Rasi S., Rintala, J. (2011). “Biogas Upgrading and Compression”, Journal of Renewable and Sustainable Energy pp122.

Kapdi S.S, Vijay V.K., Rajesh S.K., Rajendra P. (2005). “Biogas Scrubbing, Compression and Storage: Perspective and Prospectus in India Context”, Journal of renewable Energy, Vol 30, pp2-8.

Lettinga G. Velsen, A.F.M Van, Hobma, S.W. (1980). “Use of the Upflow Sludge Blanket (USB) Reactor concept for Biological Waste Water treatment, especially for Anaerobic Treatment” Journal of Biotechnology and Bioengineering. Volume 22, pp 699-734.

Mathias Thiago Rocha dos Santos, Pedro Paulo and Eliana Flavia Servilo (2014). “Solid Waste in Brewing Process a review”, Journal of Brewing and Distilling, Vol 5,pp1-9

Nasr A. Fayza. (1997). “Treatment and Reuse of Sewage slugde”. Journal on environment. Vol 17, Issue 2,pp109-113.

Noguchi N., Terao H., Sakata C. (1996).” Performance Improvement by Control of Flow Rates and Diesel Injection timing on Dual_fuel Engine with Ethanol”. Journal of Bioresource Technology, vol 56,Issue 1, pp35-39

Noor M., Wandel A.P, Yusaf T. (2014). “Air Fuel Study for Mixture of Biogas and Hydrogen on Mild Combustion”. International Journal of Automotive and Mechanical Engineering., Volume 10, pp.2144-2154.

Okonkwo P.C., Adereni B.O, Okoli C.J. (2013). “Factors affecting Biogas Production during Anaerobic Decomposition of Brewery effluent-Waste water in Fluidized Bed Digester “Journal of Environment and Earth Science, volume 3, pp32-39.

Papacz, Wladyslaw, (2011). “Biogas as Vehicle Fuel” Journal of KONES Powertrain and transport, vol 18, pp403-409.

Parkin, G.F. Speece, R.E. (1983). “Attached vs suspended Growth anaerobic reactors; Response to toxic substances.

Ramadhanie Indrani and Chakrabarti Prasad (2014). “ Studies on the Design, Evaluation and Energy Conservation Potential of a Pilot- Scale Hybrid UASB Treating a combination of Waste Activated Sludge and Distillery Spent Wash”, Journal of Chemical Engineering Communication, Vol 201- Issue 6,pp 1-8

Rao P. Narsimha, Akula K. Lakesh and Habiulla P. (2014), “Brewery Waste Water Treatment Using Sequential Batch Reaction” International Journal of Scientific Research. Journal DOI: 10:15373/22778179. Pp 1-3

Rasi S., Veijanen A., Rintala J. (2007). "Trace Compounds of biogas from different biogas plants" Journal of Energy. Vol 32, Issue 8, pp 1375-1380

Romero F., Pereda, J. (1999). "Anaerobic Purification of Dairy Waste Water in Continuous Regime: Reactor with Support" Journal of Process biotechnology, pp1-3.

Rumana Riffat, (2013). "Fundamentals of Waste Water Treatment and Engineering." Iwa, London, pp 209-224.

Ryckebosch E., Drouillon M. and Vervaeren H. (2011). "Techniques for Transformation of Biogas to Biomethane".Journal of Biomass and Energy. Vol 35, Issue 5, pp 1633-1645

Searcy K. James, (1959). "Flow Duration Curves. Manual of Hydrology: part 2, Low Flow Techniques "Journal of Geological Survey Water- Supply Paper 1542-A, pp 1-6.

Seghezzo L., and Zeeman G. (1998). "A review: The Anaerobic Treatment of Sewage in UASB and EGSB Reactors" Journal of Bioresource Technology, Vol 65, Issue3, pp175-190

Sinnot, R.K. (2004). "Chemical Engineering Design" Volume 2, Fifth Edition, Butter Worth Heinemann, Linacre House, Jordan Hill, pp 57-88

Sinnot, R.K. (2005). "Chemical Engineering Design" Volume 6, Fourth Edition, Butter Worth Heinemann, Linacre House, Jordan Hill, pp 794-889

Speece, R.E. (1996). "Anaerobic Biotechnology for Industrial Wastewaters" Archae Press Nashville Tennessee, pp 143.

Stams A.J.M, Reith J.H, T.Z.D. De Mes, Zeeman G. (2003). "Methane Production by Anaerobic Digestion of Waste Water and Solid waste. Pp58-95

Tumwesige Vianney, Fulford David, Grant Davidson (2014). "Biogas Appliances in Sub-Sahara Africa "Journal of Biomass and Energy, vol 70,pp40-50.

Vogel M. Richard and Fennessey M. Neil (1994). "Flow –Duration Curves "Journal of Water Resources, Planning and Management. Vol 120, pp 485-502

Vrellas G., Charisis Tsiotras, George D. (Feb 2014). “Operational Excellence in the Greek Brewery Industry “Journal on Global Business and Organization Excellence, pp 31-36.

Woodruff, D.E. Lammers T.F. (1984). “Steam Plant Operations” (1984). 5th Edition McGraw – Hill, Inc New York, p1-19.

Woodruff, E.B. Lammers H.B. (1977). “Steam Plant Operations.” 4th Edition, McGraw – Hill, Inc. New York p, 5,20,21,126-129.

www.saacke.de/downloads/lands/en/Delivery_Program_a105_engl.pdf - Accessed on 2/01/2017.

Young C. James, McCarty L. Perry (1969). “The Anaerobic Filter for Waste Treatment” Journal (Water Pollution Control Federation), volume 41, pp160-173.

