A STUDY OF THERMAL ENERGY USE AT A BREWING PLANT WITH EMPHASIS ON WORT BOILING PROCESS

By

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DECLARATION

A. Student's declaration

I confirm that this project is my work and has never been submitted before for examination purposes or any other purpose.

Charles Muigai Githuka, F56/72076/2008

Signature……………………………………..

Date…………………………………………...

B. Supervisors' Declaration

I can confirm that the above student carried out this project work under my supervision for the entire period of the project.

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Signature………………………………………

Date……………………………………………

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Date……………………………………………

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ABSTRACT

High energy costs and the need to reduce on CO2 emissions have brought to the fore the importance of reduction of energy usage in beer production. It is important that brewing process be analyzed to identify and evaluate opportunities for saving energy in specific process applications. This will determine savings on energy use and recovery, and process improvements required for implementation without negative effects on plant performance and final product specification.

The brewing process is energy intensive, especially in the brew house, where wort boiling is the main heat consuming process. None of the energy audits done at the study plant has fully tackled energy use in this major energy consuming process in brew house. In this regard a study was made of the wort boiling process and related technology of the energy recovery systems used at Tusker Breweries, Nairobi.

The study found that;

(i) Atmospheric boiling should be avoided. Though this is driven by production demands and requirements, the energy that would have been recovered is lost. There is need for the company to strike a balance between the production demand and loss of energy.
(ii) The wort pre-heater is critical equipment in the determination of the thermal efficiency of wort boiling process, and energy recovery and should never be bypassed.

The results from the study demonstrate that significant savings of up to 20% of the daily steam consumption (equivalent to 93,380 MJ) can be made by efficient use of a pre-heater which leads to better utilization of the recovered energy from wort boiling. The study shows that by reducing energy and waste, variable utilities and production costs will be improved. Additional advantages resulting from efficient use of energy in the brew house are presented, whilst also making a significant reduction in carbon dioxide emissions required by legislation.

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ABBREVIATIONS AND ACRONYMS

AB	Atmospheric boiling
abs	Absolute
ATM	Atmospheric
AV	Auto valve
BAT	Best available technique
BOD	Biochemical oxygen demand
BREF	Best available technique reference
CIP	Cleaning-in-place
DYN	Dynamic
EC	European Commission
hr	Hour
HFO	Heavy fuel oil
hl	Hectolitre
HLT	Hot liquor tank
IMS	Industrial methylated spirit
KBL	Kenya breweries ltd
Ksh	Kenya shilling
LPB	Low pressure boiling
MF	Mash filter
ncv	Net calorific value
PCV	Pressure control valve
PHE	Plate heat exchanger
PID	Proportional, integral and derivative
SCADA	Supervisory control and data acquisition
TCV	Temperature control valve
VSD	Variable speed drive
WC	Wort cooler
WPH	Wort pre-heater
WK	Wort kettle

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CHAPTER ONE

INTRODUCTION

1.1 Energy Demand

Energy is a critical input to the socio-economic development of any nation as well as to the protection of the nation's environment. It fuels the industry, commerce, transportation, agriculture and other economic activities.

The energy crises (the oil shocks of the 1970's) occasioned by sudden sharp increases in the price of petroleum and its products had devastating impacts on the economies of many countries, both developed and developing, but in particular the latter. A number of factors have brought to the fore the importance of, and urgency for energy efficiency. These include the high energy prices, insecurity of energy supply, concern about adverse environmental and health impacts and unease over the rate at which the major energy resources are being depleted.

Concern has, furthermore, been mounting about the spiraling depletion of the environment as exemplified by local air pollution and acid precipitation from ever growing fossil fuel combustion. Associated with these are emerging global issues such as potential climate change as a result of greenhouse gases emissions. All these as well as the attendant adverse health impacts have become important drives for increased energy efficiency.

1.2 Current energy situation in the industrial sector in Kenya

While access to energy in Kenya is still very limited, sufficient potential opportunities, however, exist for improving energy in all sectors of economy including in particular the industrial sector. In this sector, food, beverages, and tobacco, paper and paper products are among the major consumers of energy.

In the year 2004, the industrial sector in Kenya consumed an estimated total of 514 million tonnes of oil equivalent [6] .The rate of economic growth in the country had meanwhile picked up in the period between 2003 and 2006 and had increased continually in the years that followed. All these should set a stage for the savings in the energy consumption in the industrial sector if the necessary measures are put in place. Increasing local as well as international competition is causing Kenyan enterprises to look at their energy use critically. Potential energy savings exist even in highly efficient, well managed industrial plants.

The current electricity demand is 1,191 MW while the effective installed capacity under normal hydrology is 1,429 MW [9]. This gives a reserve margin of 238 MW (20%). However during low hydrology, the reserve margin diminishes necessitating load shedding and procurement of expensive emergency power. The peak load is projected to grow to about 2,500MW by 2015 and 15,000 MW by 2030. To meet this demand, the projected installed capacity should increase gradually to 19,200 MW by 2030 [9].

