UNIVERSITY OF NAIROBI

DEPARTMENT OF MECHANICAL AND MANUFACTURING ENGINEERING

ANALYSIS OF ENERGY USE IN THE CERAMIC MEMBRANE FILTER PLANT AND IN THE UNITED DISTILLERS VINTNERS PLANT

[A Case Study at Kenya Breweries Ltd]

BY

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A Research Project Submitted in Partial Fulfillment of the Requirement for the Award of the Degree of Master of Science in ENERGY MANAGEMENT of the University of Nairobi

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DECLARATION

Student’s declaration

This project report is my original work and has not been submitted to any other college or university for academic credit.

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

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Supervisors’ declaration

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DEDICATION

I dedicate this project to my family, my wife Mary, my son Trevor my daughters Zanita and Teofila for their support and understanding during my entire project research and study period. To my brother Joseph God bless you more.

ABSTRACT

The global challenge on energy has been there for some period, this is being driven by the need for safer clean and environmentally friendly sources of energy. Currently most of the world production utilizes electricity and heavy fuel oil. High costs of production has driven the mitigation against the high cost energy in beer production. The best way to lower the energy cost of production is by analyzing of the existing system with a view of making cost effective improvements. The brewing process is energy intensive operation right from the onset at the brew house to the packaging lines. This project focused on energy analysis of UDV plant and the CMF plant. Data was collected on both plant during the study period and analyzed to evaluate areas of energy savings opportunities. In this regard the UDV plant sugar boiling system was analyzed and modifications proposed. The modifications will be able to safe 33.3% of the steam used translating to ksh3.56 million per year. The UDV packaging lines was also modified to incorporate proximity sensors which can save 3% of the energy used translating to 83,643 ksh per year. The power factor correction bank analysis identified a gap which when the solution is implemented can give 43.4% return on investment. CMF operation was modified at the yeast transfer section resulting to saving of between 3.8% to 9.4%. The yeast harmonization section was optimized reducing the time from one hour to 20 minutes, further research work was proposed for both plants to lower the cost of production.

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Praise to the Almighty Father for the gift of life. My lord has given me this opportunity to further my education and above all the knowledge and humility for the period of this study.

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Wish to thank East African Breweries for allowing me to do my research in their facilities and giving me the freedom to try different theories.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

ACs	Air conditioners
AL_2O_3	Aluminum oxide
^{O}C	Degrees centigrade
CIP	Clean-in-place
CMF	Ceramic Membrane Filter
DOL	Direct on line
EABL	East African Breweries ltd
ECM	Energy Conservation Measures
EMR	Energy Management Regulations
EPRA	Energy and Petroleum Regulatory Authority
ESO	Energy Saving Opportunities
EVI	Energy Use Indices
HFO	Heavy Fuel Oil
HL	Hectoliter
IMS	Industrial Mentholated Spirit
KPLC	Kenya Power & Lighting Company
kW	Kilowatt
kWhr	Kilo watt hour
m	Metre
mm	Millimeter
MW	Mega watt
NO	Normally Open
PFC	Power Factor Correction

ppm	Parts per million
RO	Reverse osmosis
RTD	Ready to drink
UDV	United Distillers Vintners
V	Volts
VAT	Value Aded tax
VSD	Variable Speed Drive

CHAPTER ONE

INTRODUCTION

1.0 Background Information

Globally, the focus on energy sector has increased and so is the need to face the range of challenges in the sector **[1]**. The energy demand is predicted to grow by one-third over 2015-2040 primarily in developing countries **[2].** The primary drivers of this demand are; a global population growth from the current 7.5 billion to 9 billion by 2040, a projected 150% growth in the global economy, and trends in increasing urbanization and mobility. At the same time, the energy sector needs to reposition itself to counter the emerging risks such as increasing volatility of the weather patterns, and create a framework to integrate new technologies which will bring positive impact to the sector. As the world changes it way of life and people become more and more committed to decreasing the negative environmental impact of the energy sector which currently is responsible for 35% - 40% of global greenhouse gas (GHG) emissions, will put strain on energy systems **[3].** Therefore, energy use analysis will become an integral part of our day to day operations which utilize any form of energy. Energy resources are abundant and can meet the growing demand for energy for decades to come. However, their distribution around the world and implications for energy markets call for more efficient use of these resources and use of efficient energy systems **[4]**.

Energy is the driver of the industrial production, economic growth, environment and comfort of mankind. It is the central force behind our productivity, our leisure and our environment. Energy conservation is cost effective with a short payback period and modest investment. The gap between supply and demand of energy can be bridged with the help of energy conservation. Thus, energy conservation is essential in developed as well as developing countries.

1.1 Kenyan Energy Sector

Kenya's energy sector has not grown enough to meet the energy demand of its growing economy **[5]**. Although there is a lot of emphasis in investing in the energy sector, she strives to meet her energy demand. To overcome the deficiency challenge, improvements are being done such as, increasing our electricity generation options and capacity, exploring oil and coal mining for power generation purposes, and utilization of renewable energy mostly solar and wind. The current electricity generation capacity is outlined in Table 1.1. From Table 1.1, most of the power in Kenya is hydro generated at 36.96% equivalent to 820.73MW. Fossil fuel comes next with 716.32MW at 32.71%, Geothermal power contributes 28.46% equivalent to 632MW, wind contributes 25.5 MW while cogeneration contributes 26MW. The total installed capacity is 2220.55MW. This amount is below the expected capacity as per the projections of Kenyan Vision 2030. According to the economic pillar the country should have a capacity of 2500MW by 2017. **[6].**

Table 1.1: Electricity Power Generation Sources in Kenya [5]

Sources of electric power generation (June 2017)		Installed capacity by (June 2017)	
Renewable energy		(MW)	Percentage
	Hydro	820.73	36.96%
	Geothermal	632	28.46%
	Wind	25.5	1.14%
	Cogeneration	26	1.17%
Fossil fuels	(including gas, diesel and emergency power)	716.32	32.71%
	Total power	2220.55	100%

The main sources of energy which drives the manufacturing sector is electricity and petroleum for its day to day operations. Kenya is currently dominantly depended on hydro-generated power and production varies from season to season as per the amount water in the dams. These variations result to fluctuations of the price of electricity as more expensive thermal power option is used to fill in any power deficit. The electricity cost varies with fuel cost whose price is volatile and unpredictable, and this makes power more expensive. Hence energy conservation is inevitable for all energy users. Energy use analysis is composed of various aspects which includes, inspection, survey and analysis of energy flow in an energy consuming system or process with the aim to reduce the amount of energy input without negatively affecting desired output. The analysis is required to identify where energy is lost and make energy use operations more efficient and hence conserve some energy, thus saving money. Energy use analysis can give a positive orientation to energy cost reduction, preventive maintenance and quality control programs which are vital for production and utility activities. It can keep focus on variations which occur in the energy costs, availability and reliability of supply of energy, decide on appropriate energy mix, identify energy conservation technologies, and retrofit for energy conservation equipment. Thus, a well performed energy use analysis can result to energy use restructuring, for efficient energy use.

1.2 Kenya Breweries Ltd (KBL)

Kenya Breweries Ltd is the largest brewery in Kenya with an annual production output of about 800 million litres of beer and other alcoholic beverages, and an annual sales turnover of 64 billion shillings. The main production unit is divided into four main departments namely: utilities, brewing, spirits and packaging. The main energy types at KBL are electricity and thermal energy obtained from steam boilers **[7]**. The total electricity consumption for the year 2014 was 52,572,112 kWh and 52,112,468 kWh in the year 2015. This shows a reduction in electricity consumption which was due to implementation of recommendations identified by the previous two energy audits. Electricity contributed 24% of the total energy used in both years. The total fuel energy obtained from the boilers was 570,343,108 MJ in the year 2014 and 570,212,260 MJ in 2015 **[7].** This shows that with proper energy use analysis the cost of energy can be reduced which can also result to lowering the cost of production.

Energy consumption cost accounts for 3 to 8 percent of the production cost of beer making **[8].** Improvement of energy use efficiency is an effective way to reduce production cost **[9].** In order to reduce energy consumption for sustainable and energy efficient manufacturing, continuous energy use analysis and process tracking is essential. The cost of energy is one of the major costs incurred in beer production at Kenya Breweries Limited. In a bid to reduce the energy costs, energy use analysis was conducted in two plants within the facility; Ceramic Membrane Filter (CMF) and United Distillers Vintners (UDV) plants.

The CMF plant is used to recover beer from yeast-beer mixture by pumping it through ceramic membrane filters. It is a new technology in Kenya breweries and its operation is currently under stabilization stage after commissioning.

The UDV plant is used in the manufacture of spirit-based alcoholic drinks and also ready to drink non-alcoholic drinks. This plant has gone through a lot of modifications and semi automations due to changing technology in spirits manufacturing and change in demand of spirits. However, these changes have not been harmonized to maximize the efficiency of the plant.

At KBL it has been observed that the energy consumption by some of the equipment has never been evaluated to quantify their consumption and efficiency. Although the total cost of electricity and Heavy Fuel Oil (HFO) is available from consumption records, the efficiency of individual plant items has not been established. Thus, there is a need to evaluate each plant separately and identify specific energy saving opportunities at each plant. This is in line with the company's objective of bringing down the cost of production, and to maximize the profits without increasing cost of products to consumers and maintaining them at high quality. Energy use analysis is an integral part of the overall energy management process. Such an analysis can unearth huge savings to the company and it's a key approach for systematic decision making in process management; the purpose is to balance the total energy inputs with the output or the uses and pinpoint areas of improvement **[12]**.

1.3 Energy Conservation Measures at KBL

The scale of operations at KBL makes it one of the major energy consumers in the country with an average annual energy consumption costing 1.1 Billion Kenya shillings. Kenya Breweries Ltd has formulated a policy on energy, waste management and environment conservation. The organization is committed in promoting efficient energy use, reduction of waste disposal to the environment and prevention of environmental degradation by its activities. In line with these, the company has installed carbon dioxide recovery systems in the beer fermentation tanks. During fermentation yeast metabolizes the sugars extracted from grains such as barley and sorghum producing alcohol and carbon dioxide. Carbon dioxide is one of the greenhouse gases responsible for global warming. The company has also invested in effluent treatment plant that handles all the waste from the factory. This plant treats both solid and liquid waste before disposal, generating biogas in the process.

The major sources of energy at KBL are currently petroleum and electricity, which are also the major sources of industrial power worldwide **[13]**. Legislative measures have been put in place by the national government of Kenya to efficiently use the existing capacity effectively. The Energy and Petroleum Regulatory Authority (EPRA), being the energy sector regulator, through Legal Notice No.102 published the Energy Management Regulations (EMR 2012). This Act requires all the consumers of energy whose capacity is above 180,000 kWh per month to undertake energy audits after every three years **[5]**. The purpose of this act is to enhance energy use efficiency. The recommendations made by the auditors should be shared between the company and the energy regulation commission.

In accordance to the Energy Management Regulation Act 2012, KBL has an energy policy which guides the company in the use of energy and identification of areas to improve on energy consumption. The policy covers all the energy consuming operations within the plant which comprises of a spirit distillery and a beer brewery and the associated support infrastructure namely office blocks and warehouses. The company also uses other world benchmarks **[16]** in the beer and spirit manufacturing industry to regulate its energy consumption. Not all energy input is utilized in the actual production; there is a lot of energy loss during the production process **[14]**. Most of the energy lost can be saved by implementation of simple measures and more can also be saved by use of long-time plans.

Some of the energy savings initiatives which the previous two energy audits recommended at KBL include the following;

- The use of variable speed drives for most of the pumps installed in the plant.
- Sizing of the pumps to fit the operations which they are meant to perform.
- Insulation of the steam lines to avoid heat loss.
- Recovery of condensate back to the boilers for re-use
- Switching off lights when they are not in use.
- Sealing of any water, steam and compressed air leaks immediately they are discovered.

Energy use analysis can be used to lower the capital investments needed to provide additional energy supply within the brewery; this can be done by identifying where and how much energy is lost. By mitigating energy loses, heavy investments in energy provision can be abated. This study focused on the energy use analysis in two plants within KBL, the UDV and CMF plants.

1.4 The UDV-plant

The United Distillers Vinters (UDV) plant manufactures spirit-based alcoholic beverages and few ready to drink non-alcoholic beverages. The UDV plant operates daily for 24 hours, 7 days a week, throughout the year unless when on maintenance. In the year 2015, the average annual production was 24 million litres of various blends, and electrical power consumption of 130,070 kWh. This compared with the power consumption in 2014 of 120,500 kWh and a production of 23.8 million litres. This represented a 7.9% increase in power consumption. This increase could be attributed to energy loss and poor plant efficiency since it was not equivalent to the 0.83 % increase in production.

Several operations are undertaken at the plant to produce the various beverages. These include reception and offloading of the concentrated spirits, dilution and blending of the spirits, packaging and warehousing. Support operations include a testing laboratory and Reverse Osmosis plant. All these operations mainly use electrical energy though Steam and hot water are also used. Unlike the beer brewing plant which has developed a standard of measure for the energy used to brew a hectolitre of beer which is about 103MJ/hl **[17],** the spirit manufacturing process has never been well evaluated in form of energy consumption. In accordance to the changing consumer trends in Kenya whereby the demand of spirits has been on upwards trajectory compared to the beer demand, KBL spirits sales increased by 13% in financial year to June 2017 and 18% in 2018**[11].** This has increased the energy consumption of the plant. The plant has also undergone a lot of upgrading in form of new technology and machinery. These developments have necessitated an energy use analysis to determine how well the plant has integrated with the other old machinery and determine its efficiency. This will give an outlook of what needs to be changed in form of machinery or the process operation.

1.5 The CMF-Plant

The Ceramic Membrane Filter (CMF) plant is used to recover beer from spent (or waste) yeast slurry. It is a new technology at KBL and also in the beer world, having only been installed and tested at one brewery site in Europe **[18].** Most of the operations of the plant are not fully optimized. The plant consists of three sections; the yeast storage tanks, the yeast homogenization, and the filtration section.