APPENDICES

Appendix 1: Biogas Analysis

SGS

FINAL REPORT: MA15-12967

SAMPLE DATA

Order Nº: TEDLAR-OCTOBER 2015
Product: Tedlar bag
Description: Sampling support
Container: Sampling media for occupational health
Received: 15/10/2015

CLIENT DATA

SGS Kenya,Ltd
PO Box 90264
80100 Mombasa (Kenya)
KENYA

Atn: Chrisphine Oduor

TEST

ANALYSIS	TEST METHOD
Organic Compounds (*)	NIOSH 5500

RESULTS *Metano* UNIT: ppm

Laboratory ID	Client ID	RESULT.
MA15-12967.001	EABL 1	614000
MA15-12967.002	EABL 2	635000

Analysed: 27/10/2015

Report Printed in Madrid October, 27th of 2015

Alfonso Moreno Pulido
Physical Chemistry Technical Director

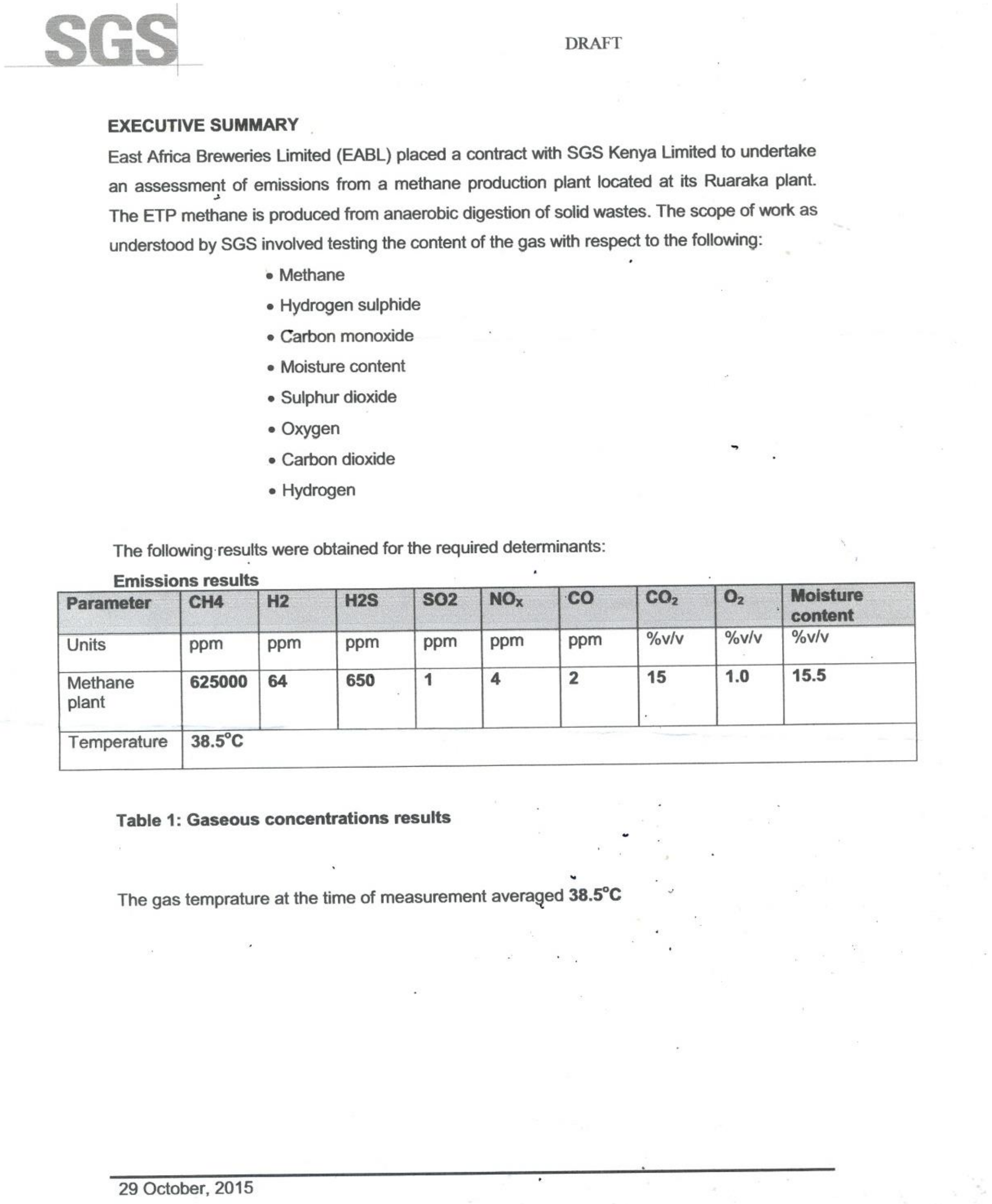
These results refer exclusively to the samples analysed.
The results shown in this report refer only to the sample(s) unless otherwise stated.
This document cannot be reproduced without the written consent of the Laboratory Management.
The Laboratory has the uncertainties estimated for each of the accredited tests, which are at the disposal of the client (0000171449)
All data from the sample and their identity were facilitated by the applicant.
Interpretations and data expressed in the comments are not included in the range of accreditation.
All those methods that the laboratory realized following a particular standard, are refered to the latest revision thereof.

Page 1 of 1

SGS Tecnos S.A. **Laboratorio Medio Ambiente** c/ Trespaderne, 29 Edificio Barajas I (Barrio Aeropuerto) 28042 Madrid www.sgs.es
t (34) 913 13 80 00 f (34) 913 13 80 99

miembro del grupo sgs (sgs sa

inscrita registro mercantil de madrid, tomo 3.475, general 2.746, sección 3ª, folio 88, hoja m-25966, inscripción 1.ª, libro de sociedades - c.i.f.: a-28345577 - sociedad unipersonal



DRAFT

EXECUTIVE SUMMARY

East Africa Breweries Limited (EABL) placed a contract with SGS Kenya Limited to undertake an assessment of emissions from a methane production plant located at its Ruaraka plant. The ETP methane is produced from anaerobic digestion of solid wastes. The scope of work as understood by SGS involved testing the content of the gas with respect to the following:

- Methane
- Hydrogen sulphide
- Carbon monoxide
- Moisture content
- Sulphur dioxide
- Oxygen
- Carbon dioxide
- Hydrogen

The following results were obtained for the required determinants:

Emissions results

Parameter	CH4	H2	H2S	SO2	NO_x	CO	CO_2	O_2	Moisture content
Units	ppm	ppm	ppm	ppm	ppm	ppm	%v/v	%v/v	%v/v
Methane plant	**625000**	**64**	**650**	**1**	**4**	**2**	**15**	**1.0**	**15.5**
Temperature	**38.5°C**								

Table 1: Gaseous concentrations results

The gas temprature at the time of measurement averaged **38.5°C**

29 October, 2015

USEPA Reference Method 18

This method is applicable for the determination of methane in a gas stream. Air sample is collected in a Tedlar bag and the samples analysed using the GC/MS.