As Kenyans manufacturers face an increasing competitive environment from East Africa region, they seek out opportunities to reduce production costs without negatively affecting the yield or the quality of their finished products. The volatility of energy prices in today’s marketplace can also negatively affect predictable earnings.

1.3 Energy use in Kenya Breweries Ltd

East Africa Breweries Ltd is the parent company of among others, Kenya breweries ltd (KBL), Serengeti breweries ltd (SBL), Uganda breweries ltd (UBL), East African maltings ltd (EAML) and Central glass industries (CGI). KBL is the largest brewery in Kenya and the region, with an annual production output of about 5.0 million hectoliters of beer and other alcoholic beverages and an annual sales turnover of 30 billion shillings. Almost all the production requirement is carried out at Tusker Breweries situated at Ruaraka, Nairobi. The main production unit is divided into three main departmental areas namely: Utilities, Brewing, and Packaging & Spirits.

Total beer production output was 4.48 million hectoliters in the year 2010 and 4.55 million hectoliters in the year 2011 [8]. The main energy types at Kenya breweries ltd are; electricity and thermal energy obtained from steam boilers. The total electricity consumption for the year 2010 was 43,574,112 kWh and 42,031,766 kWh in the year 2011. Electricity contributed 22% of the total energy in both years. The total fuel energy obtained from the boilers was 540,984,213 MJ in the year 2010 and 525,343,567 MJ in 2011 [8].

1.4 Statement of the problem

Increasingly, we are all facing rising energy costs, stricter environmental regulations or even taxes on energy or emissions. Tusker breweries site is keen to be an industry leader in energy conservation measures and efficient use of energy.

Over the last 8 years, several energy audits have been done, mainly confined to the brewery utilities department. The scope covered includes; site electricity supply mapping, steam boilers (with regard to feed water, fuel use and oil use), steam supply and distribution, electricity consumption in refrigeration systems, site water layout and usages, and compressed air supply and leaks in process areas. From the audit findings, several savings opportunities have been identified e.g. preheating of boiler make up water, improve condensate recovery, fitting of boiler economizers, installing of VSDs on several IMS and water pumps, air leaks around site, increase IMS Plant evaporating temperature and upgrading of old utilities refrigeration equipment.

However, the audits have not tackled energy use and utilization in the process areas, and how these can be optimized. Production process areas are the main users of the utilities generated and any inefficiency observed in the process plant equipment and processes, results in high utilities consumptions and costs. The high energy and utilities costs can be reduced if a systematic study was done in all high energy consuming processes in the brewery, to determine and recommend the optimal use of the utilities.

Wort boiling is an energy intensive process, and a very important part of the brewing process. It is at this point in brewing that most thermal energy is used (up to 50%) and therefore the focal point of the study. The study intends to determine the energy consumption of individual wort boiling process and other inter related processes of wort cooling and hot water generation in brew house plant and specific ways of optimizing these processes.

1.5 <u>Objectives</u>

1. Establish current energy consumption levels for wort boiling process in brew house.
2. Determine annual energy costs of electricity and fuel oil, and relate this to the production for the same period to establish energy cost of beer production.
3. Identify energy saving opportunities.

CHAPTER TWO

LITERATURE REVIEW

In this chapter, a review is presented on wort boiling process with regard to energy use and recovery. Detail of what is acceptable in the industry is shown with highlights on common industry practice as regards thermal energy use in brew house. A review of what has been done in other brewery sites in energy saving measures is also presented. This chapter describes energy use and utilization in interrelated processes of energy storage system, wort cooling, chilled water system and hot water usage.

2.1 Plant layout and beer making process

2.1.1 Beer process description

The brewing process uses malted barley and/or cereals, unmalted grains and/or sugar/corn syrups (adjuncts), hops, water, and yeast to produce beer. Depending on the location of the brewery and incoming water quality, water is usually pre-treated with a reverse osmosis carbon filtration or other type of filtering system. Figure 2.1 shows a block diagram flow of the main stages of beer production in a brewery.

The first step of brewing, ***milling***, takes place when malt grains are transported from storage facilities and milled in a wet or dry process to ensure that one can obtain a high yield of extracted substances [7]. Sometimes the milling is preceded by steam or water conditioning of the grain. The mixture of milled malt, gelatinized adjunct and water is called mash. The purpose of ***mashing*** is to obtain a high yield of extract (sweet wort) from the malt grist and to ensure product uniformity. Mashing consists of mixing and heating the mash in the mash tun, and takes place through infusion, decoction or a combination of the two. During this process, the starchy content of the mash is hydrolyzed, producing liquor called sweet wort. In the infusion mashing process, hot water between 71-82°C is used to increase the efficiency of wort extraction in the insulated mashing tuns (kettles). The mashing temperature is dictated by wort heating using steam coils or jackets. In decoction mashing, a portion of the mashing mixture is separated from the mash, heated to boiling and re-entered into the mash tun. This process can be carried out several times, and the overall temperature of the wort increases with each steeping. Part of this mash is evaporated. This process requires an estimated 12-16 MJ/hl for medium-sized breweries [7]. The type of mashing system used depends on a number of factors such as grist composition, equipment and type of beer desired. Infusion mashing is less energy intensive than decoction mashing requiring roughly 10-12 MJ/hl of fuel [7].