The inclination in beer manufacturing is to reduce the amount of beer which is disposed with the waste yeast. From analysis, yeast slurry which settles at the bottom of beer storage tanks usually contains 40-70% of beer **[17]**. Kenya Breweries Ltd has been faced with the challenge of recovering beer from the disposal yeast for many years thus incurring huge loss when yeast is disposed with high level of beer in it. It is due to this fact that the company acquired and installed a yeast beer recovery plant in the year 2014 to help cut down on production losses. The plant comprises of three filter modules each fitted with 70 ceramic filters. Two heavy duty pumps rated at 415V, 130A, 55kW are used to pump the yeast-beer mixture through the filters during the separation process. The input flow rate to the pumps of the homogenized beer yeast mixture is between 420,000l/h and 460,000l/h while the output from the ceramic filters is 2000l/h to 6000l/h. If the plant runs for 12hrs, the total production will be an average of 48,000 litres. Currently the plant output is at most 36,000l in 12hrs period. The production capacity of the plant compared to the rate of input at 460,000l/h shows a very high disparity. Energy use analysis will establish the energy consumption of the CMF plant. The energy use analysis should improve the efficiency of the plant thus increasing the output.

1.6 Problem Statement

To match the competitive production costs worldwide, energy efficiency and energy conservation measures cannot be overemphasized. The production dynamics have changed we are facing rising energy costs, more informed consumers, stricter environmental regulations and also taxes on energy or emissions. Kenya Breweries Ltd is focused to be an industry leader in energy conservation measures and efficient use of energy. Two energy audits have been conducted at the Kenya Breweries Ltd plant over the last six years and the outcome has shown that energy is wasted that can be conserved. The audits were specifically done on the brewery's utilities department. These audits have been especially on the steam supply and distribution system, electricity consumption in the cooling system, the water usage and compressed air supply and leakages in the process areas. From the audit findings several savings opportunities have been identified, and implemented.

However, those energy audits did not cover energy use and utilization in the process areas. Production process areas are the main users of the utilities which includes electricity, water, compressed air and steam. Thus, any inefficiency in the process plant equipment and processes results in high utilities consumptions and equally high costs. The high energy and utilities costs can be reduced if proper energy evaluation is done in all high energy consuming processes in the brewery. This can help to determine how much energy each plant is consuming and come up with measures to optimize energy utilization. For this study, the CMF and UDV plants were selected for energy use analysis.

1.7 Study Objectives

The main objective of this study was to analyse energy usage of the CMF plant and the UDV plant at KBL and to suggest improvement measures. To achieve this objective, the following specific objectives were pursued,

a) To determine the energy consumption of both the UDV and the CMF plants.

b) To identify sources of energy loss at both UDV and the CMF plant.

c) Propose energy saving measures for the identified sources of energy loss.

d) Estimate the cost of implementing the identified energy saving measures in both plants.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter highlights literature on the aspects the UDV plant and the CMF plant with regard to energy use, recovery and proper utilization. The study is on energy use and utilization at the UDV and CMF plants with focus on steam and electricity consumption.

2.1 Energy Use in Breweries

The challenge of maintaining high product quality while simultaneously reducing the cost of production can be met through investment in energy efficiency. The process of achieving this can be met by purchasing energy-efficient technology. Implementation of energy efficient practices within a plant can offer additional benefits, such as products quality improvement, increased production, and improved process efficiency. Energy efficiency is also an important component of a company's overall environment strategy, because energy efficiency improvements can often lead to reductions in greenhouse gases emissions and other environmental pollutants.

Brewery processes are relatively intensive users of both electrical and thermal energy. The target for every brewing company should be the development of sustainable processes with efficient energy consumption to achieve increased savings in both fuel and electricity energy costs. Energy consumption accounts for about 3-8% of production costs of beer making **[8]**. This makes energy efficiency improvement an important way to reduce production cost. Thermal energy is used in breweries extensively to produce steam for wort boiling in the initial stages of beer manufacturing, and also for water and sugar solution boiling during spirit manufacturing. The specific energy consumption of a brewery is mostly influenced by utility systems and process designs; however, every brewery is designed differently due to different products and also the type of packaging used. The location of the brewery also matters because of the temperature of the incoming water and climatic variations in different regions of the world. Energy consumption in a brewery can vary from 100-200 mega joules per hectolitre; this translates to 0.1-0.2 kWh per bottle of 0.5 litres, depending on size and the kind of technology used mostly for the utilities **[21]**.

2.2 Energy Audits at KBL

At the time of this study, two energy audits had been undertaken at KBL. The audits had mainly covered the utilities department, which supplies electricity, water, compressed air and steam to all the production process areas. Some of the main equipment covered under the audits included the following:

a) Site water mapping- reducing wastage, installation of metering point.

b) Steam distribution- elimination of leaks, lagging of pipes and replacement of steam traps.

c) Refrigeration plant- mapping of the site refrigeration demand, installation of VSD to IMS pumps, replacement of old energy inefficient compressors.

d) Boiler plant-evaluation of fuel oil usage, boiler feed water balance and condensate recovery.

2.3 The CMF plant operation

A ceramic membrane filter plant is designed to recover beer from yeast. The layout of the CMF plant is as shown in Figure 2.1.

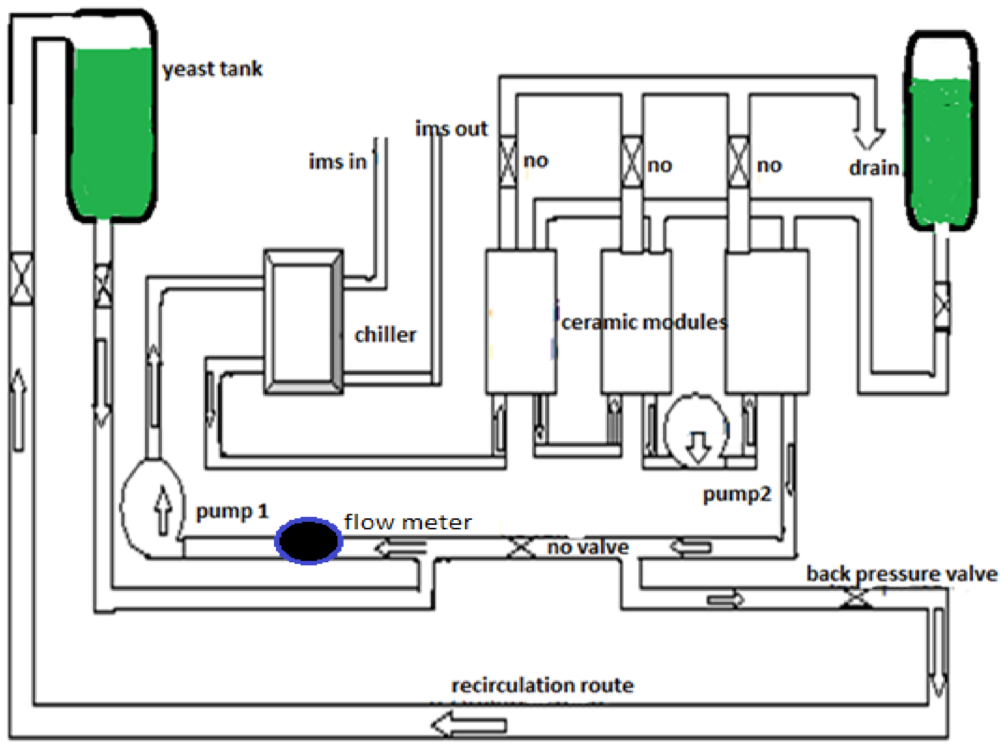

Figure 2.1: CMF Plant Layout and Operation Diagram

The process starts with the harvesting of yeast beer mixture from the beer fermentation and conditioning tanks. This is done after beer has matured to the set specifications. The process of beer manufacturing includes the fermentation and maturation. During maturation, enzymes are added into the beer at the maturation tank to help separate beer from yeast. The yeast settles at the bottom of the tank which is then separated and transferred to the CMF plant for further processing to separate the mixture further and recover some beer **[10]**. The yeast is harvested and stored in the yeast tank as shown in Figure 2.1. Once the tank is full the yeast beer solution is pumped by pump1 through the heat exchanger where cooling takes place before it enters the filter chambers. The separation of yeast and beer takes place at the ceramic modules. The filter chambers are made up of three filter modules which consist of ceramic cartridges. The ceramic membranes can be operated in cross-flow or direct flow filtration mode. The cross-flow filtration mode is a continuous process in which the feed stream flows parallel to the membrane filtration surface and generates two outgoing streams. A small fraction of feed permeates through as purified beer passing through the membrane. The remaining fraction of feed, called retentate or concentrate contains particles rejected by the membrane. The separation is driven by the pressure difference across the membrane, or the trans-membrane pressure. The parallel flow of the feed stream, combined with the boundary layer turbulence created by the cross-flow velocity, continually sweeps away particles and other material that would otherwise build up on the membrane surface. This mode has the benefit of maintaining a high filtration rate for membrane filters compared with direct flow filtration mode. At KBL, the ceramic membranes are operated in the cross-flow filtration mode.

From the modules the filtered beer is stored at the beer tank while the yeast is circulated back for further filtration. The circulation continues until most of the beer is filtered. This is established by analysing the alcohol content of the yeast mixture. The batch is complete when the alcohol in the mixture is below 2%v/v. In case of pressure build up, dilution is done with water. Pump 1 and pump 2 creates a force, which push the yeast through the cartridges, and allow the beer to sip through to the output. The high flow rate is maintained by the use of the backpressure valve and the flow meter. When he flowrate drops below 4600hl\h the backpressure valve receives a signal to close to a certain percentage. The closing and opening of the backpressure valve maintain the high flow rate at the ceramic modules by directing more yeast back to the ceramic modules. The plant makes use of electrical energy for running the pumps and compressed air for operating the valves.

2.3.1 The Ceramic Membrane Cartridge

Ceramic membranes are a type of artificial membranes made from inorganic materials such as alumina, Titania, zirconia oxides, silicon carbide or some glassy materials. By design the ceramic membrane cartridges are robust, reliable and can be sterilized. The main advantages of ceramic filters are that they are: reliable with 8 to 10 years' life time, sterilization is possible and requires cleaning only with detergents which includes caustic and acid **[18]**. The design of the ceramic filter is as shown in Fig 2.2. The filter is made of ceramic material which is food neutral so there is no risk of contamination. The cartridges can withstand elevated temperatures, very low and high PH, and high operating pressures up to 10 bars without concern for membrane compaction, delamination or swelling. Thus, ceramic membranes are ideal for in-place chemical cleaning at high temperatures while using caustic, chlorine and other strong inorganic acids. The ceramic membrane cartridges are often formed into an asymmetric, multi-channel element as shown in Fig. 2.2. These elements are grouped together in housing forming a filtration module. Several membrane pore sizes are available to suit specific filtration needs covering microfiltration, ultrafiltration and Nano filtration.

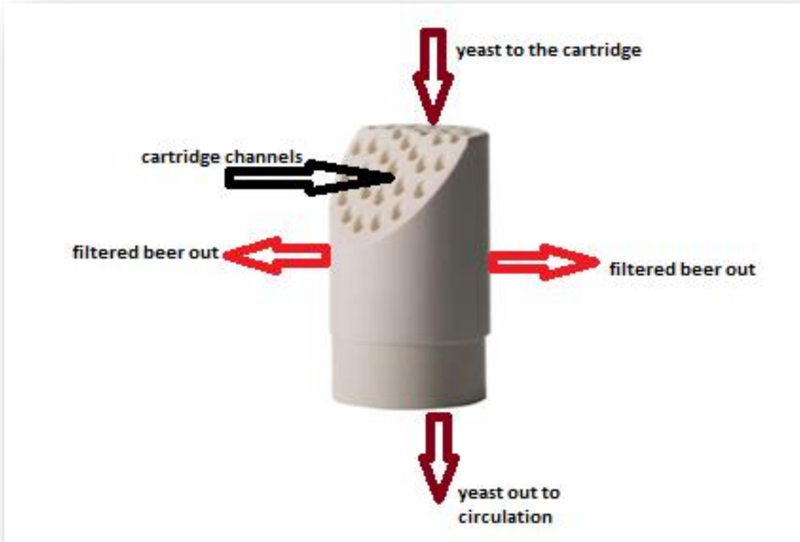

Figure 2.2: The Ceramic Membrane Cartridge Filter [18]

Table 2.1 shows the properties of the alumina ceramic membrane filter. Some of the advantages of the filter is that it can withstand high pressure of up to 10 bar without being damaged, resistance to chlorine, stability over a wide PH range, and high temperature stability.

Table 2.1: Properties of Alumina Ceramic Filter Cartridge (18)

Property	**Specifications**
Material	AL_2O_3
Length	1200 mm
Channel diameter	8 mm
Ph	0-14
Poles	1 Micron
Chlorine resistance	1000 ppm
Temperature range	$0\text{-}1000^0C$
Maximum pressure	10 bar
Shelf life (guaranteed)	8 years

The yeast mixture is pumped into the channels of the ceramic filters at a flow rate of above 4600hl/h. As shown by figure 2.2, the filtered beer is pushed through the walls of the ceramic filter due to the pressure. The unfiltered yeast comes out from the other end of the channels and circulates back for continuous beer filtration. The operation pressure of the ceramic cartridges is up to a maximum of 10 bars. The cartridges are easily damaged by pressure shocks in case a regulating valve is instantly closed while the plant is in operation. During power failure the plant is designed with the power failure safe conditions where some valves are normally opened (no) during power failure.

The fitting of the ceramic cartridges and the yeast flow inside the modules is as illustrated in Figure 2.3. The operation of the system is by dual flow whereby the input flows parallel to the output. This system has an advantage of increased flowrate. Figure 2.3 shows that each module is divided into two sections, the inlet and the outlet of the yeast and each side comprises of 39 cartridges.

The capacity of each element is 130hl/h, which gives the rated flow rate of the plant as 5070 hl/h at the optimum operation flow. Beer comes out from the surface of the cartridges due to the applied pressure. As the cartridge poles get blocked by yeast particles the beer output reduces thus more energy is consumed per unit of beer produced.