List of Equipment and Chemicals Used

Table 3: List of Equipment used during sampling and measurements

EQUIPMENT	**MANUFACTURER**
Isokinetic source sampler: • Manometer Dry Gas Meter • Temperature/flow Controls • Vacuum system • Digital Timer	Apex Instruments Inc.
Pitot Tubes Sampling Probe/ Probe brush Sampling Hose	Apex Instruments Inc.
Portable Gas Analyzer. The analyzer measures up to five separate gas components: NOx, SO$_2$, CO, CO$_2$ and O$_2$.	Testo AG,
Tedlar Bags	
Analytical Balance	Ohaus Corporation
Calculator with inbuilt programs for isokinetic calculations	Casio
Sample Collection Bottles Labels	-

Appendix 2A: UASB Influent and Effluent Parameters

Date	Inlet COD	Outlet COD	COD Removal	Flow to UASBs	COD load 2	TSS	COD Removed
	<4474	< 900		<7215	<32280	< 225	
	mg/l	mg/l	%	m³/day	kgCOD/day	mg/l	mg/l
1-Jun	5400	197	*96*	1082	5843	90	5203
2-Jun	5670	559	*90*	2473	14022	188	5111
3-Jun	3920	502	*87*	3313	12987	198	3418
4-Jun	4923	716	*86*	3748	18451	219	4207
5-Jun	5215	759	*85*	3698	19285	207	4456
6-Jun	6180	614	*90*	3396	20987	192	5566
7-Jun	5870	381	*94*	2490	14616	185	5489
8-Jun	4770	347	*93*	3260	15550	197	4423
9-Jun	8000	469	*94*	3340	26720	226	7531
10-Jun	7230	592	*92*	3160	22847	211	6638
11-Jun	5810	501	*91*	3320	19289	198	5309
12-Jun	3540	440	*87*	3650	12921	185	3100
13-Jun	4480	175	*96*	3330	14918	175	4305
14-Jun	5120	180	*97*	3350	17152	196	4940
15-Jun	4910	873	*82*	3630	17823	138	4037
16-Jun	6600	444	*93*	3830	25278	217	6156
17-Jun	7800	498	*94*	3240	25272	148	7302
18-Jun	8640	398	*95*	3230	27907	220	8242
19-Jun	6505	404	*94*	2900	18865	190	6101
20-Jun	4990	540	*89*	3700	18463	192	4450
21-Jun	7450	799	*89*	3010	22425	193	6651
22-Jun	4883	545	*89*	3290	16065	207	4338
23-Jun	5783	441	*92*	3890	22496	180	5342
24-Jun	5353	386	*93*	4310	23071	160	4967
25-Jun	7630	431	*94*	3470	26476	204	7199
26-Jun	9270	363	*96*	2800	25956	209	8907
27-Jun	6500	471	*93*	1640	10660	195	6029
28-Jun	6330	425.3	*93*	1770	11204	202	5904.7
29-Jun	5630	432	*92*	2780	15651	195	5198
30-Jun	6450	529	*92*	2700	17415	204	5921

Appendix 2A: UASB Influent and Effluent Parameters Contd.

Date	Inlet COD	Outlet COD	*COD Removal*	Flow to UASBs	COD load 2	TSS	COD Removed
	<4474	< 900		<7215	<32280	< 225	
	mg/l	mg/l	*%*	m³/day	kgCOD/day	mg/l	mg/l
1-Jul	6375	693	*89*	3745	23874	157	5682
2-Jul	7140	546	*92*	4004	28589	162	6594
3-Jul	5960	906	*85*	3816	22743	196	5054
4-Jul	6140	427	*93*	3293	20219	177	5713
5-Jul	7030	335	*95*	3183	22377	187	6695
6-Jul	7750	350	*96*	3247	25164	201	7400
7-Jul	6780	336	*95*	11467	77746	197	6444
8-Jul	4306	421	*90*	5429	23377	183	3885
9-Jul	5066	475	*91*	3237	16399	111	4591
10-Jul	5505	252	*95*	3281	18062	201	5253
11-Jul	5760	240	*96*	4140	23846	221	5520
12-Jul	5980	173	*97*	2723	16284	228	5807
13-Jul	8100	236	*97*	3000	24300	195	7864
14-Jul	5890	195	*97*	3355	19761	166	5695
15-Jul	7950	457	*94*	2789	22173	204	7493
16-Jul	5810	473	*92*	3272	19010	183	5337
17-Jul	5810	143	*98*	4116	23914	208	5667
18-Jul	6010	616	*90*	3084	18535	113	5394
19-Jul	5180	479	*91*	2954	15302	138	4701
20-Jul	11760	220	*98*	2443	28730	221	11540
21-Jul	4710	284	*94*	2741	12910	222	4426
22-Jul	9290	384	*96*	2890	26848	159	8906
23-Jul	4880	457	*91*	3228	15753	201	4423
24-Jul	5570	327	*94*	3088	17200	201	5243
25-Jul	4520	398	*91*	3506	15847	196	4122
26-Jul	6570	378	*94*	3437	22581	89	6192
27-Jul	6336	407	*94*	3741	23703	188	5929
28-Jul	5220	381	*93*	2833	14788	201	4839
29-Jul	5320	704	*87*	4355	23169	156	4616
30-Jul	3740	941	*75*	4327	16183	212	2799
31-Jul	3843	851	*89*	3956	15867	187	4321