Following the completion of the mash conversion, the wort is separated from the mash. The most common system in large breweries is a lauter tun or a mash filter. With the use of the lauter tun, the converted mash is transferred to a lautering vessel where the mash settles on a false bottom and the wort is extracted. Lautering is a complex screening procedure that retains the malt residue from mashing on slotted plates or perforated tubes so that it forms a filtering mass.

The wort flows through the filter bed. In the lauter tun, the grains are also sparged (i.e. sprayed and mixed) with water to recover any residual extract adhering to the grain bed. The extracted grain, termed “spent grain,” is most often used as animal feed. In a mash filter, the mash is charged from the mash mixer. The filter is fitted with fine pore polypropylene sheets that forms a tight filter bed and allows for high extract efficiency. However, the quality of the filtered wort may be affected through the use of a mash filter process and may not be applicable for all types of brewing.

The next step, ***wort boiling***, involves the boiling and evaporation of the wort (about a 4-12% evaporation rate) over a 1 to 1.5 hour period. The boil is a strong rolling boil and is the most fuel-intensive step of the beer production process. It is estimated that 55 to 57MJ/hl is used for conventional wort boiling systems in Germany [9]. The boiling sterilizes the wort, coagulates grain protein, stops enzyme activity, drives off volatile compounds, causes metal ions, tannin substances and lipids to form insoluble complexes, extracts soluble substances from hops and cultivates colour and flavour. During this stage, hops, which extract bitter resins and essential oils, can be added. Hops can be fully or partially replaced by hop extracts, which reduce boiling time and remove the need to extract hops from the boiled wort. In order to remove the hot break, the boiled wort is clarified through sedimentation, filtration, centrifugation or whirlpool (being passed through a whirlpool tank).