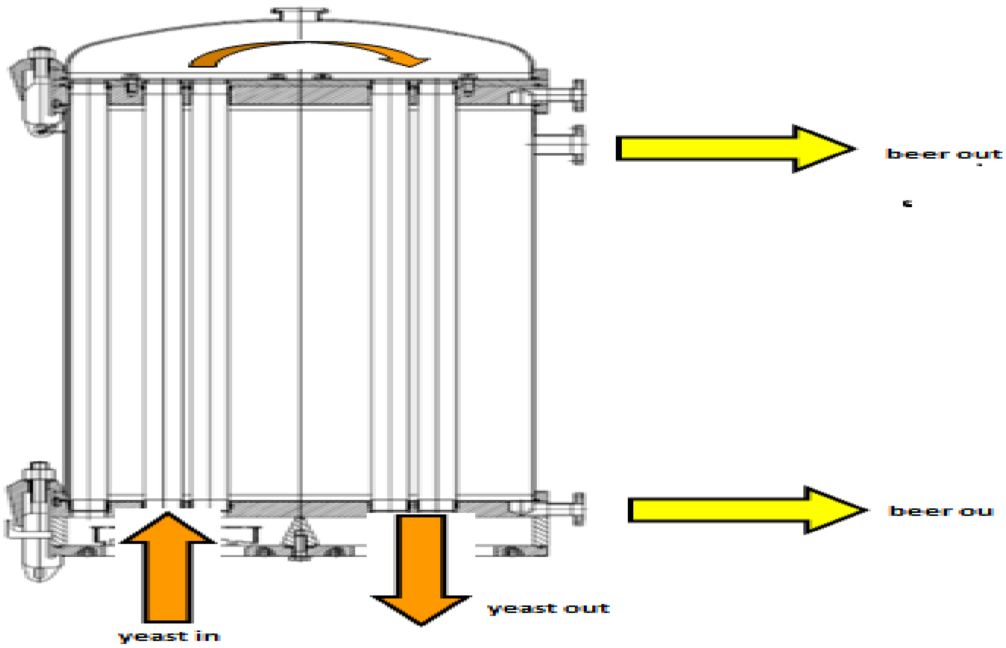

Figure 2.3: The Arrangement of the Cartridges in the Module [18]

2.4 The UDV Plant Operation

The UDV plant is in the manufacture of spirit-based alcoholic drinks and ready-to-drink non-alcoholic drinks. The spirit making process uses water, sugar solution, distilled spirit and different food grade flavours. Before the start of the spirits manufacturing process, the blending water is prepared. Water is usually pre- treated with reverse osmosis carbon filtration or other type of filtering system. The UDV water production plant has a capacity of 10,000 l/h. The water is also used for sugar dissolving and boiling at the start of the spirit drinks production. Figure 2.4 shows a block flow diagram of the main stages of spirit drinks production in a brewery.

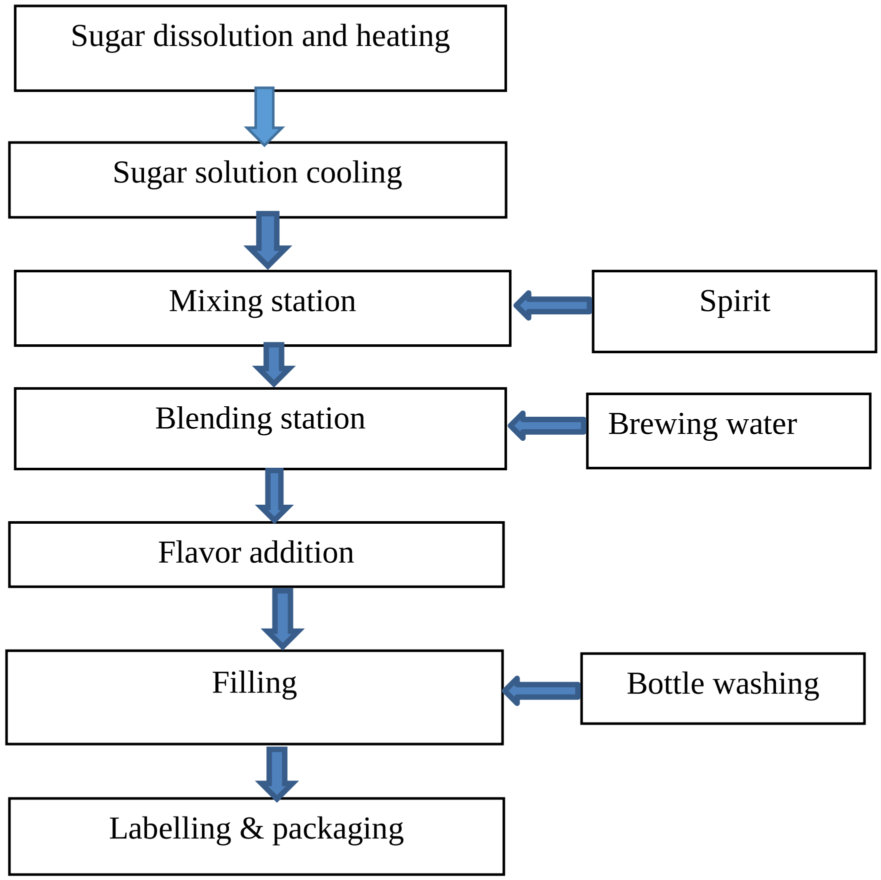

Figure 2.4: Main Stages of Spirit Production

The first step in making spirits is the sugar solution heating for those drinks which requires sugar addition, normally referred as ready to drink (RTD). The sugar solution is heated by use of steam through heat exchangers to 80^{o}C to facilitate the dissolving of sugar and sterilization. The type of heating is a strong rolling boil and is the most fuel intensive step of the spirit production process which takes over 1 to 1.5-hour period. It is estimated that 55 to 57 MJ/hl is used for heating in beer and spirit making processes in Germany **[21].** After heating the next stage is the solution cooling to below 7^{o}C before addition of spirit; the cooling is carried out by use of industrial methylated spirit (IMS) through heat exchangers. The spirit cannot be added to the sugar solution at a temperature of 80^{o}C since at this temperature evaporation will take place and result to loss of the spirit. Cooling involves continuous pumping of IMS from the utility plant to the UDV plant and recovery of the IMS back to the utility plant. The process makes use of two pumps rated at 25 kW and 15 kW.

After the solution has cooled to below 7^{o}C it is pumped to the mixing station. At this stage spirit is added to the sugar solution. This is done by the use of pre-determined formula which is used to calculate the amount of spirit to add as per the volume of the sugar solution. During the mixing process an agitator rated 7.5 kW continuously stirs up the mixture to maintain homogeneity. This process takes 1 hour then the mixture is pumped to the blending station**.** At this stage brewing water is added to dilute the mixture to the required alcohol content. This can be a significant volume as high as 50% **[17].** The alcohol level is measured by use of an alcohol meter to ascertain the alcohol content. Correction is done in case of deviation from the required alcohol content level as per the set quality standards. When the required quality standards have been achieved the next stage is the flavour addition. This gives the spirit its special distinct taste. The flavour varies from one brand to the other, and this process involves stirring the mixture continuously to achieve homogeneity. When the required product quality is achieved, the final product is then passed to the packaging lines. At the packaging lines, filling of the spirits to bottles takes place. Once the spirit has been bottled pasteurization is carried out for those spirits containing sugar solution. This is done to clear the beer of all the harmful bacteria hence increase its shelf life. During pasteurization the product is heated up to 70^{o}C to destroy all the biological contaminants. There are different pasteurization techniques like tunnel or flash pasteurization. Energy requirements for pasteurization can vary from 20-25 kWh per 1000 bottles for tunnel pasteurization system **[21].** The final stage once the product has been filled into the bottles and pasteurized is packaging into cartons and crates for transportation.

2.4.1 The Sugar Heating Process

The base ingredient for most carbonated beverages is sugar syrup, prepared by combining crystalline sugar or beet sugar and water. Syrup is prepared to specific concentration, measured in degrees' brix. This is measurement of mass ratio of dissolved sucrose to water and is monitored by an in-line mass flow meter that measures the specific gravity of the solution. The process of heating the sugar solution consists of the sugar dissolving tank, the solution storage tank, plate heat exchanger circulation pump, pipes, valves and a chiller as shown in Figure 2.5.

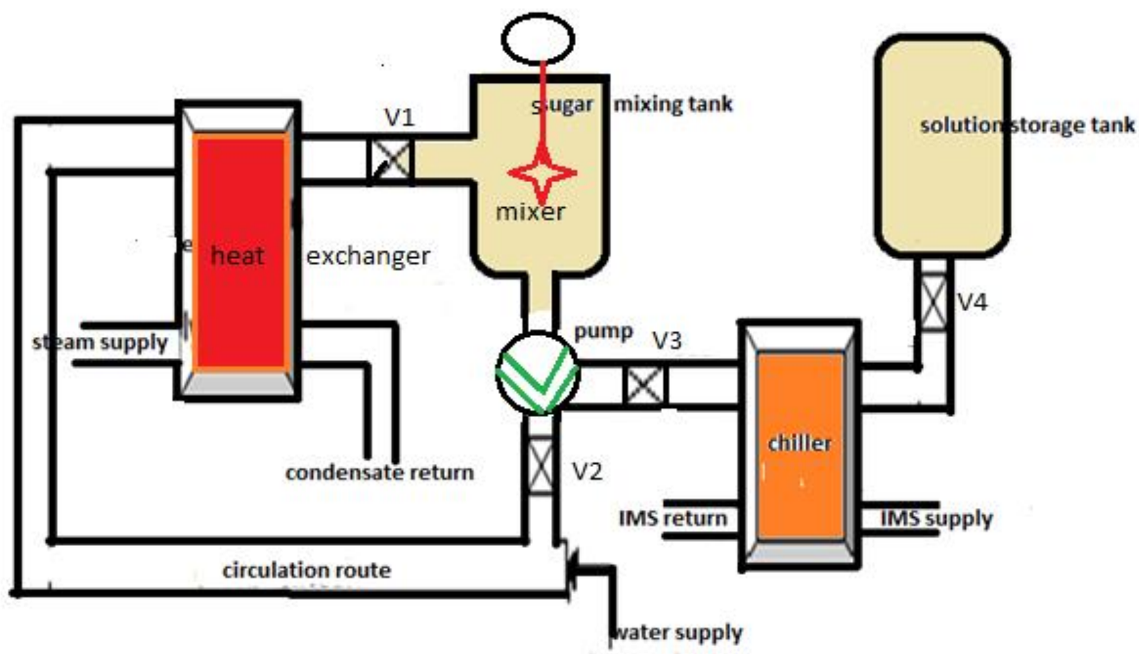

Figure 2.5: Sugar Dissolving and Mixing System

The sugar mixing tank is filled with brewing water to the required level, the water is then pre-heated from 23^oC to 60^oC before the addition of sugar. Dry sugar is metered into dissolving tank via a screw feeder equipped with frequency converter for capacity regulation. The initial dissolving of sugar is achieved via use of a stirrer then high velocity recirculation of the solution. The mixture is stirred for 30 minutes in the mixing tank before starting the circulation through the heat exchanger. Steam from the boilers is continuously supplied to heat the solution until a temperature of between 80^oC and 85^oC is uniformly attained. In liquid heating process, it is advantageous to supply the heat areas with saturated steam because this leads to much better heat convection during condensation than with superheated water vapour. In boiler plants superheated water vapour can be produced directly by use of super heaters or it can be produced during throttling of saturated steam/wet steam from high pressure to lower pressure level.

Fire tube exhaust gas-tube boiler plants which are used in breweries very often provide live steam with steam quality of 95 to 98% in practice. Live steam from a boiler plant with a boiler operating pressure of 8 bar (absolute) is reduced to a pressure of 3 bar (absolute) before it is used for internal or external heating **[22]**. This reduction is basically to avoid damage to the product like the change of colour of the sugar solution thus affecting the colour of the final product which should be within a pre-set quality standard.

When the mixture achieves homogeneity valve V3 is opened and the syrup is pumped through the chiller cooling it from 80^oC to around 20^oC and below. This solution is then passed through valve V4 to the storage tank. From the storage tank a sample is taken for lab analysis to verify the brix before addition of the spirit and blending. The IMS for the cooling is supplied at a temperature of -5°C and a pressure of 3 bars. There are critical control parameters during the process which should be monitored. These include;

a) *Water flow for sugar dissolving*

Accurate measurement of water flow to ensure consistent product formulation and sugar concentration.

b) Steam flow and temperature measurement

Plate heat exchangers use saturated steam to heat the re-circulating sugar solution. Steam flow control maintains consistent plate heat exchanger temperature, optimizes end product quality and avoids unnecessary energy use.

c) Syrup Temperature

Optimum control of syrup temperature ensures complete dissolution of sugar and ensures the required brix concentration is attained.

d) Sugar dissolving tank level

Liquid level is monitored to confirm the vessel contents volume and to provide fill and empty alarm points.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

This chapter describes the procedure and steps that were taken to achieve the stated objectives, and includes the data collected and the various types of tools used to collect it.

3.1 Data Collection and Evaluation at the CMF plant and UDV plant

To enable the evaluation of the energy consumption at the CMF and UDV plants, the following data was collected.

a) Production rate

The daily, monthly and annual production throughput, i.e. the amount of beer filtered by the CMF plant, and the amount of spirit produced by the UDV plant in a selected time duration (l/hr, l/day) were obtained. The data was obtained from flow meters installed in the study plants, plant process and production records, equipment name plates, and operating or instruction manuals. For the UDV plant, magnetic flow meters were used where the fluid being measured was a conducting fluid. Endress + Hauser(promag50) mass flow meters were also used in both UDV and CMF plant where high accuracy was needed.

b) Power input ratings

Power input ratings were obtained for motors and pumps. They were obtained from equipment name plates, operating or instruction manuals, vendor catalogues or other materials supplied by the vendor. Energy input ratings were expressed in a variety of units such as Kw, kWh, or MJ/hr. This data was used to compare the power consumption of the machines at full load versus the rated power.

c) *Plant Energy Consumption*

The energy used in various processes i.e. sugar boiling, sugar solution cooling, spirit packaging section, CMF filtration process and yeast transfer process were determined. Energy consumption data for the UDV plant was recorded for a period of two years. A sub-meter installed at the UDV plant recorded the electrical power consumption. Figure 3.1 shows a utility meter and the sub-meter.