Appendix 2A: UASB Influent and Effluent Parameters Contd

Date	COD total	COD total	COD Removal	Flow to UASBs	COD load 2	TSS	COD Removed
	<4474	< 900		<7215	<32280	< 225	
	mg/l	mg/l	%	m³/day	kgCOD/day	mg/l	mg/l
1-Aug	6906	668	*90*	*2870*	19820	201	6238
2-Aug	5697	682	*88*	*4290*	24440	197	5015
3-Aug	7280	423	*94*	*2500*	18200	228	6857
4-Aug	7380	576	*92*	*3860*	28487	206	6804
5-Aug	6360	461	*93*	*2950*	18762	192	5899
6-Aug	6440	432	*93*	*4320*	27821	201	6008
7-Aug	6260	623	*90*	*4310*	26981	184	5637
8-Aug	6855	389	*94*	*3490*	23924	184	6466
9-Aug	6373	692	*89*	*4170*	26575	192	5681
10-Aug	6915	326	*95*	*3100*	21437	189	6589
11-Aug	5422	298	*94*	*3110*	16862	163	5124
12-Aug	11310	537	*95*	*1960*	22168	212	10773
13-Aug	7660	785	*90*	*3020*	23133	181	6875
14-Aug	8530	813	*91*	*3250*	27723	234	7717
15-Aug	6190	491	*92*	*3380*	20922	214	5699
16-Aug	5190	512	*90*	*2580*	13390	207	4678
17-Aug	6540	440	*93*	*2890*	18901	201	6100
18-Aug	6440	650	*90*	*3060*	19706	202	5790
19-Aug	6257	618	*90*	*2440*	15267	212	5639
20-Aug	5635	811	*88*	*4420*	24907	194	4824
21-Aug	7030	387	*95*	*3270*	22988	203	6643
22-Aug	5460	393	*93*	*3210*	17527	235	5067
23-Aug	7820	443	*94*	*3130*	24477	191	7377
24-Aug	5600	464	*92*	*2910*	16296	210	5136
25-Aug	7480	621	*92*	*2640*	19747	199	6859
26-Aug	4290	464	*89*	*2550*	10940	211	3826
27-Aug	5450	464	*92*	*4180*	22781	205	4986
28-Aug	5280	884	*83*	*2160*	11405	209	4396
29-Aug	8400	602	*93*	*1390*	11676	302	7798
30-Aug	5410	774	*86*	*2410*	13038	204	4636
31-Aug	5040	385	*92*	*3580*	18043	210	4655

Appendix 2A: UASB Influent and Effluent Parameters Contd.

Date	COD total	COD total	COD Removal	Flow to UASBs	COD load 2	TSS	COD Removed
	<4474	< 900		<7215	<32280	< 225	
	mg/l	mg/l	%	m³/day	kgCOD/day	mg/l	mg/l
1-Sep	4430	396	91	2463	10911	177	4034
2-Sep	4960	531	89	4312	21388	208	4429
3-Sep	5020	646	87	3715	18649	194	4374
4-Sep	5695	437	92	3683	20975	230	5258
5-Sep	4283	390	91	3556	15230	187	3893
6-Sep	6377	683	89	3605	22989	201	5694
7-Sep	6060	448	93	3177	19253	161	5612
8-Sep	5910	474	91	2814	16631	171	5436
9-Sep	4650	471	90	3671	17070	216	4179
10-Sep	4480	543	88	3718	16657	209	3937
11-Sep	7160	568	92	3602	25790	207	6592
12-Sep	4110	526	87	2829	11627	190	3584
13-Sep	4460	491	89	3284	14647	160	3969
14-Sep	4040	492	88	3235	13069	160	3548
15-Sep	6103	746	88	3951	24113	184	5357
16-Sep	8365	449	95	3689	30859	198	7916
17-Sep	7450	758	90	3724	27744	159	6692
18-Sep	6270	506	92	3432	21519	249	5764
19-Sep	6550	557	92	3891	25486	192	5993
20-Sep	6800	354	95	3227	21944	200	6446
21-Sep	6980	589	92	4041	28206	199	6391
22-Sep	6755	594	91	3949	26676	210	6161
23-Sep	5750	588	90	4232	24334	188	5162
24-Sep	12135	774	94	2265	27486	183	11361
25-Sep	7410	619	92	2167	16058	215	6791
26-Sep	7920	250	97	2167	17163	196	7670
27-Sep	9170	239	97	2167	19871	107	8931
28-Sep	7910	207	97	2166	17133	76	7703
29-Sep	5830	249	96	2166	12628	182	5581
30-Sep	7810	458	94	2165	16909	211	7352

Appendix 2B: Biogas Flow Parameters

Date	BIOGAS FLOW (m^3/day)	Date	BIOGAS FLOW (m^3/day)	Date	Biogas Flow (m^3/day)	Date	Biogas Flow (m^3/day)
1-Jun	5430	1-Jul	2280	1-Aug	5510	1-Sep	9875
2-Jun	2000	2-Jul	5420	2-Aug	5430	2-Sep	5430
3-Jun	2610	3-Jul	7280	3-Aug	2000	3-Sep	2000
4-Jun	6480	4-Jul	7620	4-Aug	2610	4-Sep	2610
5-Jun	10950	5-Jul	8230	5-Aug	6480	5-Sep	6480
6-Jun	9890	6-Jul	9950	6-Aug	10950	6-Sep	10950
7-Jun	10100	7-Ju1	8670	7-Aug	9890	7-Sep	9890
8-Jun	9720	8-Jul	8350	8-Aug	10100	8-Sep	10100
9-Jun	8010	9-Jul	9130	9-Aug	9720	9-Sep	9720
10-Jun	9490	10-Jul	10770	10-Aug	8010	10-Sep	8010
11-Jun	8260	11-Jul	9670	11-Aug	9490	11-Sep	9490
12-Jun	8570	12-Jul	9580	12-Aug	8260	12-Sep	8260
13-Jun	9090	13-Jul	9050	13-Aug	8570	13-Sep	8570
14-Jun	8700	14-Jul	8570	14-Aug	9090	14-Sep	9090
15-Jun	780	15-Jul	10270	15-Aug	8700	15-Sep	8700
16-Jun	2330	16-Jul	11370	16-Aug	780	16-Sep	780
17-Jun	10360	17-Jul	11540	17-Aug	2330	17-Sep	2330
18-Jun	10830	18-Jul	9610	18-Aug	10360	18-Sep	10360
19-Jun	10100	19-Jul	9120	19-Aug	10830	19-Sep	10830
20-Jun	11320	20-Jul	10240	20-Aug	10100	20-Sep	10100
21-Jun	10380	21-Jul	9050	21-Aug	11320	21-Sep	11320
22-Jun	7450	22-Jul	9000	22-Aug	10380	22-Sep	10380
23-Jun	10120	23-Jul	10400	23-Aug	7450	23-Sep	7450
24-Jun	9270	24-Jul	9910	24-Aug	10120	24-Sep	10120
25-Jun	8090	25-Jul	10850	25-Aug	9270	25-Sep	9270
26-Jun	9530	26-Jul	9570	26-Aug	8090	26-Sep	8090
27-Jun	9650	27-Jul	9830	27-Aug	9530	27-Sep	9530
28-Jun	6450	28-Jul	9850	28-Aug	9650	28-Sep	9650
29-Jun	4840	29-Jul	9900	29-Aug	6450	29-Sep	6450
30-Jun	2420	30-Jul	9640	30-Aug	4840	30-Sep	4840
31-Jun	#VALUE!			31-Aug	2420	1-Oct	2420