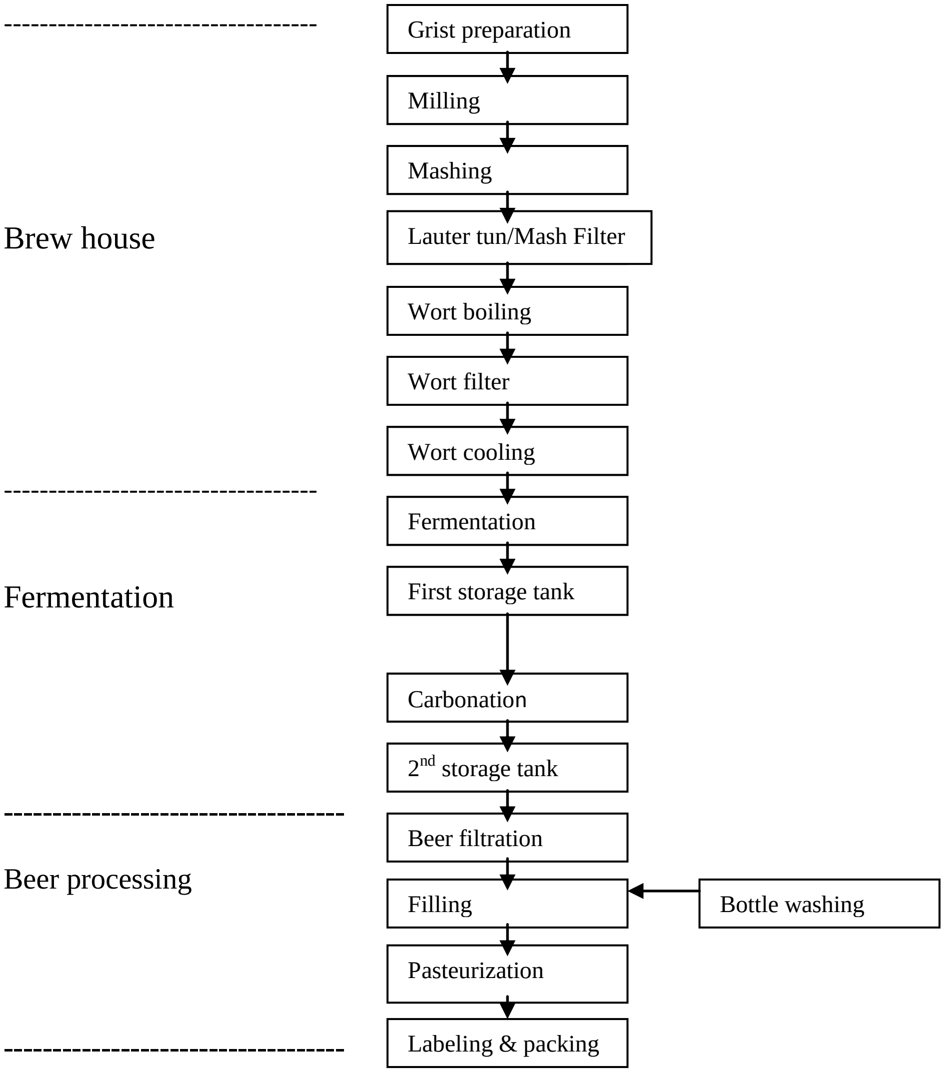


Figure 2.1: Main stages of beer production

After clarification, the cleared hopped wort is cooled. Cooling systems may use air or liquids as cooling medium. Atmospheric cooling uses air stripping columns (used by Anheuser-Busch) while liquid cooling uses plate heat exchangers. Heat exchangers are of two types: single-stage (chilled water only) or multiple-stage (ambient water and glycol).Wort enters the heat exchanger at approximately 94-97ºC and exits cooled to pitching temperature. Pitching temperatures vary depending on the type of beer being produced. Pitching temperature for lagers run between 6-15°C, while pitching temperatures for ales are higher at 12-25°C [7]. The amount of heat potentially recovered from the wort during cooling by a multiple stage heat exchanger is 43-45 MJ/Hl [9].

Once the wort is cooled, it is oxygenated and blended with yeast on its way to the fermenter. The wort is then put in a fermentation vessel. For large breweries, the cylindrical fermentation vessels can be as large as 3,000-5,500 hectolitres tanks [7]. During fermentation, the yeast metabolizes the fermentable sugars in the wort to produce alcohol and carbon dioxide (CO_2). The process also generates significant heat that must be dissipated in order to avoid damaging the yeast. Fermenters are cooled by coils or cooling jackets. In a closed fermenter, CO_2 can be recovered and later reused. Fermentation time will vary from a few days for ales to closer to 10 days for lagers. The rate is dependent on the yeast strain, fermentation parameters (like the reduction of unwanted diacetyl levels) and taste profile that the brewer is targeting [7]. At the conclusion of the first fermentation process, yeast is removed by means of an oscillating sieve, suction, a conical collector, settling or centrifugation. Some of the yeast is reused while other yeast is discarded. Some brewers also wash their yeast. Some brewing methods require a second fermentation, sometimes in an aging tank, where sugar or fresh, yeasted wort is added to start the second fermentation. The carbon dioxide produced in this stage dissolves in the beer, requiring less carbonation during the carbonation process. Carbonation takes place in the first fermentation also. Yeast is once again removed with either settling or centrifugation.

Beer aging or conditioning is the final step in producing beer. The beer is cooled and stored in order to settle yeast and other precipitates and to allow the beer to mature and stabilize. For beers with a high yeast cell count, a centrifuge may be necessary for pre-clarification and removal of protein and tannin material. Different brewers age their beer at different temperatures, partially dependent on the desired taste profile.
Ideally, the beer at this stage is cooled to approximately -1°C, although this can vary in practice from -1°C to 10°C. Beer is held at conditioning temperature for several days to over a month and then chill proofed and filtered. A kieselguhr (diatomaceous earth) filter is typically used to remove any remaining yeast. Brewers use stabilizing agents for chill proofing.

Colouring, hop extracts and flavour additives are dosed into the beer at some breweries. The beer's CO_2 content can also be trimmed with CO_2 that was collected during fermentation. The beer is then sent to a bright (i.e. filtered) beer tank before packaging. In high gravity brewing, specially treated water would be added during the conditioning stage. This can be a significant volume, as high as 50% [7].

Finally, the beer must be cleaned of all remaining harmful bacteria before bottling. One method to achieve this, especially for beer that is expected to have a long shelf life, is pasteurization, where the beer is heated up to 60°C to destroy all biological contaminants. Different pasteurization techniques are tunnel or flash pasteurization. Energy requirements for pasteurization can vary from 19-23 kWh per 1000 bottles for tunnel pasteurization systems [7].

A large amount of water is used for cleaning operations. Incoming water to a brewery can range from 5 to 19 hectolitres of water per hectoliter of beer, while wastewater is usually 1.5 to 2.4 hectolitres less than water use per hectoliter of beer [7]. The wastewater contains biological contaminants (0.8-2.5 kg of BOD/ hectoliter). The main solid wastes are spent grains, yeast, spent hops and diatomaceous earth. Spent grains are estimated to account for about 19 kg/ hectoliter of wort, while spent yeast is an additional 2.3-6 kg/ hectoliter of beer [7]. These waste products primarily go to animal feed. Carbon dioxide and heat are also given off as waste products.

2.1.2 Layout of main energy consumers at the Study plant

Main consumers of energy at the plant are Electricity and thermal energy obtained from steam boilers. The main operations plant is divided into three main departments namely; Brewing, packaging and utilities.

1. In the Utilities department there are several plants:
- Distribution of 66KV Electricity supply to the plant.
- Four boilers for steam generation, three rated at 18 tonne/hour and one rated at 12 tonne/hour.
- Refrigeration plant which utilizes ammonia as the primary refrigerant. Ammonia is then used to cool industrial methylated spirit which is used in the production areas.
- Air compressors which deliver 6 bar of compressed air to the rest of plant
- CO_2 plant which is used in beer production
- The water supply and distribution as well as recovered water in the plant.
2. Brewing department has three main functional locations:
- Brew house which comprise raw material handling, mashing, mash filtration, wort boiling, whirlpool, aeration plant, wort cooling and wort transfer to fermentation plant.