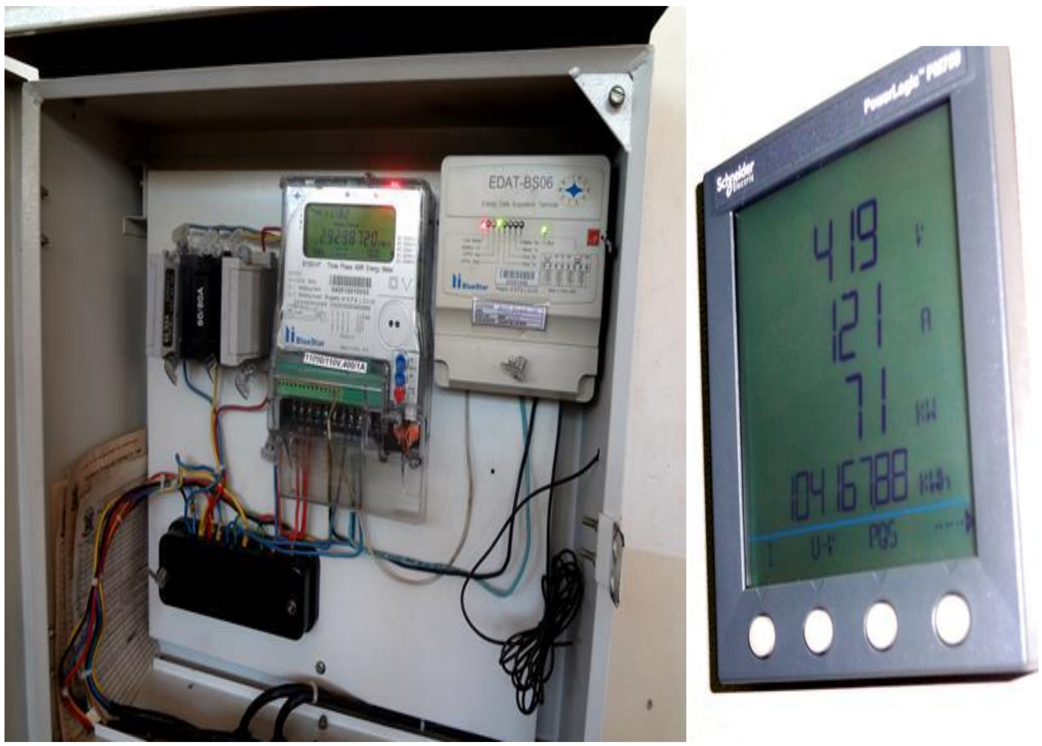

Figure 3.1: The Utility Meter and sub meter for the UDV plant

The sub meter indicated energy consumption in form of amperes, kilowatts and the total consumption inform of kWh. Where the individual meters were not available for electrical power consumption measurement like for the CMF plant which is not installed with its own meter but its metered from the brewing plant main supply, energy use measurement and recording was done by means of portable power energy meter. These measurements were carried out for a period of two months and data recorded. The meter was used to record the current, the voltage, kWh, and also used to monitor any fluctuations during the production process. The portable energy meter (data logger) has a memory and stored the data captured in its memory.

d) Energy Cost

The cost of energy was expressed in demand charges that are based on usage during times of peak demand, and fuel cost in KES/litre. Monthly electrical bills and fuel oil delivery invoices were used as primary data sources. This data was collected for the purpose of analysing the cost of the energy consumed. The data was also used to calculate return on investment of any proposed energy saving measures in both plants.

e) Process Temperatures

Various process temperatures were obtained during the sugar solution heating process. This was done at various stages of heating and cooling. Reliable and accurate temperature measurement was achieved by use of sensor mounted temperature transmitters using 4-20mA with HART protocol. The temperature reading was achieved by use of(PT100) temperature sensors. This sensor offered the highest accuracy and linearity, and the use of transmitter provided a clean signal to the temperature controller. Other temperature measurement instruments like spot infrared thermometer were used. For the medium temperatures ($<300^{o}C$) process or product temperature, an RTD (resistance thermocouple detector) was used to measure the temperature. Platinum 100 (PT 100) thermocouple probe has a linear temperature and resistance characteristics, good sensitivity and fast response, and hence provided reliable results. This data was required for the calculation of the heat loss at the sugar mixing tank and the heat exchanger.

f) Steam Measurement

Steam flow and cumulative meters were used to measure the amount of steam being supplied from the utilities plant to the UDV; Vortex steam flow meters were used. Pressure gauges were used to monitor the steam line pressures.

In all the above cases where existing instruments were used care was taken to verify their accuracy. This was done by calibrating the instruments.

g) Plant Power factor

The UDV plant power factor was monitored through measurement over a period of two months on 24 hours' intervals by use of an energy meter.

CHAPTER FOUR

RESULTS AND ANALYSIS

4.0 Introduction

In this chapter results of the study are presented. The energy consumption for the CMF plant and for the UDV plant is analysed. Energy losses are identified and illustrated and energy conservation measures (ECMs) are suggested also and a cost benefit analysis is done.

4.1 Energy Consumption at UDV Plant

Table 4.1 shows the monthly energy consumption of energy for a period of two years, i.e. 2015 and 2016 for the UDV plant**.** Both monthly and annual energy intensity (in MJ/hl) were also calculated for the same period. Energy intensity is the amount of energy consumed per unit of output produced. Low energy intensity represents an efficient plant. Energy intensity helps in establishing baseline and tracking any deviations from the established baseline. Determination of plant energy intensity is a critical first step in effectively managing energy use. Energy conversions was tabulated using the following relationship, 1 kWh = 3.6 MJ Electricity energy and 1 litre of HFO = 42.67 MJ fuel energy (Grade 180)

Table 4.1: Production and Power Consumption for UDV Plant [7].

Month	Production (hl)	Energy Consumption					Energy Intensity		
		HFO (litres)	HFO (MJ)	Electricity (kWh)	Electricity (MJ)	Total (MJ)	HFO (MJ/hl)	Electricity (MJ/hl)	Total
Jul-2014	12,120	1,031	43,992.77	8,646	31,125.60	75,118.37	3.63	2.57	6.19
Aug-2014	17,232	1,230	52,484.10	10,462	37,663.20	90,147.30	3.05	2.19	5.23
Sep-2014	20,112	1,450	61,871.50	11,582	41,695.20	103,566.70	3.08	2.07	5.15
Oct-2014	16,460	1,190	50,777.30	10,474	37,706.40	88,483.70	3.08	2.29	5.38
Nov-2014	14,000	1,114	47,534.38	10,363	37,306.80	84,841.18	3.39	2.66	6.06
Dec-2014	18,422	1,242	52,996.14	10,547	37,969.20	90,965,34	2.88	2.06	4.94
Jan-2015	19,211	1,382	58,969.94	11,346	40,845.60	99,815.54	3,07	2.13	5.21
Feb-2015	22,430	1,550	66,138.50	11,868	42,724.80	108,863.30	2.95	1.90	4.85
Mar-2015	26,321	1,614	68,869.38	13,809	49,712.40	118,581.78	2.62	1.89	4.51
Apr-2015	24,000	1560	66,565.20	12,441	44,787.60	111,352.80	2.77	1.87	4.64
May2015	21,152	1,484	63,322.28	12,092	43,531.20	106,853.48	2.99	2.06	5.05
Jun-2015	17,804	1,212	51,716.04	10,704	38,534.40	90,250.44	2.90	2.16	5.06
Jul-2015	18,449	1,244	53,081.48	10,526	37,893.60	90,975.08	2.88	2.05	4.93
Aug-2015	14,963	1,475	62,961.60	6,200	22,321.20	85,282.28	3.21	2.49	5.69
Sep-2015	18,226	1,224	52,228.08	10,622	38,239.20	90,467.28	2.87	2.10	4.68
Oct-2015	22,634	1,556	66,394.52	11,864	42,720.40	109,114.92	2.93	1.89	4.82
Nov-2015	22,632	1,552	66,223.84	12,644	45,518.40	111,742.24	2.93	2.01	4.94
Dec-2015	23,327	1,550	66,138.50	12,666	45,597.60	111,736.10	2.84	1.95	4.93
Jan-2016	23,384	1,552	66,223.84	12,118	43,624.80	109,848.64	2.83	1.87	4.70
Feb-2016	21,822	1,720	73,407.62	8,444	30,399.20	103,806.82	2.91	1.85	4.76
Mar-2016	19,867	1,860	79,396.64	6,028	21,702.40	101,099.04	2.99	2.10	5.09
Apr-2016	21,217	1,935	82,596.89	6,070	21,853.60	104,450.49	2.95	1.97	4.92
May2016	20,417	1,926	82,212.86	6,542	23,552.80	105,765.66	3.05	2.13	5.20
Jun-2016	21,720	1,469	62,682.23	11,920	42,912.00	105,594.23	2.89	1.98	4.86
SUM F15	178,943	16,059	685,237.77	134,334	483,602.40	1,077,874.59			
SUM F16	248,658	17,064	728,947.58	139,277	501,335.20	1,229,882.52			
AVG F15	14,911	1,338	57,103	11,194	40,300	97,403	3.03	2.15	5.19
AVG F16	20,721	1,422	60,745	11,606	41,777	102,490	2.94	2.03	4.96

Energy intensity is taken as a ratio between the total amount of power the plant has consumed for a specific period and the production output during the same period. As shown in Table 4.1 energy intensity for July 2014 and June 2015 was calculated as;

Energy Intensity July 2014 $= \frac{75,118.37}{12,120} = 6.19$

Energy intensity June 2015= $\frac{90,250.44}{17,804} = 5.06$

Energy intensity for the UDV plant is depended on various factors which include:

1. Capacity utilization- operating the plant at optimum capacity gives a lower energy intensity.
2. The type of spirit being processed during a particular period- some brands are high energy consumers.
3. Plant efficiency.
4. Plant operation – avoid plant idling with power on especially the conveyers. Plan for long production run to avoid frequent starting of the machine

In 2016, there was a reduction of average fuel energy consumed with increased production at the study plant. For every hectolitre of beer produced, 4.95 MJ of fuel energy was consumed. The HFO use data shows an influence by production as per Table 4.1. The energy intensities are low when production peaks. This shows that as production increases the HFO energy intensity reduce. A similar data is shown on the total energy as HFO forms a large part of total energy. The energy analysis from the consumption of the UDV plant for the two-year period show that fuel energy is used twice than the electricity energy, this can be partly due to the system design losses. This means not all the energy which is used by the plant goes into the actual production.

The energy consumption and production output of the UDV plant for the financial year 2015 and 2016 is as shown by Table 4.1. The focus was on the amount of spirit produced monthly versus the power consumption during the same period. The energy consumption was classified as per the source that is electricity and fuel oil. The total energy intensity for each month was calculated to help in identification of energy saving opportunities. From analysis of both electrical energy and fuel energy as per the data of the two-year period shows that more effort should be geared towards the fuel energy. The fact that it is used more in the UDV plant operations presents us with opportunities for more savings.

Figure 4.1 shows a comparison between the energy used both electrical and fuel and the amount of spirit produced. From Figure 4.1 it is observed that as the product production increases the energy consumption also increases. From Figure 4.1 the relationship between energy and production is a linear one. Which means energy consumption increases as the production increases. This shows that energy savings can be realised better by improving the power consumption efficiency of the plant.

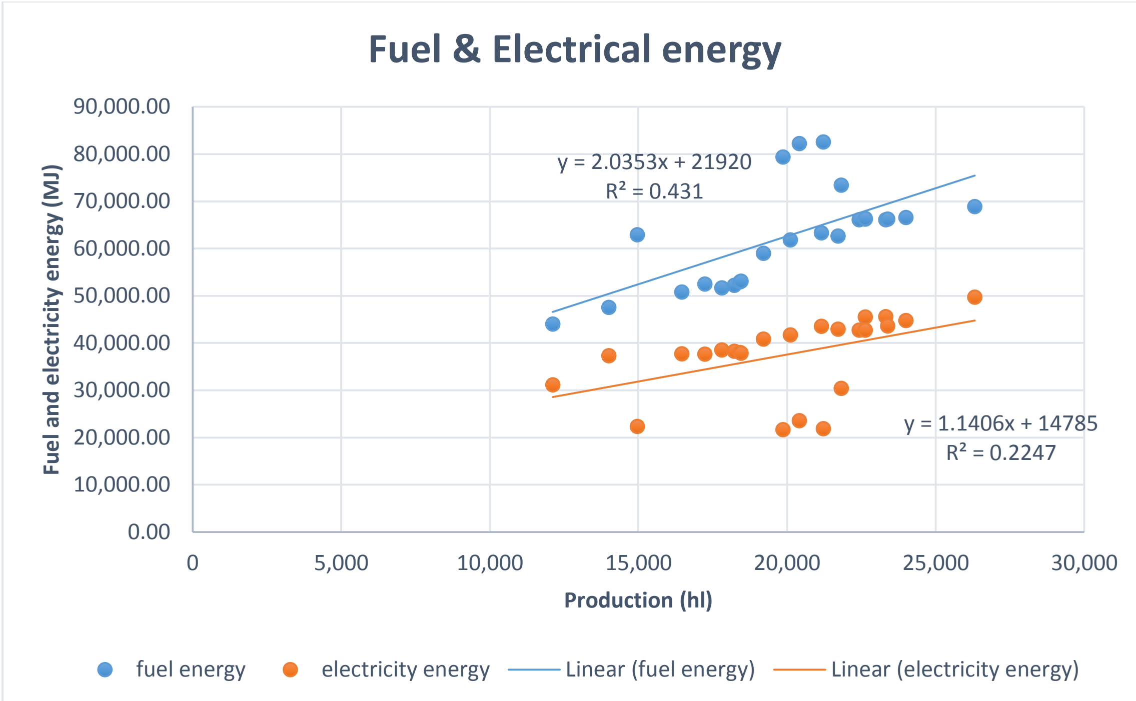

Figure 4.1: Comparison of Energy Consumption and Production for the UDV plant

From the preliminary analysis of the plant during this study there were energy saving opportunities which were identified and some were implemented. Those measures included the no cost measures like stopping the plant when there is no production. Training and sensitization of employees on energy management practices. Switching off light when not needed, Pumps and motors load sizing.