Appendix 3: HFO (Litres) Usage and Estimated Steam (tonnes)

DATE	HFO DAY	HFO NIGHT	HFO TOTAL	EST STEAM	**DATE**	HFO DAY	HFO NIGHT	HFO TOTAL	EST STEAM
5/28/2015	15212	12823	**28035**	391	**6/31/2015**	18410	14937	**33347**	465
6/1/2015	7053	5394	**12447**	173	**7/1/2015**	16732	18380	**35112**	489
6/2/2015	1586	13653	**15239**	212	**7/2/2015**	16095	18070	**34165**	476
6/3/2015	14632	13786	**28418**	396	**7/3/2015**	8400	9428	**17828**	248
6/4/2015	18880	15572	**34452**	480	**7/4/2015**	16396	20117	**36513**	509
6/5/2015	19108	18439	**37547**	523	**7/5/2015**	16778	14407	**31185**	434
6/6/2015	15329	18105	**33434**	466	**7/6/2015**	14741	13534	**28275**	394
6/7/2015	16378	14009	**30387**	423	**7/7/2015**	17401	13097	**30498**	425
6/8/2015	11213	10753	**21966**	306	**7/8/2015**	16000	16018	**32018**	446
6/9/2015	8195	10876	**19071**	266	**7/9/2015**	17328	17519	**34847**	485
6/10/2015	16642	13310	**29952**	417	**7/10/2015**	14422	15220	**29642**	413
6/11/2015	20667	18742	**39409**	549	**7/11/2015**	17137	17996	**35133**	489
6/12/2015	16061	18463	**34524**	481	**7/12/2015**	15050	16114	**31164**	434
6/13/2015	15227	18255	**33482**	466	**7/13/2015**	8381	8693	**17074**	238
6/14/2015	16669	17613	**34282**	478	**7/14/2015**	14114	15429	**29543**	412
6/15/2015	14059	16219	**30278**	422	**7/15/2015**	16147	14838	**30985**	432
6/16/2015	13453	18316	**31769**	443	**7/16/2015**	16376	15833	**32209**	449
6/17/2015	14715	16060	**30775**	429	**7/17/2015**	16313	15618	**31931**	445
6/18/2015	16196	15819	**32015**	446	**7/18/2015**	17324	15616	**32940**	459
6/19/2015	17122	17624	**34746**	484	**7/19/2015**	11802	11893	**23695**	330
6/20/2015	19254	17776	**37030**	516	**7/20/2015**	13941	11275	**25216**	351
6/21/2015	16966	12078	**29044**	405	**7/21/2015**	13393	15038	**28431**	396
6/22/2015	9274	10871	**20145**	281	**7/22/2015**	13406	14138	**27544**	384
6/23/2015	14089	15628	**29717**	414	**7/23/2015**	15228	15436	**30664**	427
6/24/2015	18107	14110	**32217**	449	**7/24/2015**	15646	16454	**32100**	447
6/25/2015	13306	16638	**29944**	417	**7/25/2015**	13513	15759	**29272**	408
6/26/2015	15990	18484	**34474**	480	**7/26/2015**	15205	12879	**28084**	391
6/27/2015	16693	16437	**33130**	462	**7/27/2015**	9532	11527	**21059**	293
6/28/2015	18280	15210	**33490**	467	**7/28/2015**	12437	15744	**28181**	393
6/29/2015	14452	13576	**28028**	390	**7/29/2015**	13354	16823	**30177**	420
6/30/2015	11180	16725	**27905**	389	**7/30/2015**	13041	7296	**20337**	283

HFO (Litres) Usage and Estimated Steam (tonnes) (cont')