- Central CIP plant and Fermentation plant which comprise; 56 fermentation and beer maturation vessels ranging from capacity of 1800 hl to 3600 hl, centralized CIP plant for cleaning process pipes and vessels. Fermentation plant is the main user of refrigeration.
- Filtration plant which comprise three filter lines with a combined capacity of 1500 hl/hr of beer. Here matured beer is filtered and blended with de-aerated liquor for onward transmission to packaging department.

3. Packaging plant comprise of three bottling lines, two keg barrels filling lines and a new canning line under commissioning.

2.2 Energy use in the brew house

2.2.1 Beer, Energy, and the Environment

The challenge of maintaining high product quality while simultaneously reducing production costs can always be met through investment in energy efficiency, which can include the purchase of energy-efficient technologies and the implementation of plant-wide energy efficiency practices. Energy-efficient technologies can often offer additional benefits, such as quality improvement, increased production, and increased process efficiency, all of which can lead to productivity gains. Energy efficiency is also an important component of a company’s overall environmental strategy, because energy efficiency improvements can often lead to reductions in emissions of both greenhouse gases and other important air pollutants. Investments in energy efficiency are therefore a sound business strategy in today’s manufacturing environment.

Brewery processes are relatively intensive users of both electrical and thermal energy, and the target for every brewing company should be the development of a sustainable process with efficient energy consumption to achieve savings in fuel and energy costs. Energy consumption is equal to 3-8% of the production costs of beer [6], making energy efficiency improvement an important way to reduce costs, especially in times of high-energy price increases.

Thermal energy is used to produce steam, which is used largely for wort boiling, mashing and water heating in the brew house, and in the bottling hall. The major consumers of electricity in breweries are refrigeration (44%), packaging (20%), and compressed air (10%). The process refrigeration system is typically the largest single consumer of electrical energy, but the brew house, bottling hall, and wastewater treatment plant can account for substantial electricity demand [6]. The specific energy consumption of a brewery is heavily influenced by utility system and process design; however, site-specific variations can arise from differences in product recipe and packaging type, the incoming temperature to the brewery of the brewing water and climatic variations. Specific energy consumption in a brewery can vary from 100–200 mega joules per hectoliter (MJ/hl), depending on size, sophistication, and the factors listed above.

2.2.2 Energy-related Technology in the Brew house

In 2005, the European Commission (EC) released best available techniques reference (BREF) documents for food and beverage industries. BREF documents can be regarded as guidelines for reduced energy consumption and sustainable production technologies in European industry in general. In addition, the report also presents best available techniques (BAT) for the brewing process, with significant improvements in terms of thermal energy and electricity consumption.

The average power consumption of European breweries with a wort kettle with an internal boiler and heat recovery from wort boiling using a vapour condenser in combination with an energy storage system is 8.1 kWh/hl; the best available techniques (BAT) minimum benchmark value is 7.5 kWh/hl [6]. The average thermal energy consumption for such breweries is 28.3 kWh/hl [6]; the BAT minimum benchmark is 24 kWh/hl [6].

From table 2.1, comparison of average thermal and electricity energy consumption in KBL for the year 2010 and 2011, shows that though the power and thermal consumptions are higher compared with the European breweries, the figures are within the European BAT benchmark.

Table 2.1: Energy consumption at study plant compared with European benchmarks.

Energy Parameter	European breweries (BAT) benchmark per hectoliter	European breweries average consumption/hl	KBL plant average [8] (Per hectoliter)	
			Year 2010	Year 2011
Thermal energy consumption	23.6 – 33 KWh	28.3 kWh	33.5 KWh	32.2 KWh
Electricity consumption	7.5 - 11.5 KWh	8.1 kWh	9.73 KWh	9.25 KWh

Breweries use different set points for wort boiling regarding time and evaporation rate. Formerly, the standard evaporation rate for acceptable wort quality was 10–12%. A homogeneous boiling temperature in the kettle was often difficult to achieve due to the design of the wort kettle and agitator or inadequate heating surfaces on the bottom or shell of the wort kettle, which causes insufficient heat transfer to all wort particles. The installation of an internal boiler or the pumping of wort through an external boiler can reduce the problem of low homogeneity. The design of Huppmann's Jetstar internal boiler, in combination with dynamic low-pressure boiling, has proven to have a remarkable influence on wort homogeneity during boiling and the subsequent high quality of the finished beer [6].

The energy demands for wort boiling under different pressure conditions and evaporation rates are summarized in Table 2.2 for German breweries with an output >1 million hl/year [6]. The recovery of heat energy is achieved by a vapour condenser in combination with an energy storage system. For wort preheating during transfer from the wort collection tank to the wort kettle, the recovered and stored heat energy is applied in a closed hot water circuit with a plate heat exchanger.

Table 2.2: Energy demands for heating and wort boiling under different pressure conditions and evaporation rates [6].