The initial energy saving measures which were identified and implemented during this study partly contributed to the lower electrical energy utilization per hl of the spirit produced. Energy use analysis is an effort to establish energy consumption per unit of production as shown by Table 4.1 the target is to reduce the amount of energy used in producing one hectolitre of spirit. From Table 4.1 it shows that in 2015 the utilization was 5.19 then reduced to 4.94 in 2016.

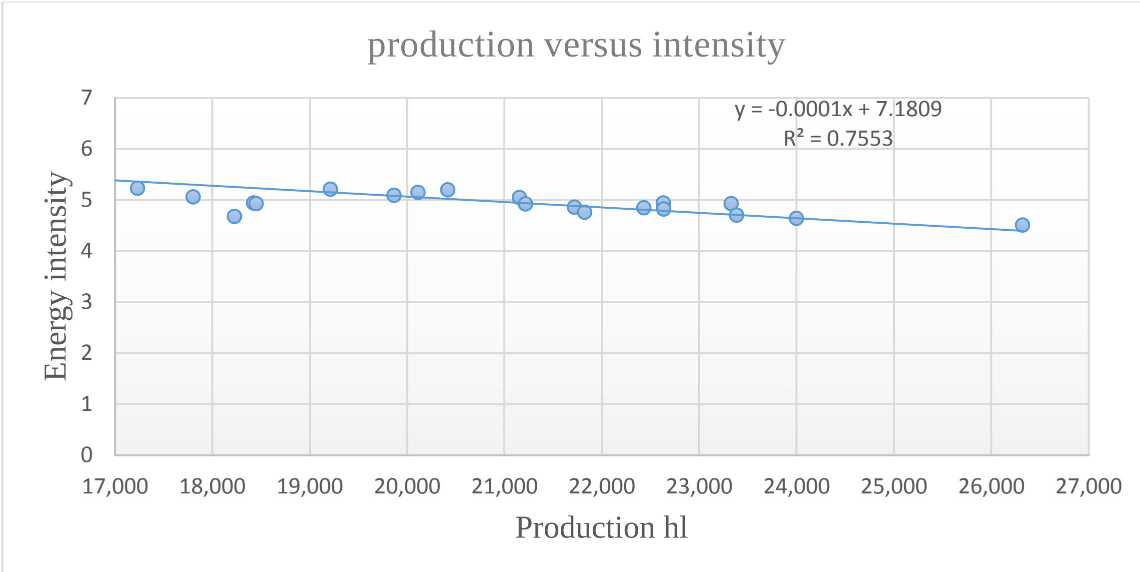

Figure 4.2 Comparison of Energy Intensity and Production of the UDV plant

Energy intensity is defined as the amount of energy used to produce one unit of a product. Figure 4.2 shows that as the production of spirit increases the energy intensity decreases. From the energy efficient point of view, efficient operation of a plant should translate to a lower energy intensity **[15]**. From Fig. 4.2 it is clearly shown that in an ideal situation it can be more efficient for the plant to be unscheduled when production is low and capitalise on high production to safe on energy.

4.2 Power Loss Sources in the UDV plant

In the UDV plant, the main power loses were found to be in the spirit and sugar mixing station, and in the spirits packaging section. The losses, proposed mitigation measures, and cost-benefit analysis of each are as discussed below.

4.2.1 The Spirits and Sugar Mixing Section

A higher percentage of spirits brands are manufactured with dissolved sugar solution as one of the ingredients. The most energy intensive operation of this process is the sugar solution heating. Figure 4.3 shows the arrangement and the equipment set up of the process. Key to this operation is the heat exchanger which makes use of steam for heating the solution. The chiller is another major energy consuming equipment which cools the solution once the required temperature has been achieved and sterilization completed.

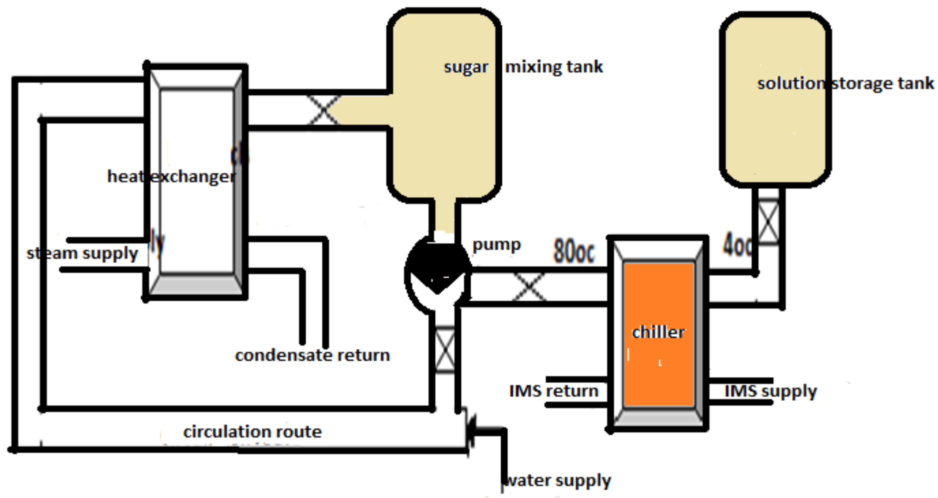

Figure 4.3: The Spirit and Sugar Mixing Process Diagram.

This process is comprised of two process stages, the solution heating stage and the cooling stage. Refined white sugar is measured into the mixing tank which already has water as per the calculated mixing ratio. The solution is circulated through the heat exchanger until the temperature rises to 80^{o}C. The process makes use of heat exchanger and the heating medium is superheated steam which is supplied at a pressure of 3 bars and 150^{o}C temperature. The mixing tank acts as the buffer during the heating process. The tank was observed to be one source of energy loss since it is not insulated. Raising the water temperature from the room temperature of around 23^{o}c to 80^{o}c is an energy intensive operation, of which some energy is lost by convection/radiation to the atmosphere. The second source of energy loss was the chiller. Cooling of the sugar solution from temperature of 80^{o}c to 4^{o}c uses a lot of energy for pumping IMS and the subsequent cooling of the heated IMS after use. The energy use analysis of the plant identified a design gap which when implemented could reduce the amount of steam used by the plant and also save the energy used by the IMS system for pumping and cooling the solution. The proposed modified system is shown by Fig 4.4. The modified system will include an additional heat exchanger and a hot water storage tank. The additional heat exchanger will act in two ways. It will preheat water for the sugar mixing using the hot sugar solution, and at the same time precool the sugar solution before entering the chiller. This heat exchanger is envisaged to make energy savings for both heating and cooling the sugar solution. Since the plant operates in a batch process, a hot tank will be installed to store the preheated water to be used in the next batch. The selection of the additional heat exchanger is also important since a bigger size is required to increase the contact surface area during both heating and cooling.

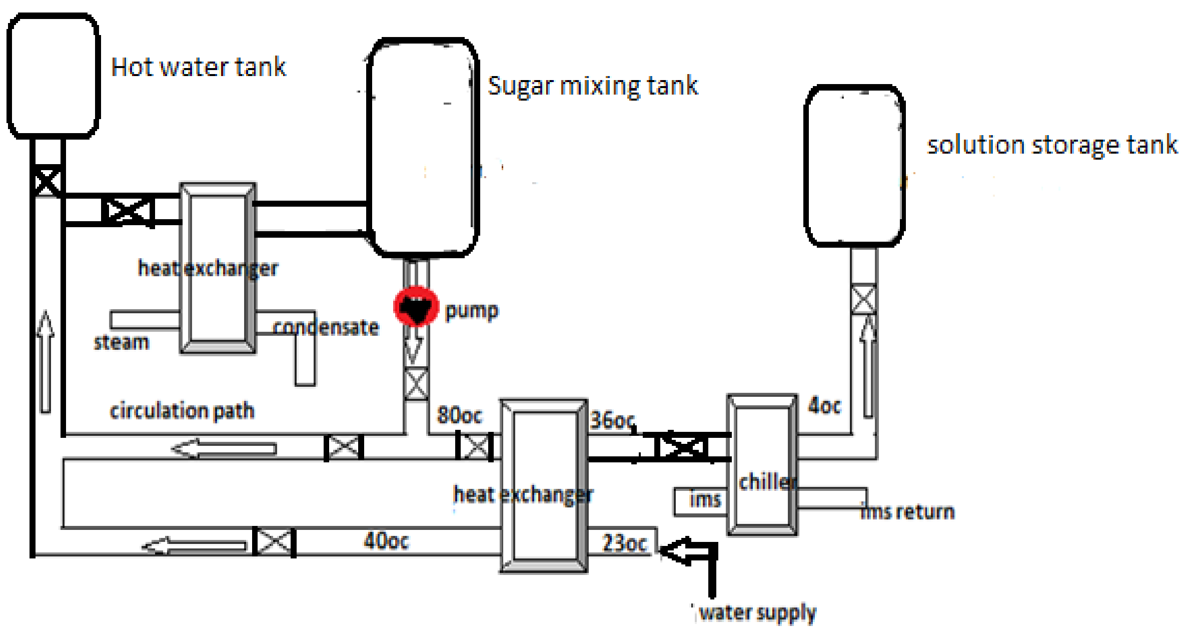

Figure 4.4: The Modified Sugar Boiling and Mixing System

4.2.1.1 Energy Loss Calculation for Sugar Boiling

The mass of water for one batch is 50000 kilograms at room temperature of 20°C. The sugar solution has the following specifications; Brix = 22%, and purity of 99.99% (approx. 100%). The dependence of heat specific capacity on temperature of the solution is as shown in figure 4.5. Taking a mean temperature of 50°C for the solution, a heat specific capacity of 3.72 kJ/kg K is adopted for calculations.

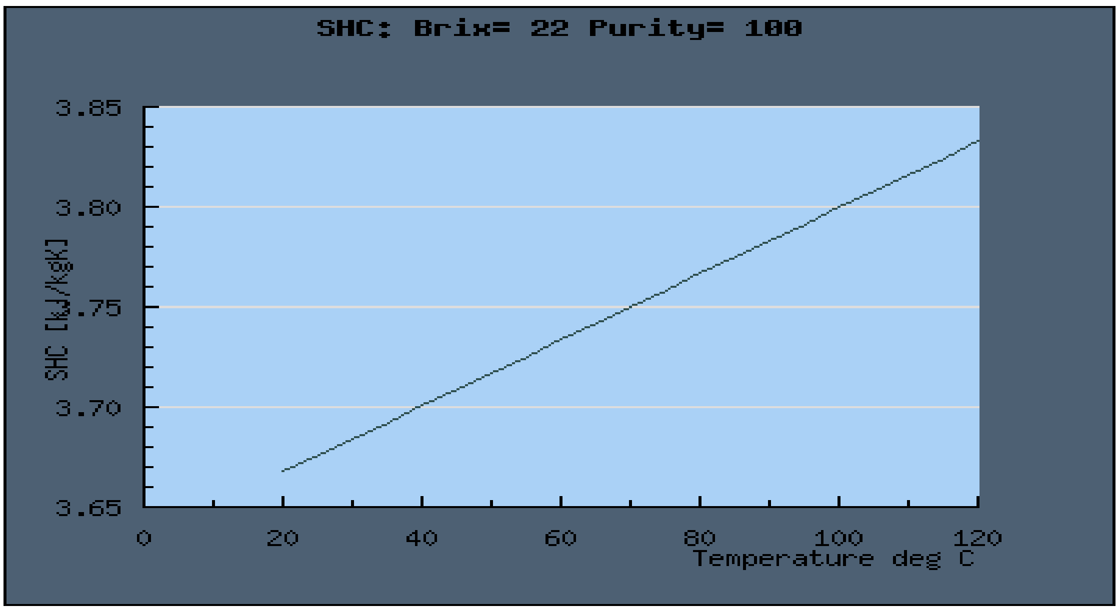

Figure 4.5: Specific Heat Capacity of Sugar Solution [27]

The mass of water for one batch is 50000 kilograms at room temperature which was measured by an infra-red thermometer at 20°c

Energy required to raise the temperature from 20℃ to 80℃ is given by;

$E = m \times Cp \times \Delta T$

Where m is the mass of water Cp is the heat capacity and ΔT is the change in temperature

$E = 50000 \times 3.72 \times 10^3 \times (80-20) = 11160$ MJ

The steam is supplied at 100℃ and it supplies steam by condensing to water through the heat exchanger at 100℃, the heat of vaporization of water is 2257 KJ/kg.

Amount of steam = $\frac{11160000kJ}{2257kJ/kg}$= 4,944.62 kg of steam.

The modified system will incorporate another heat exchanger as shown in figure 4.3 whereby the heated solution at 80^{o}c with a flow rate of 500hl\h is passed through and is used to pre-heat the incoming water which is at 20^{o}C and a flowrate of 500hl\h. the temperature can raise to 40^{o}c **[23]**.

Energy required to raise the temperature from 40^{o}C to 80^{o}C is calculated as

E= 50000×3.72×10^3× (80-40) = 7440 MJ

Amount of steam = $\frac{7440000kJ}{2257kJ/kg}$ =3,296.41 kg.

The difference in steam consumption before and after the modification will be

Amount of steam saved = $[4944.62 \text{ kg } - 3296.41\text{kg}]$ = 1648.21 kg of steam.

Percentage savings= $\frac{4944.62 \text{ kg } -3296.41\text{kg}}{4944.62kg}$ × 100 = 33.3%

1kWh of energy = 1.1 kg of steam [26]

Energy saved =$\frac{1648.21}{1.1}$ = 1498.37 kWh

Calculated Cost of steam is Ksh 6.2/kWh **[7]**

Thus the cost of energy saved =$[1498.37 \times 6.2]$= KSh. 9,289.89 for every batch produced.