DATE	HFO DAY	HFO NIGHT	HFO TOTAL	EST STEAM	**DATE**	HFO DAY	HFO NIGHT	HFO TOTAL	EST STEAM
7/30/2015	13041	7296	**20337**	283	**8/31/2015**	13174	1013	**14187**	198
8/1/2015	0	281	**281**	4	**9/1/2015**	0	609	**609**	9
8/2/2015	15721	16376	**32097**	447	**9/2/2015**	12690	14786	**27476**	383
8/3/2015	15458	16864	**32322**	450	**9/3/2015**	12546	17822	**30368**	423
8/4/2015	14261	13125	**27386**	382	**9/4/2015**	15589	14830	**30419**	424
8/5/2015	12485	13271	**25756**	359	**9/5/2015**	14988	16187	**31175**	434
8/6/2015	13805	13543	**27348**	381	**9/6/2015**	14777	13969	**28746**	400
8/7/2015	12994	13122	**26116**	364	**9/7/2015**	13595	14379	**27974**	390
8/8/2015	11372	14743	**26115**	364	**9/8/2015**	6038	13133	**19171**	267
8/9/2015	11443	12601	**24044**	335	**9/9/2015**	16014	15785	**31799**	443
8/10/2015	12220	9889	**22109**	308	**9/10/2015**	15788	11950	**27738**	386
8/11/2015	1	12003	**12004**	168	**9/11/2015**	19859	16474	**36333**	506
8/12/2015	12457	11167	**23624**	329	**9/12/2015**	16153	16173	**32326**	450
8/13/2015	14640	13234	**27874**	388	**9/13/2015**	15523	14606	**30129**	419
8/14/2015	11500	11915	**23415**	326	**9/14/2015**	12698	3577	**16275**	226
8/15/2015	12980	15590	**28570**	398	**9/15/2015**	3765	13402	**17167**	239
8/16/2015	14646	14934	**29580**	412	**9/16/2015**	16881	13461	**30342**	423
8/17/2015	12852	13379	**26231**	365	**9/17/2015**	22630	18021	**40651**	566
8/18/2015	13214	14191	**27405**	382	**9/18/2015**	17500	16391	**33891**	472
8/19/2015	12825	12547	**25372**	353	**9/19/2015**	18917	18692	**37609**	524
8/20/2015	14324	13021	**27345**	381	**9/20/2015**	15678	12126	**27804**	387
8/21/2015	20788	14392	**35180**	490	**9/21/2015**	11721	10282	**22003**	307
8/22/2015	16761	14789	**31550**	440	**9/22/2015**	12419	10274	**22693**	316
8/23/2015	12521	12054	**24575**	342	**9/23/2015**	11798	13976	**25774**	359
8/24/2015	6441	5079	**11520**	161	**9/24/2015**	12704	13781	**26485**	369
8/25/2015	1766	12878	**14644**	204	**9/25/2015**	11867	11773	**23640**	329
8/26/2015	14340	15481	**29821**	415	**9/26/2015**	10767	10239	**21006**	293
8/27/2015	12036	14951	**26987**	376	**9/27/2015**	11230	8692	**19922**	276
8/28/2015	13659	16489	**30148**	420	**9/28/2015**	1595	3163	**4758**	66
8/29/2015	15917	14605	**30522**	425	**9/29/2015**	535	82	**617**	9
8/30/2015	15976	13305	**29281**	408	**9/30/2015**	6787	3381	**10168**	142
8/31/2015	13174	1013	**14187**	198					

Appendix 4: Detailed Process Calculations

1. GAS VOLUMES

Gas Volume = % Gas Composition x Biogas Volume

The volume of methane:

V_{CH4}= % CH_4 ×V_{Tb}

=0.64 ×9,973

=6,383m^3*day*

The volume of Carbon dioxide:

$V_{CO2}=\%CO_2\times V_{Tb}$

=15% x 9,973

=1,496 m^3*day*

The volume of Carbon monoxide:

$V_{CO}=\%CO \times V_{Tb}$

=0.0002% x 9,973

=0.02m^3*day*

The volume of Hydrogen Sulphide:

$VH_2 S$== % H_2S × V_{Tb}

=0.065% × 9,973

=6.5m^3/*day*

The volume of Nitrogen Oxide

$V_{NO}= \% NO \times V_{Tb}$

$= 0.0004\% \times 9{,}973$

$= 0.04 m^3/day$

The volume of Sulphur dioxide

$V_{so2} = \%\ SO_2 \times V_{Tb}$

$= 0.0001\% \times 9{,}973$

$= 0.01 m^3/day$

The volume of Hydrogen

$V_{so2} = \%\ H_2 \times V_{Tb}$

$= 0.64\%\% \ x\ 9{,}973$

$= 64 m^3/day$

2. Mass and Density of Gases

Mass is given by:

Mass =Density × Volume

3. Partial Pressure of Gases

Partial Pressure = Number of mole × gas constant × temperature / biogas volume Table App 4 shows a summary of the Mass, Mole and Partial Pressures of gases.