Thermal energy process consumer	Atmospheric boiling (7.5% total evaporation)		Dynamic low pressure boiling (4.5% total evaporation)		Atmospheric boiling with internal boiler (3.0% total evaporation)	
	kWh/hl	**%**	**kWh/hl**	**%**	**kWh/hl**	**%**
Mashing, 52/78 °C	2.21	19.8	2.21	24.3	2.21	27.9
Heating, 74/99 °C	3.38	30.2	3.29	36.3	3.24	40.8
Wort boiling	5.03	45.0	3.02	33.2	2.01	25.3
CIP	0.28	2.5	0.28	3.1	0.23	2.9
Hot service water	0.28	2.5	0.28	3.1	0.25	3.1
Total consumption brew house	11.18	100	9.07	100	7.94	100
Consumption at boiler house	13.84		11.23		9.81	

The recovered thermal energy is sufficient to preheat the collected wort during transfer from the wort tank to the wort kettle; a temperature increase from 74 to 95°C can be achieved. The wort at a temperature of between 72-74°C in the wort tank comes from previous mash filtration process.

The recommended installation with wort boiling at low pressure and 4.5% total evaporation compared with conventional wort boiling under atmospheric conditions without an energy storage system and with 7.5% total evaporation, leads to an energy savings of approx. 19%; the equivalent reduction of CO_2 emissions is 0.43 kg/hl of cast wort [6].

For the brew house plant under study (referred to as study plant) with an internal boiler and energy storage system, the data collected on Table 4.3 for this study shows that compared to atmospheric boiling, low pressure boiling uses less energy of 49.8% or 9.89 kWh/hl.

This change in wort boiling technology can result in a reduction of 1,880 metric tonnes of CO_2 for a production volume of 2 million hl/year. Another advantage of low-pressure boiling with an internal boiler installation is an optimum hot water balance due to complete heat recycling in the brew house. There is no need to store surplus hot water, probably at a lower temperature, and no need to transfer hot service water to any other consumer in the brewery. The installation of storage tanks, pipes, and pumps is not necessary. In addition, there is no extra power consumption needed to supply surplus hot water to consumers.

Condensation of wort kettle vapour in the condenser guarantees minimum vapour emissions into the atmosphere, which will help the brewery to meet the target of a “zero emission brewery.” The Jetstar internal boiler can work with a minimum total evaporation of approx. 3–5% for kettle-full wort and, in a best energy balance scenario, at 4.5% for heating collected lauter wort to near boiling [6].

2.2.3 Energy Audits at study plant

Several energy efficiency audits have been undertaken in the study plant. The audits have mainly covered the Utilities department, which is the main utilities supply and generating point to production process areas. Some of the main equipments covered under the audit are:

- Boiler plant – fuel oil usage, boiler feed water balance and condensate recovery.
- Steam distribution – lagging of pipes, elimination of leaks & replacement of steam traps.
- Refrigeration plant – mapping of site refrigeration demand, need of replacement of old energy inefficient compressors, installation of VSDs to IMS secondary pumps, etc.
- Compressed air plant – elimination of site air leaks, installing of dryers, etc.
- Site water mapping – Area usage, installing metering points, reducing wastage, etc.

2.3 Wort boiling

2.3.1 Requirements for the Wort Boiling Process

During the last decade there have been significant developments and improvements in wort boiling technique. Driven by the demand to reduce energy consumption new processes and technical solutions have been introduced into the brewing industry.

Though rarely used in view of low fuel prices then prevailing, so-called “new” boiling processes such as pressure boiling and low-pressure boiling made a contribution towards saving energy.

Conventional (classical) low-pressure boiling where the wort boils at a constant evaporation pressure of 1.08 bar (boiling temperature = 102 °C) to 1.21 bar (boiling temperature = 105 °C) has been used in breweries all over the world as of 1979 [9]. By installing low-pressure boiling, the drawbacks of wort boiling at different barometric pressures, primarily as a consequence of different geographic elevations of brewery locations and the resulting boiling temperatures below 100 °C, can be more than compensated. The required air free boiling process had given impetus at the time to development of a new internal boiler generation which has been produced and operated very successfully meantime.

2.3.2 Internal boiler

A thermal apparatus with simple design for wort heating and wort boiling is a vertical shell and tube heat exchanger operating as a natural circulation evaporator, i.e. an internal boiler. It offers marked advantages over an external boiler. The internal boiler works on the basis of a purely physical principle: steam bubbles create a density difference between the wort in the internal boiler and the surrounding kettle, thus ensuring continuous circulation. This principle, also known as natural circulation, operates without additional circulation pump and minimizes mechanical stress on the wort. With internal boilers, wort circulation rates are much higher than with external boilers. During boiling, wort is circulated 20–30 times per hour, which ensures a homogeneous temperature throughout the entire wort kettle.

The advantages of the internal boiler result from the very simple, uncomplicated and economical construction and from the thermodynamic principle of partial evaporation of wort in the tubes.