4.1.1.2 The Cost Benefits Analysis

The modification will use a plate heat exchanger.

Alfa laval M10 gasketed plate heat exchanger with the following specification will be used

Dimensions: length 1.5m, width 0.5m, height 1.7m

Maximum flow rate 1000hl/h

Plate thickness 0.5mm

Temperature range -20°C to 100°C

Pressure max 10 bars

The cost of the heat exchanger is Ksh 9,000,000.

The installation cost and the piping including the material will amount to Ksh 300,000.

Thus, total cost will be Ksh9,300,000.

The plant produces around 8 batches per week in one year this translates to

8×4×12= 384 batches on average

Total cost of savings per year: 384× 9,289.89 = KSh. 3,567,317.76

Simple Payback period $=\frac{9,300,000}{3,567,00}$ = 2.6 years.

Return on investment $= \frac{savings}{total\ investment} \times 100 = \frac{3,567,317}{9,300,000} \times 100 = 38.36\ \%$.

4.2.2 Spirits Packaging Section

Two automated packaging lines are used for filling and packing the spirits.

Packaging Line 1 is the oldest and has capacity to pack 8,500 bottles of 200,250 or 350 mililiters per hour. The same line has a packaging capacity of 3500 bottles of 750ml or 1500 bottles of 1liter per hour. Line 2 packs only 250ml or 205ml bottles and its capacity is 9000 bottles/hour. The spirit packaging line energy consumption was analysed for two months as shown by Table 4.2. The analysis was done for one month before any modification of the line was done and then another one month after modification was done. The modification included installation of proximity sensors to stop the line when there was no product running on the line. The modifications were carried out during the research of this project, data was recorded for power consumption in a period of one month. The modifications were carried out and data recorded again for a period of one month taking into consideration the amount of spirit produced during the two months' study period.

Table 4.2: Energy Consumption Analysis During Packaging (1 month)

Operation	Energy consumption (kWh)		Energy saved	Percentage (%)
	Before modification	After modification		
Bottle cleaning	4624	4271	353	7.6
Filling	836	775	61	7.2
Labelling	539	523	16	2.9
Total	5999	5569	430	7.2

From Table 4.2 the bottle cleaning is the highest consumer of energy at the spirit packaging line. At 7.6% energy saving realised by implementation of the low-cost energy saving measures more savings can be realised at this section. Energy savings were also realized in the filling and labelling sections by 7.2% and 2.9% respectively.

For financial year 2014-2015 the total electrical energy consumed by all the plants within the brewery was 35,051,700 kWh for which the company paid KSh. 568,200,360 inclusive of taxes, levies and 16% VAT. The average unit cost was therefore KSh.16.21 per kWh **[24]**. The maximum demand peaked at 6689 kVA with the average being 6099. The average Power factor was 0.96. The whole brewery tariff rates apply to the UDV so the unit costs can be used for analysing UDV costs. Thus, before the modification the spirits packaging lines power consumption was: $[5{,}999 \times 16.21]$= KSh. 97,243.79.

After the modification the consumption was: $[5569 \times 16.21]$= KSh. 90,273.49.

This represent a saving of KSh. 6,970.30 in one month.

In one year: $[6{,}970.30 \times 12]$= KSh. 83,643.60

The cost of the modifications which included the cost of sensors, the hardware installation cost and the cost of software change to factor in the changes was KSh. 96,200.00

The Simple payback period $= \frac{initial\ investment}{savings} = \frac{96{,}200}{83{,}600} = 1.1 years$

From this analysis the payback period of 1.1 years shows that the investment is very viable. The spirits packaging lines are not power intensity as the beer one and their power consumption is not high. Any small savings in this section translates into a big savings.

4.2.3 Power factor of the UDV Plant

While power factor may vary over time, high power factor indicates effective utilization of electrical power. A low power factor indicates poor power utilization. A power factor of 1 (unity) is an indication of operating at a perfectly effective use of power while a 0.5 is an indication of a very inefficient use of power. A power factor of any value other than unity is caused by inductive or capacitive reactance and harmonics on the system **[25]**.

The data collected is tabulated in Appendix 1. Figure 4.6 shows a plot of power factor against production.

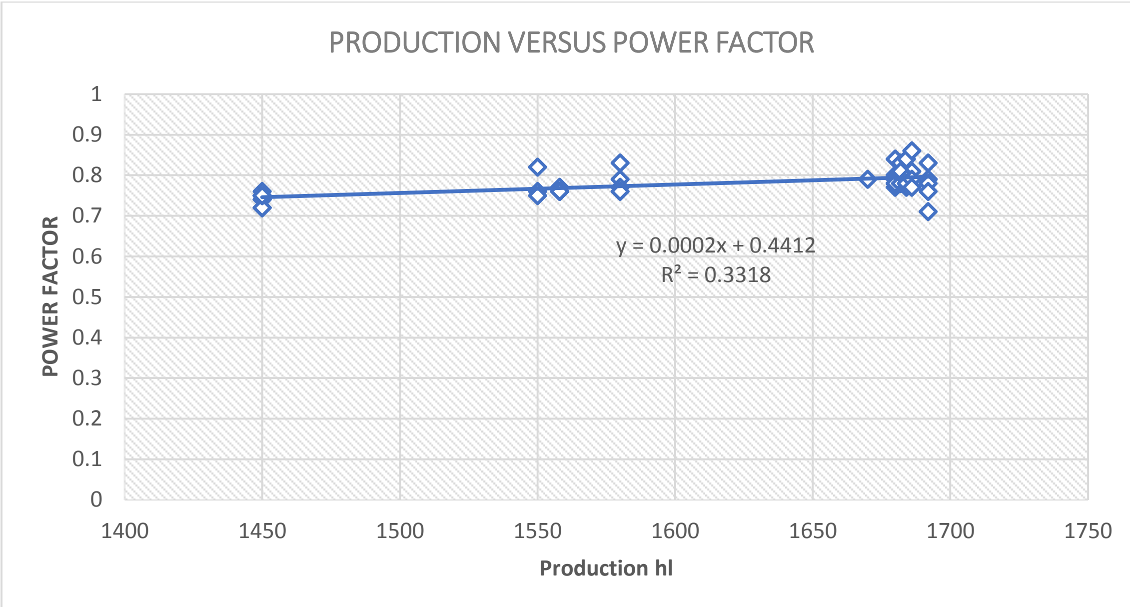

Figure 4.6: Production versus Power factor[appendix1]

Figure 4.6 shows that PF varies between 0.72 to 0.86, this is low compared with other areas within the brewery whereby average power factor is 0.96. This power factor is low which translates to high energy cost. Fig 4.6 shows that most of the time the plant is operating at 0.80 power factor, this shows that the capacitor bank is working but the rating is low for this plant. An ideal power factor should be above 0.96, improving power factor means reducing the phase difference between voltage and current. Since the majority of loads are inductive in nature, they require some amount of reactive power for them to function. The capacitors or bank of capacitors installed parallel to the load provides this reactive power.

It can be observed that at high production volumes the plant has a better power factor.

Improving the power factor of a plant can reduce energy losses, power factor corrective capacitors act as reactive current generators. They help offset the non-working power used by inductive loads, thus improving the power factor. Some capacitors do currently exist at the bus bar which has proved to be ineffective thus needs replacement. As per the plant power capacity it requires a 45 kVar capacitor bank to increase the PF to 0.98. A 50kVar capacitor bank is recommended since it's readily available and it will also have room for future expansion of the plant **[19]**. The cost of purchasing and installation of a 50kVar capacitor bank is KSh. 95,000.00. This can raise the power factor to 0.98 which is in line with the other sections of the brewery. The UDV is charged for 15.66KVA every month, demand charge is KSh. 220 per KVA per month, this power is paid for but not used for any productive use.

This translates to 188KVA per year

The total cost is [$188 \times 220 = KSh. 41{,}360$]

Payback period $= \frac{initial\ investment}{cost\ energy\ savings} = \frac{95000}{41300} = 2.3\ years$

Return on investment $= \frac{net\ profit}{total\ investment} \times 100 = \frac{41360}{95000} \times 100 = 43.4\%$

The investment has a very short payback period which makes it very viable and the return on investment is high enough to justify the implementation of the project.

4.3 Evaluation of Energy Savings at the CMF plant

Figure 4.7 shows the production of the CMF plant for a period of two years and the corresponding power consumption for the same period. The source of energy for the CMF operation is electricity.

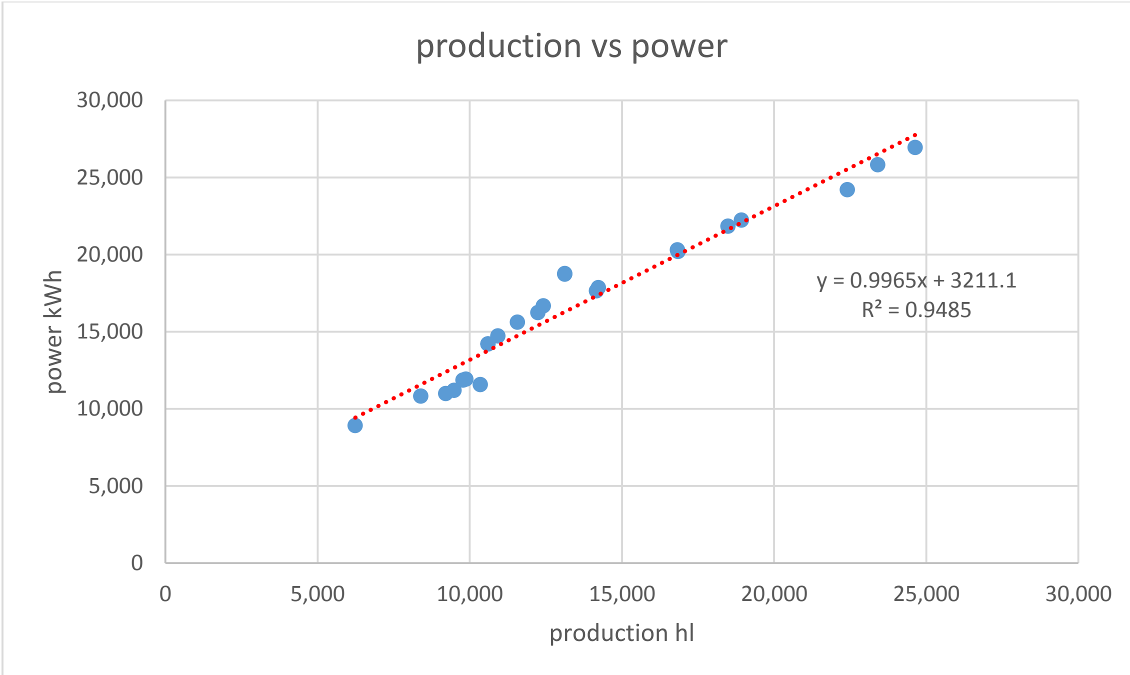

Figure 4.7: Production Versus Power Consumption for the CMF plant

As observed in figure 4.7, production increases relatively with power consumption, the most important aspect is the plant efficiency in this case the amount of power consumed should relate directly to the production output. Figure 4.7 shows a clear relationship between the amount of beer filtered through the plant, the amount of energy used for the production. The desire is to maximize the production at a low cost per unit of production.

Figure 4.8 shows the energy intensity comparison for the two years' period. In the brewing industry energy intensity is the amount of energy used to produce 1hl of beer, thus it's calculated as a ratio of energy consumed divided by the amount of beer produced during the same period the data is from July 2014 when the plant was installed and commissioned. For this analysis month was taken as the time period. From Fig 4.8 it is observed that energy intensity decreases as the production increases. This means that the plant is consuming less energy and producing more. The objective of the energy analysis is to maximize on production and minimise on energy inefficiencies to achieve low energy intensity.

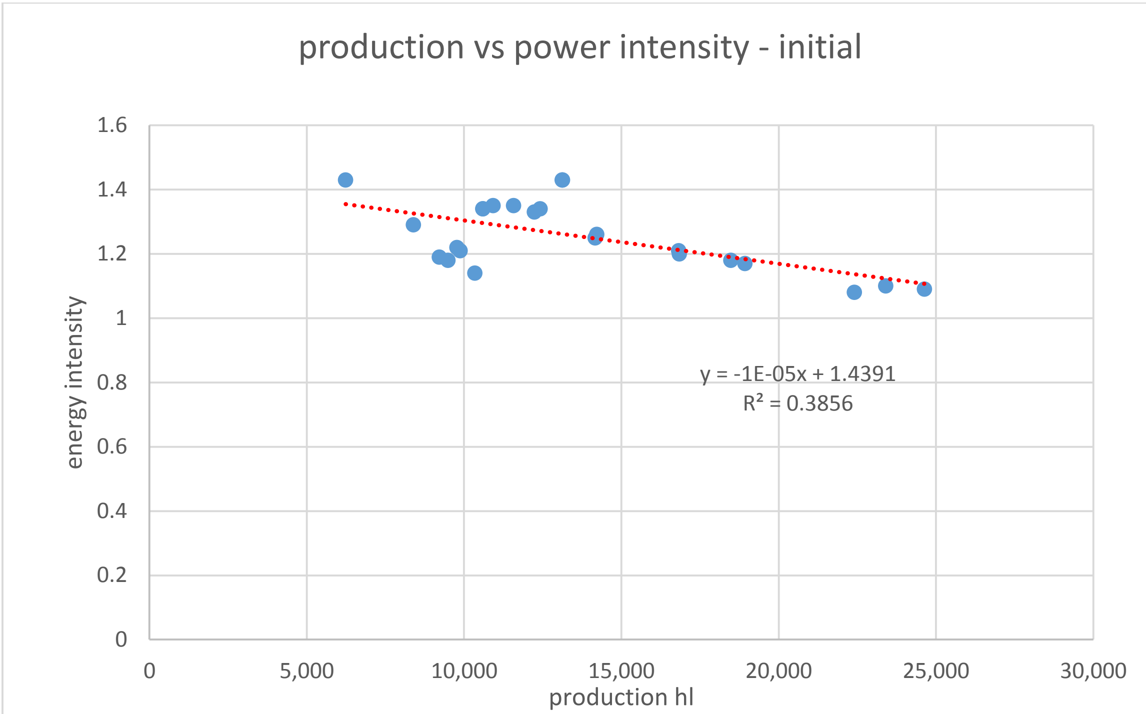

Figure 4.8: CMF Energy Intensity Versus Production [appendix3]

Figure 4.8 shows that at some point the energy intensity was 1.42 and the production was 6000hl as shown by figure 4.8 this shows the energy consumption was high. When production went up to 22500hl then the energy intensity reduced to 1.08 this shows a better utilization of the plant. Lowering the energy intensity contributes for the low energy cost.