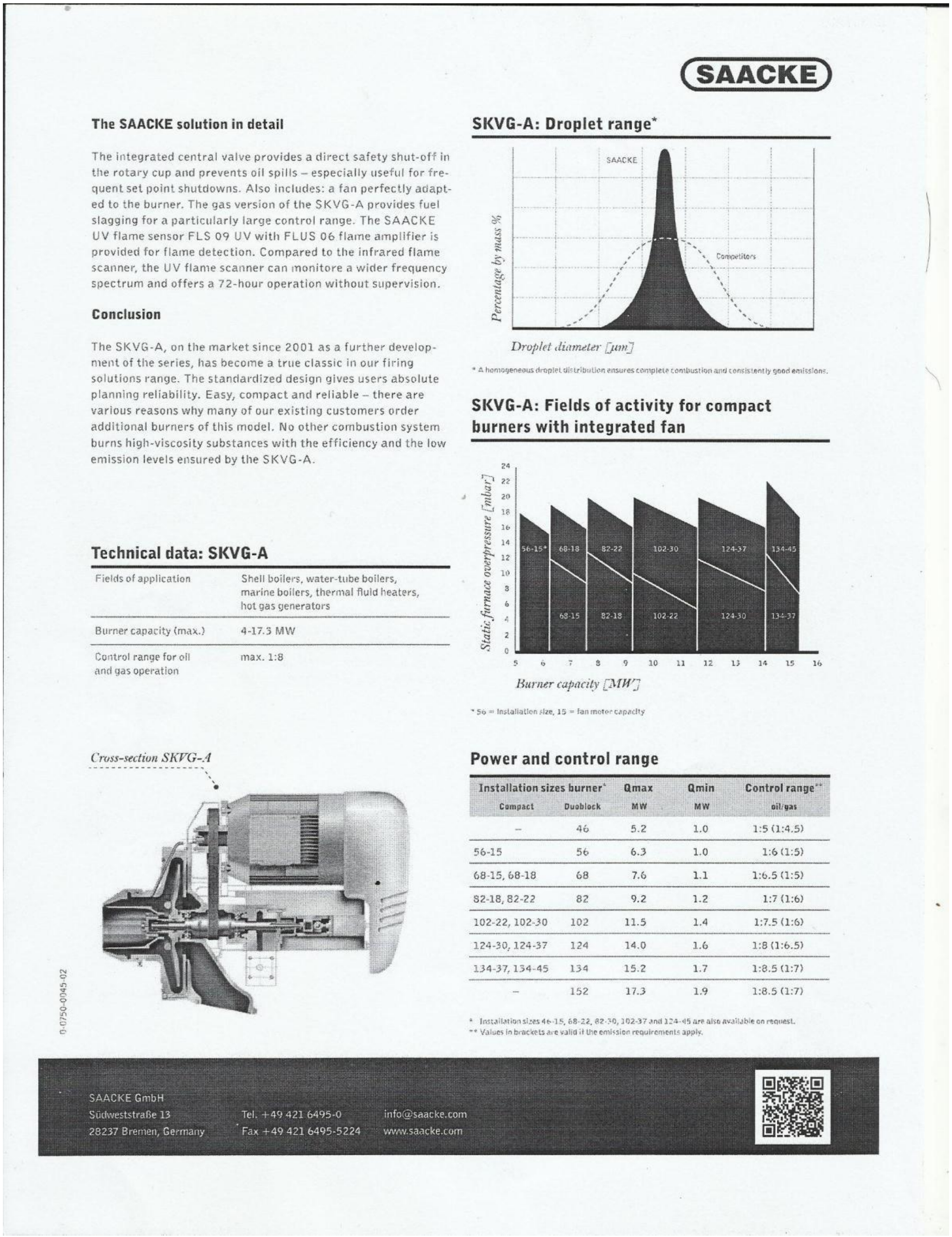
Table App 4. Summary of Gas Parameters

No.	Gas	Mass (Kg/day)	Mole (mole/day)	Partial Pressure (Kpa)
1	Methane	4263.84	403.5	0.05
2	Carbon Dioxide	2755.63	2.4	0.0006
3	Carbon Monoxide	0.023	65.3	0.02
4	Hydrogen Sulphide	9.32	12.8	0.003
5	Nitrogen Oxide	280	9.3	0.02
6	Sulphur Dioxide	0.02	5.6	0.002

Appendix 5: GG 90 VSD Biogas Compressor Specifications

TECHNICAL
SPECIFICATIONS
GG VSD compressor
Electrical cubicle
Gas handled Biomethane, methane
Working pressure Up to 16 bar (a)
Flow rate at minimum speed 75 Nm^3/h
Flow rate at maximum speed Up to 900 Nm^3/h
Installed motor power 90 / 132 kW
Dimensions (L x W x H) 2530 x 1100 x 1450 / 1617 mm
Weight Approximately 1800 / 2500 k

Appendix 6: Dual Fuel Burner Catalogue



The SAACKE solution in detail

The integrated central valve provides a direct safety shut-off in the rotary cup and prevents oil spills – especially useful for frequent set point shutdowns. Also includes: a fan perfectly adapted to the burner. The gas version of the SKVG-A provides fuel slagging for a particularly large control range. The SAACKE UV flame sensor FLS 09 UV with FLUS 06 flame amplifier is provided for flame detection. Compared to the infrared flame scanner, the UV flame scanner can monitore a wider frequency spectrum and offers a 72-hour operation without supervision.

Conclusion

The SKVG-A, on the market since 2001 as a further development of the series, has become a true classic in our firing solutions range. The standardized design gives users absolute planning reliability. Easy, compact and reliable – there are various reasons why many of our existing customers order additional burners of this model. No other combustion system burns high-viscosity substances with the efficiency and the low emission levels ensured by the SKVG-A.

Technical data: SKVG-A

Fields of application	Shell boilers, water-tube boilers, marine boilers, thermal fluid heaters, hot gas generators
Burner capacity (max.)	4-17.3 MW
Control range for oil and gas operation	max. 1:8

SKVG-A: Droplet range*

* A homogeneous droplet distribution ensures complete combustion and consistently good emissions.