The tube bundle is located right in the middle of the medium to be heated; it emits heat straight into the wort and not to the surroundings. With the JETSTAR ™, the newest design of internal boilers, better homogeneity right from the start of wort heating is achieved

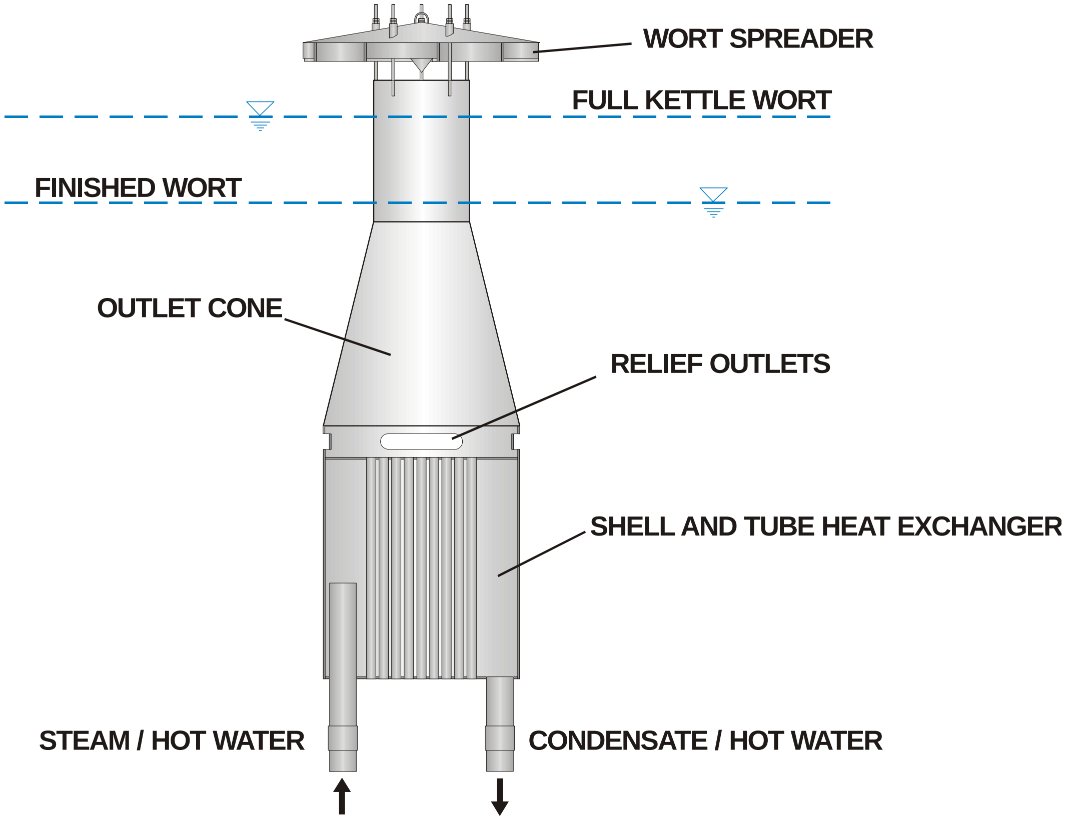


Figure 2.2: The basic arrangement of the Huppmann Jetstar™ internal boiler [5].

Figure 2.2 shows the basic arrangement of an internal boiler, with the main components [9]. Important features of the internal boiler generation of 2001 are:

- The lowest possible heating medium temperatures;
- The lowest possible thermal stress on wort with wall temperatures on the wort side of maximum 107 °C;
- Boiler geometry optimally adapted to the wort kettle size;
- Special heating tube geometry, i.e. length, diameter and wall thickness;
- Very much enlarged boiler outlet nozzle for high-circulation performance;
- The lowest possible temperature gradient between vessel contents and boiling wort at the internal boiler outlet;

- Patented 2-level wort deflector cap for dividing and spreading the wort ejection streams and thus for enlarging the evaporative surface area.

2.3.3 Analysis of energy flow in wort boiling process

Heating wort during transfer from the wort pre-run tank using hot water from the energy storage system is a process improvement. The hot water required has been obtained recuperatively from the wort boiling process using an evaporative condenser [9]. The hot water from the energy reservoir is brought to a higher temperature level via a second additional step heated with fresh steam and used for heating wort until this reaches almost the particular boiling temperature. The internal boiler can thus immediately operate pulsation-free, allowing wort boiling processes to start without loss of time.