In the CMF plant, energy losses were identified in the following sections;

1. The yeast harvesting section.

2. The yeast homogenization section.

3. The yeast-beer separation system (filtration) section.

4.3.1 The Yeast Harvesting Section

In this section, yeast is transferred from the beer storage tanks to yeast storage tanks. The process uses a 7.5 kW pump. Analysis of the system established that the transfer could be achieved by gravity method, hence making use of the pump and associated costs unnecessary as discussed below. The CMF plant operation starts with the yeast harvesting which is harvested from different maturation tanks until the yeast storage tanks are full. Figure 4.9 shows the yeast transfer process from the beer storage tank to the yeast processing tank of the CMF plant. The energy consumption in this section is by the transfer pump which is rated 7.5 Kw. The pump operates at a maximum flow rate of 350hl. The capacity of the storage tank is 700 hl; it takes a total duration of 2 hours to fill the tank operating at maximum capacity.

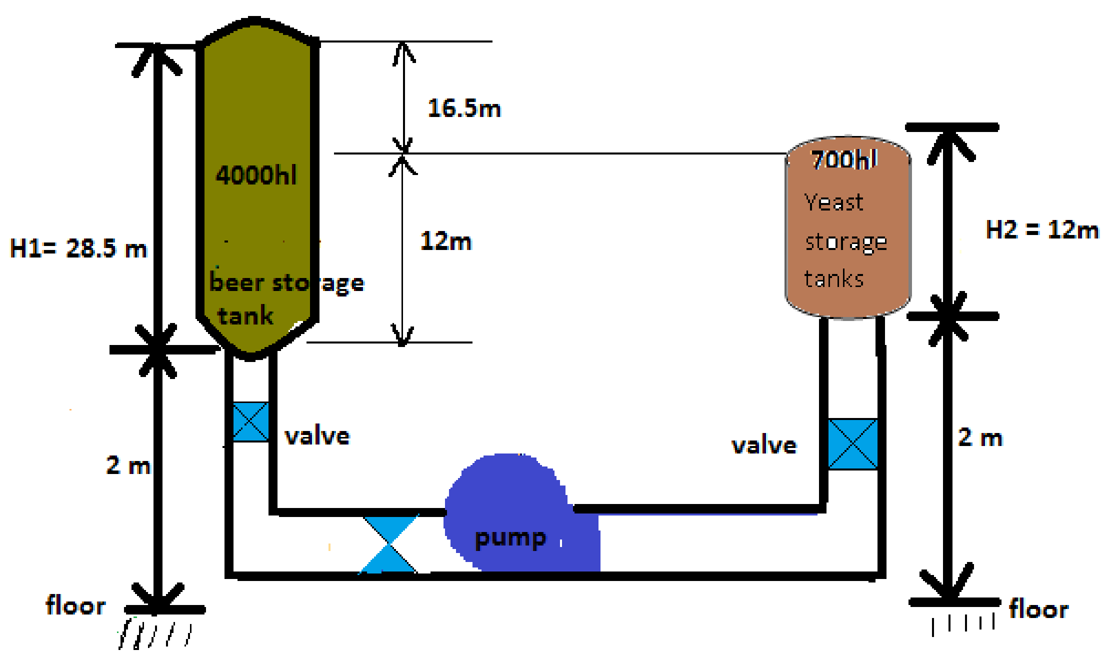

Figure 4.9: The Yeast Harvesting Process Diagram

Analysing the energy consumption in the section for every batch of production it gives;

Motor rating- 7.5 kW

Energy cost - ksh16.21 per kWh

Time duration- 2hrs

$[7.5 \times 2 \times 16.2]$ = KSh. 243.15

This is the cost of transferring one batch of the yeast to be processed. The plant can process two batches in 24hrs and most of the time operates for at least 26 days in a month. The energy cost can be calculated as follows.

$[243 \times 2 \times 26]$= KSh.16,636. Considering the highest and the lowest monthly power consumption for the study period as pre the data from appendix3 this translates to.

Lowest monthly power consumption was $[10{,}840 kWh \times 16.2] = KSh. 175{,}608$

$\frac{16{,}636}{175{,}608} \times 100 = 9.4\%$

The highest monthly power consumption was $[26{,}948 kWh \times 16.2] = 436{,}557\ ksh$

$\frac{16{,}636}{436{,}557} \times 100 = 3.8\%$

This represents the percentage energy consumed by the yeast transfer section alone. From the energy consumption analysis of this section improvements were effected during this study to transfer the yeast without the use of pump.

Modification of the transfer process was made such that at the start of the transfer a bypass route was used as shown by Fig 4.10. The pump was bypassed hence the transfer was done by use of gravity. This was able to fill half of the tank in duration of two hours. The beer storage tanks are two types with a capacity of 2000 hl and 4000hl respectively. The height of the beer storage tanks is 20.5m and 28.5 m., the clearance from the ground to the tank outlet is 2m. The yeast is harvested when the tank is full of beer around 19.5 and 27.5 m to leave an allowance of 1m space to avoid overflow of beer. The height difference is 28.5-12= 16.5 m. The pressure at the bottom is 2.9 bars and at the top is 1 bar. The destination tank is at bottom pressure of 0.2 bars and the tank height is 12m and a ground clearance of 2m thus it is possible to fill the yeast tank by use of gravity as shown in Fig 4.6. This will eliminate the cost of using the transfer pump. Yeast transfer by use of gravity will bypass the pump, given that there are two yeast tanks in the CMF plant. This gives room and time for one tank to be in production while the other tank is being filled with yeast. From the trial done during the study it took four hours to fill the yeast storage tank. To process one yeast storage tank through the CMF it takes eight hours to complete. The second yeast storage tank can be filled as the first one is being processed. The transfer of yeast by gravity was identified as the major energy saving opportunity in this yeast harvesting section.

The beer fermentation and maturation area has a total of 69 tanks which are planned to hold beer in different stages either fermentation, maturation or storage.

The source of yeast to the CMF plant is from the tanks in the maturation stage. It’s important to state that from one tank only between 50hl and 100hl can be harvested to the CMF as yeast for processing. This is because only the settled yeast at the bottom of the maturation tank is harvested, thus to fill the yeast storage tank several tanks are harvested.

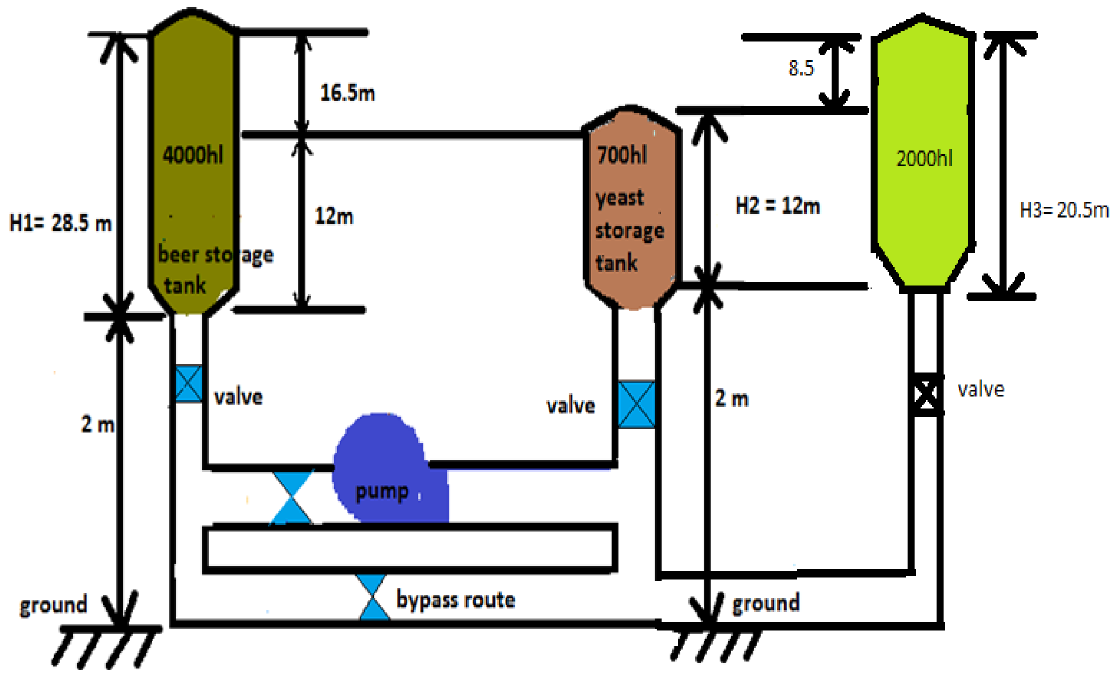

Figure 4.10: The Modified Yeast Harvesting process Diagram

Figure 4.10 shows the configuration of the system after the bypass of the pump was effected for a period of time during this study. The system is able to save the energy cost of the transfer section. The cost implementing this change included the disconnection of the pump and installation of a bypass line whose total cost was Ksh 40,000.

Thus payback period $= \frac{initial\ investment\ cost}{cost\ energy\ savings} = \frac{40{,}000}{16{,}636} = 2.4\ years$

This is the payback period for the modification of the yeast transfer section.

4.3.2 The Yeast Tanks Homogenization Section

Proper mixing of the yeast beer solution before the start of filtration is one of the factors which determine the performance of the filters. Homogenization is whereby the yeast is circulated within the storage tank to evenly mix it before the start of filtration. The study also sought to determine the relationship of yeast homogenization and the time it takes the cartridges to block. Figure 4.11 shows impact of the homogenization time compared to the time it takes the cartridges to block.

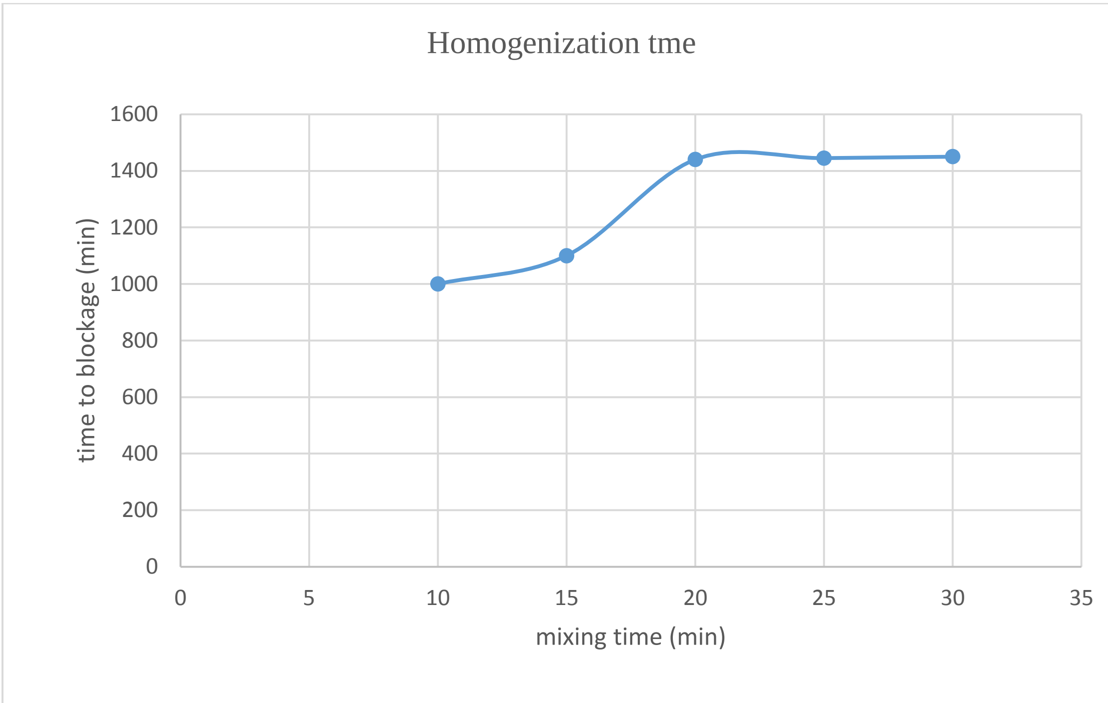

Figure 4.11: Homogenization Time[appendix4]

The results from figure 4.11 show that the plant production time is increasing with the increase in the homogenization time between 10 and 20 minutes. From 20 minutes to 30 minutes the variance is minimal this shows that full homogenization has been achieved. The impact of improper mixing of the yeast before filtration is the reduced output due to blockage. The study established that mixing for 20 minutes was enough for better results and also to save the energy used for mixing. Initially homogenization was being done for one hour. There is 40 minutes time difference, that’s means the energy the mixing pump was using for the extra 40 minutes is will be saved.

The rating of the pump for the yeast homogenization is 6.5 kw

The cost of power is ksh16.2 per kilowatt hour.

Calculating the savings: $\frac{40}{60} \times 16.2 \times 6.5 = ksh\ 70.2$ This is the amount used for every batch produced. For the yeast homogenization there was no investment made its only required reduction of time from the plant operating system. Taking an average of 4 batches in 24 hours gives: $4\times 70.2 = ksh\ 280.80$ per day for one month this translates to a saving of $280.8 \times 24 = ksh\ 6739.20$. Annualy this will be a saving of KSh. 80,870.40.

4.3.3 The Yeast-beer Separation System (filtration) Section

The focus was to reduce the pump speed thus reducing the amount of energy being consumed by the pump. Table 4.3 shows the relationship between the input flowrate and the corresponding output.