SKVG-A: Fields of activity for compact burners with integrated fan

* 56 = Installation size, 15 = fan motor capacity

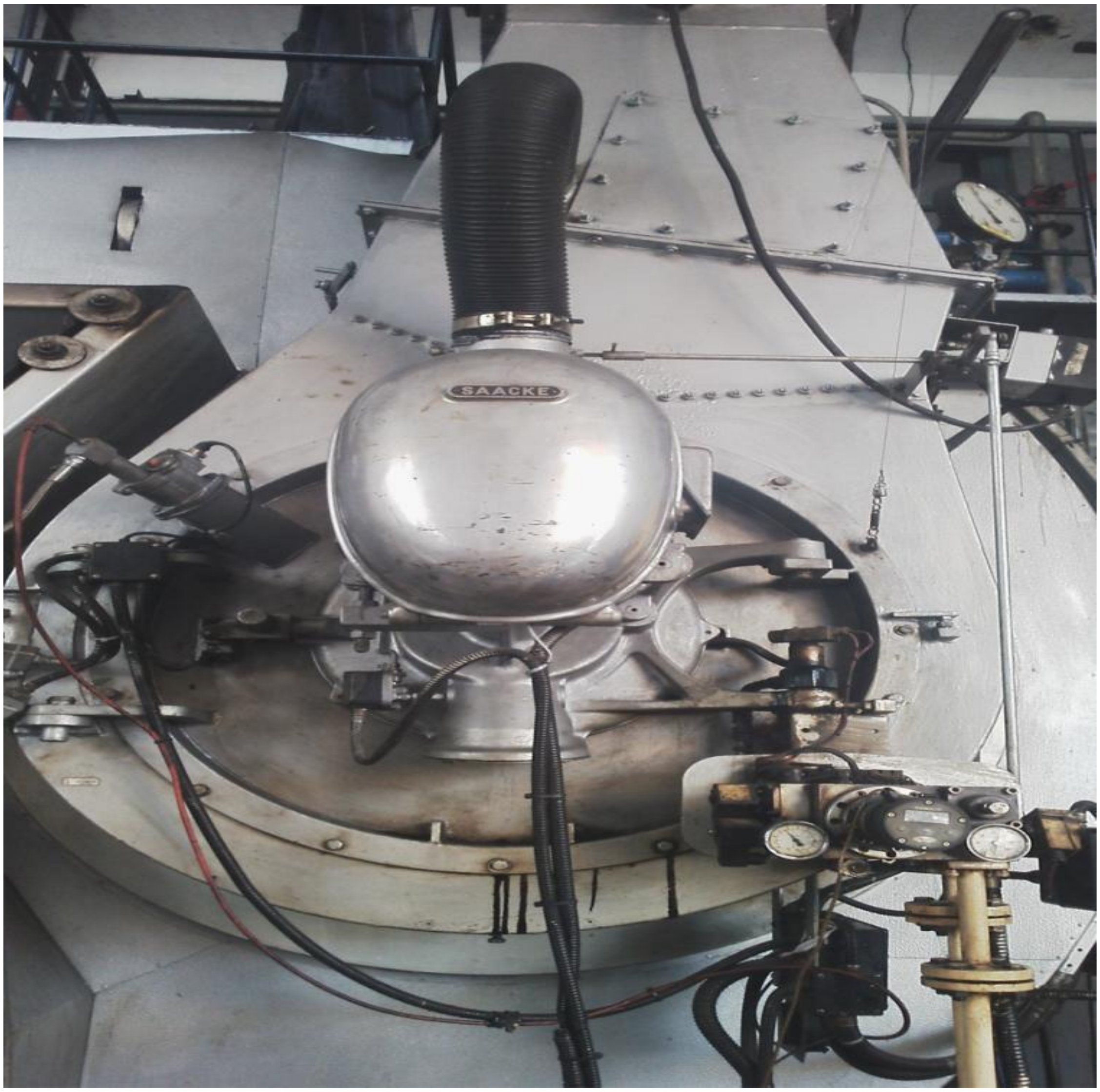
Power and control range

Installation sizes burner*		Qmax	Qmin	Control range**
Compact	Duoblock	MW	MW	oil/gas
–	46	5.2	1.0	1:5 (1:4.5)
56-15	56	6.3	1.0	1:6 (1:5)
68-15, 68-18	68	7.6	1.1	1:6.5 (1:5)
82-18, 82-22	82	9.2	1.2	1:7 (1:6)
102-22, 102-30	102	11.5	1.4	1:7.5 (1:6)
124-30, 124-37	124	14.0	1.6	1:8 (1:6.5)
134-37, 134-45	134	15.2	1.7	1:8.5 (1:7)
–	152	17.3	1.9	1:8.5 (1:7)

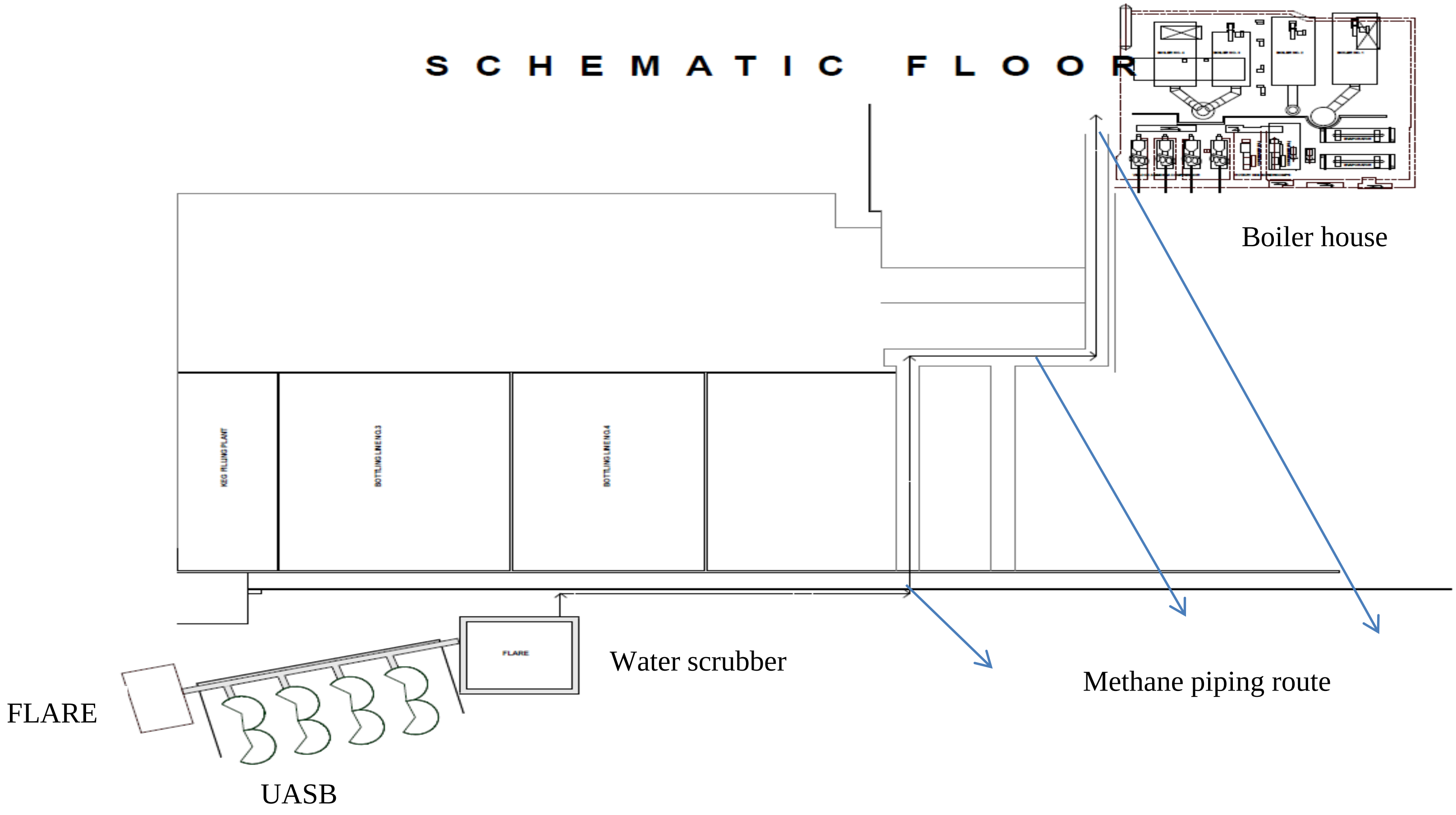
* Installation sizes 46-15, 68-22, 82-30, 102-37 and 124-45 are also available on request.
** Values in brackets are valid if the emission requirements apply.

SAACKE GmbH
Südweststraße 13
28237 Bremen, Germany
Tel. +49 421 6495-0
Fax +49 421 6495-5224
info@saacke.com
www.saacke.com

Appendix 7: Existing Boiler SAAKE Burner



Appendix 8: Proposed Methane Route to Boiler House



Appendix 9: Proposed Biogas Plant Layout