Table 4.3: Yeast Input to the Cartridges vs The Beer Output

Input flow rate hl/h	Output flow rate hl/h
4900	60
4600	50
4200	45
3600	15
3000	10
2800	8

Reducing the input flow rate shows that the output from the plant also reduces as shown by figure 4.12. The output reduces from 60hl to 8hl, this shows that the reduction of input flowrate cannot be a viable solution to control the energy consumption by the CMF plant.

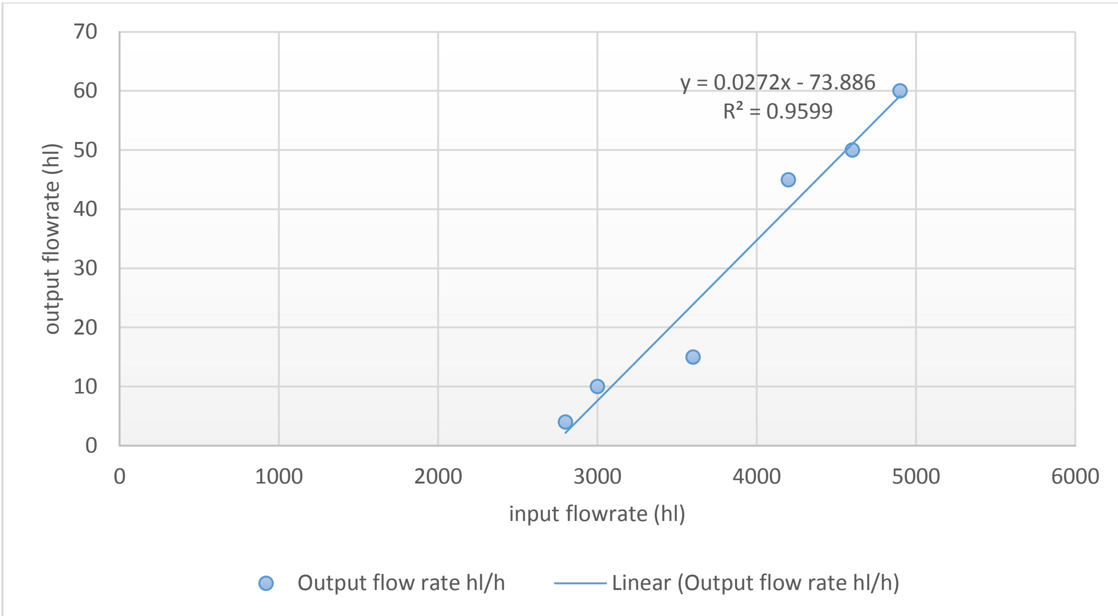

Figure 4.12: Reduction of Input Flowrate

The reduction of the output of the plant is not a desired result thus the method of reducing the input to the plant to control energy consumption did not work.

Figure 4.13 illustrates the power consumption after optimization of the plant whic2h included the bypassing of the yeast transfer pump and the fixing of the homogenization time before the start of filtration. The power consumption was measured and recorded for a period of 14 days and the corresponding production output for the same period was also recorded. The plant energy consumption shows a decline per unit production as shown by figure 4.13 after implementation of the identified energy saving measures.

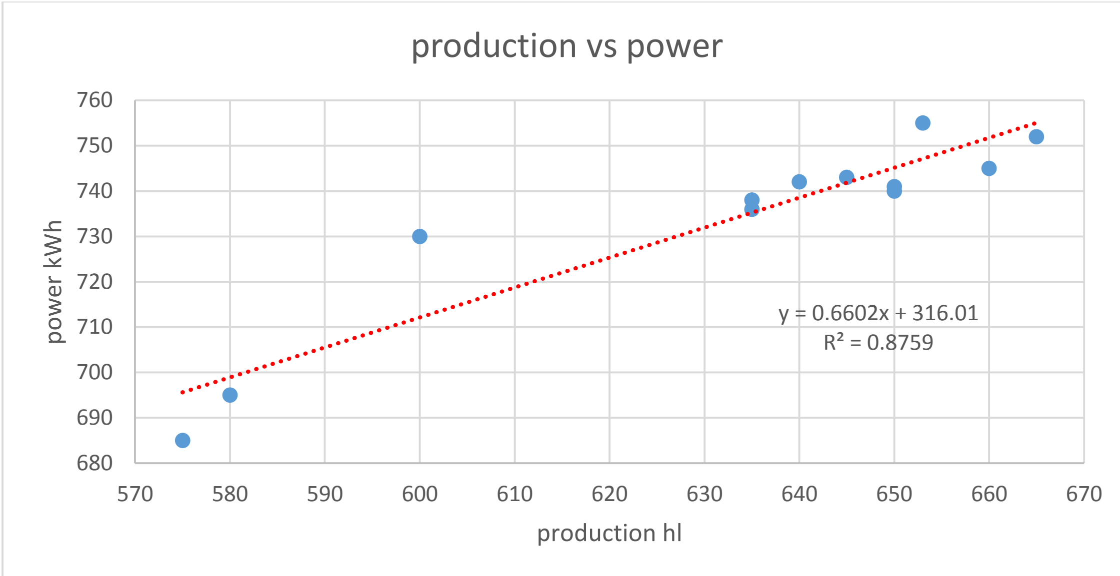

Figure 4.13: Production versus Power Consumption after Optimization [appendix 2]

The relationship between the amount of beer filtered by the CMF plant and the power consumed shows a linear representation. As shown by figure 4.13 the amount of power consumption increases as the production increases but the energy intensity is the major point of focus. Reducing the energy intensity results to low cost of production and reduced energy per unit utilization. Figure 4.14 compares the production from the plant with the power intensity of the plant. This shows a reduced energy intensity compared to intensity before the energy saving measures were implemented.

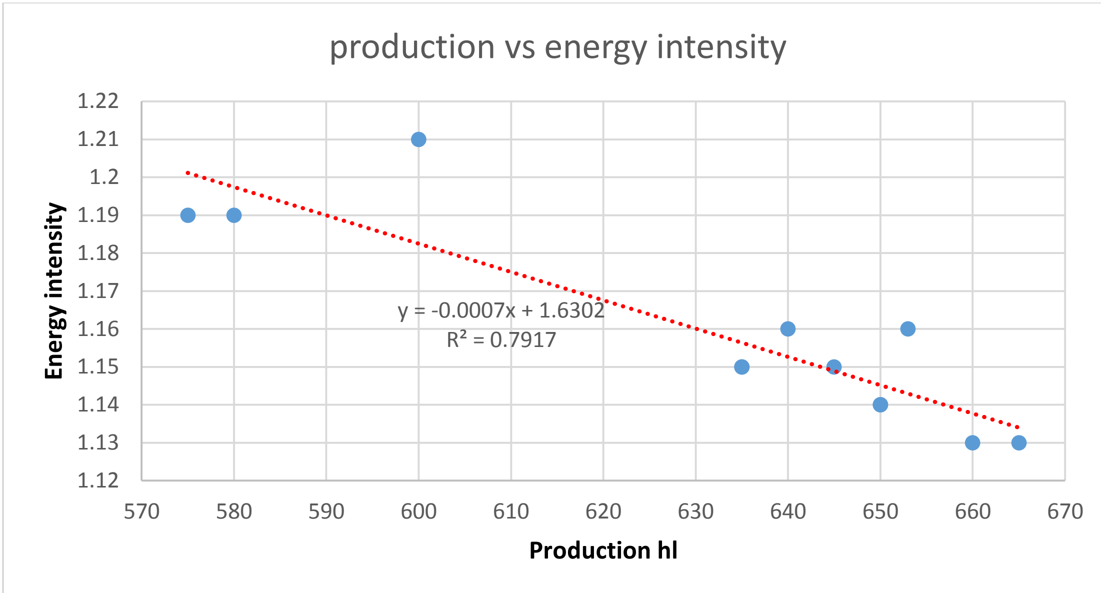

Figure 4.14: Production versus Energy Intensity [appendix2]

The energy intensity reduces with the increase in production as shown by figure 4.14. The optimization of the homogenization time and the bypassing of the yeast harvesting pump reduced the energy consumption of the plant resulting reduction of the energy intensity. Comparing figure 4.8 and figure 4.14 shows that increasing the rate of production results in reduced energy intensity.

4.3.4 Power factor of the CMF plant

The power supply of the CMF plant is tapped from the main supply to the brewing department whose power factor is 0.98 thus it's a stable supply with no foreseen savings to be made from improving it.

4.3.5 Total Savings to be Realised by the Proposed Measures

The calculations for the savings to be realised by the identified and proposed measures for a period of one year will be as shown by Table 4.4. This represents the saving from both the UDV plant and the CMF which will be realised when all the proposed measures are implemented.

Table 4.4 Total Savings to be Realised by the Proposed Measures

Specific area	Calculated savings ksh
Sugar heating and mixing system	3,567, 317
Bottle cleaning, filling and labelling,	83,643
Capacitor bank	41,360
Yeast transfer	199,632
Yeast homogenization	80,870
Total savings	3,972,822

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter presents summary of the study and conclusions. The chapter also gives limitation of the study and areas of further research.

The objective of the study was to evaluate the Ceramic Membrane Filter (CMF) plant and the United Distillers Vintners (UDV) plant at KBL in bid to establish energy conservation measures that will lower energy consumption and therefore unit cost.

5.1 Conclusion

In the CMF plant the research established that the yeast transfer from fermentation tanks to yeast storage tanks could be done by gravity, thus saving on pumping costs. Analysis of yeast homogenization time showed that optimal homogenization time was 20 minutes, and hence yeast homogenization time should be changed from 1hour to 20 minutes. From analysis of energy intensity, operating the plant at optimum capacity resulted to low energy intensity factors. In the UDV the study established that an extra heat exchanger should be installed to pre heat the sugar solution. Changing of the sugar plant system from direct heating of water to pre- heating and pre-cooling will have a big impact of 33.3 % savings on steam consumption. A capacitor bank should be installed at UDV to improve power factor from 0.81 to 0.96. Installation of motion sensors on the conveyers was found to save energy consumption by 7.2%.

5.2 Recommendations

To enhance data collection and analysis for future research work, the study recommends:

(i) Installation of online instrument for analysing alcohol at the CMF plant. This will assist in automatic calculation of the water required for dilution during the filtration process.

(ii) Change the cartridges from 1 micron to 10 microns to increase the output of the plant.

(iii) Installation of steam meter at the UDV plant, this is to measure the steam consumption by the plant during the sugar mixing.

(iv) It was recommended that when designing for any modification consideration should be for more energy efficient motors. This includes upgrading the motors when doing modifications and when the ones in place get burnt.

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APPENDICES

Appendix 1: Comparison of power consumption and equivalent power factor

Day	production (hl)	Power factor (PF)
1	1686	0.81
2	1680	0.80
3	1450	0.74
4	1692	0.79
5	1680	0.77
6	1684	0.77
7	1682	0.78
8	1558	0.76
9	1550	0.76
10	1670	0.79
11	1686	0.79
12	1680	0.78
13	1450	0.75
14	1692	0.79
15	1680	0.84
16	1580	0.83
17	1684	0.84
18	1682	0.83
19	1550	0.82
20	1686	0.77
21	1680	0.78
22	1450	0.72
23	1692	0.83
24	1680	0.84
25	1686	0.86
26	1680	0.80
27	1450	0.74
28	1450	0.76
29	1692	0.78
30	1680	0.79
31	1580	0.79
32	1684	0.79
33	1682	0.78
34	1558	0.77

Day	production(hl)	Power factor(PF)
35	1450	0.72
36	1692	0.76
37	1680	0.78
38	1580	0.77
39	1684	0.79
40	1682	0.81
41	1558	0.76
42	1550	0.75
43	1450	0.75
45	1692	0.71
46	1680	0.78
47	1580	0.76
48	1684	0.78
49	1558	0.76
50	1450	0.75
51	1692	0.86
52	1680	0.79
53	1683	0.79
54	1690	0.79
55	1692	0.78
56	1687	0.78
57	1658	0.76
58	1660	0.77
59	1590	0.76
60	1598	0.76

Appendix 2: Production versus power consumption after optimization at CMF plant

Dates	Production hl in 24 hrs	Power consumption kwh	energy intensity
15.11.2016	650	740	1.14
16.11.2016	660	745	1.13
18.11.2016	670	755	1.13
19.11.2016	665	752	1.13
20.11.2016	635	738	1.15
21.11.2016	640	742	1,16
24.11.2016	635	736	1.15
25.11.2016	645	743	1.15
26.11.2016	650	741	1.14
28.11.2016	653	755	1.16
01.12.2016	600	730	1.21
03.12.2016	575	685	1.19
04.12.2016	650	740	1.13
05.12.2016	580	695	1.19
Average		735	1.15

Appendix3: Energy consumption for F15 and F16, at the CMF plant [24].

Month	Monthly Production (hl)	Electrical energy (kWh)	Electrical Energy intensity (kWh/hl)
Jul-14	13,121	18,734	1.43
Aug-14	10,924	14,739	1.35
Sep-14	9,874	11,926	1.21
Oct-14	9,776	11,876	1.22
Nov-14	18,924	22,234	1.17
Dec-14	24,630	26,948	1.09
Jan-15	9,235	12,926	1.39
Feb-15	14,165	17,654	1.25
Mar-15	11,569	15,624	1.35
Apr-15	10,595	14,216	1.34
May-15	10,592	14211	1.34
Jun-15	12,234	16,238	1.33
Jul-15	13,124	18,780	1.43
Aug-15	12,421	16,679	1.34
Sep-15	14,220	17,864	1.26
Oct-15	16,840	20,213	1.20
Nov-15	16,820	20,314	1.21
Dec-15	22,408	24,212	1.08
Jan-16	23,400	25,840	1.10
Feb-16	8,384	10,840	1.29
Mar-16	9,484	11,208	1.18
Apr-16	9,212	11,002	1.19
May-16	10,340	11,584	1.14
Jun-16	18,480	21,840	1.18

Appendix 4: Optimum homogenization time

Homogenization time(minutes)	Time taken by cartridges to block(minutes)
10	1000
15	1100
20	1440
25	1445
30	1450