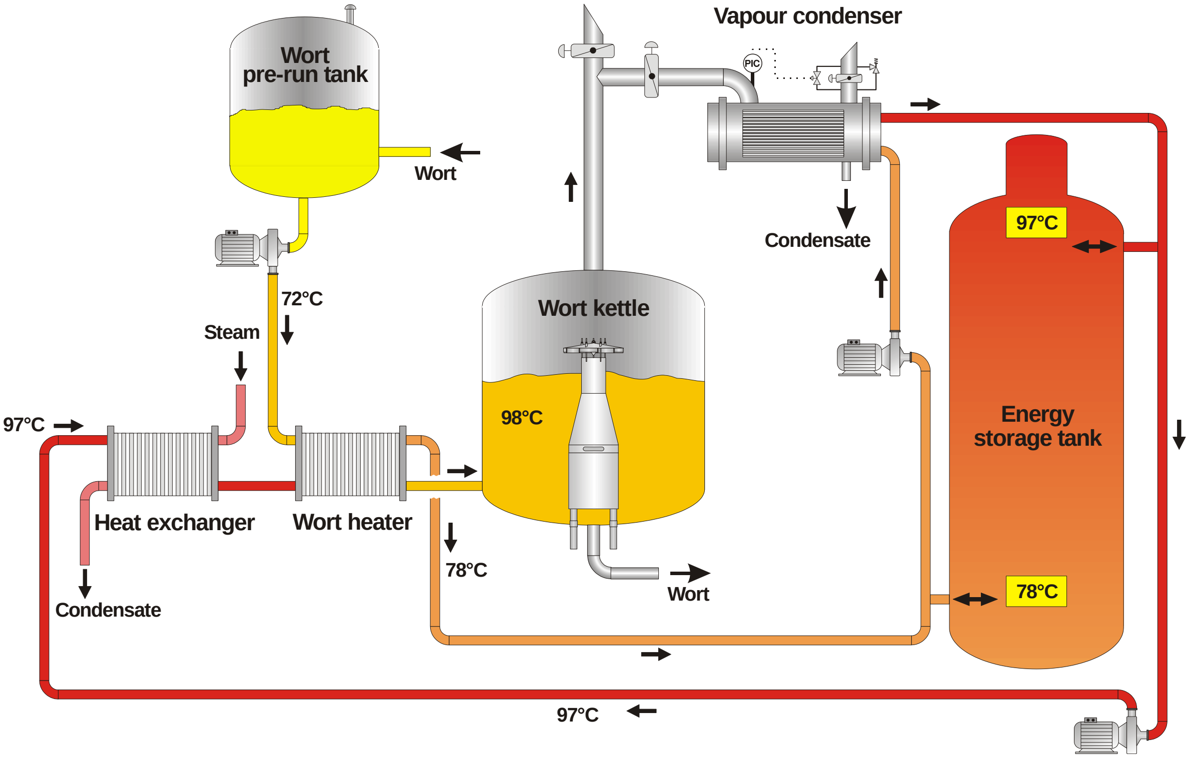


Figure 2.3: Wort boiling with an energy storage system and additional equipment [8].

An energy storage system for wort production in the brew house consists of the main components hot water displacement storage tank, wort pre-heater as plate and frame heat exchanger, vapour condenser, further plate and frame heat exchangers for heat provision, feed pumps, and pipes as well as the necessary safety devices. The main task of the energy storage system is the heating of wort from the temperature after lautering/out of the pre-run vessel of 72 °C to a temperature of about 95 °C. The necessary heat, roughly 5 %-points of total evaporation, comes from the condensation of the wort boiling vapours of the previous brew [7]. The used displacement storage tank serves as short-time heat reservoir, which is sufficiently insulated and mostly atmospherically open and thus has only insignificant heat losses.

In brewing plants with an energy storage system (Figure 2.3), water with a temperature of approx. 96 – 98 °C from the energy storage tank (circuit water) is heated up to approx. 101 °C by means of steam in a second plate and frame heat exchanger ("Booster heat exchanger"). This hot circuit water now heats up the wort very gently to almost boiling temperature of 95°C [7], (93°C for the study plant). With water as heat transfer medium the wall temperatures on the wort side remain safely below the boiling point and undesirable protein precipitation reactions are reduced considerably.

This procedure does not affect the hot water balance of the brewery, as the water is led in a closed circuit back into the energy storage tank again with a temperature of approx. 78 – 80 °C. Up to a total evaporation of just under 5 %, the energy recovered from the vapours during boiling can thus be used completely for wort preheating [7]. During the start-up of a brewing line, the steam-heated "Booster heat exchanger" can also be used to heat up the energy storage tank, which has slightly cooled down during the shut-down time.

The advantages of the energy storage system result from the fact that there are almost no maintenance and repair costs compared to other plants with heat recovery and from the high flexibility in application, like e.g. for several brewing lines. In principle, the displacement storage tank can be designed for buffering of the heat from condensation of the total wort boiling vapours or only for the heat required for wort heating.

2.4 Dynamic low-pressure boiling

2.4.1 Principles of dynamic low pressure boiling

Wort boiling processes realized under pressure are based on the fact that chemical reactions have a higher reaction speed at higher temperatures, so that the boiling time and therefore the total water mass to be evaporated can be reduced. Among other things, the aim of wort boiling processes is to achieve sufficient removal of undesirable volatile substances (aroma and aging components) from the wort. These volatile substances can only escape from the wort via the gas phase.

The advantage of dynamic wort boiling is the effect to utilize the basic physics principle of expansion evaporation. If a liquid under pressure is expanded to a lower pressure, the boiling temperature of the liquid is reduced and the released energy is used for the formation of vapour bubbles (flash vapour) in the entire liquid volume. This causes an intensive boiling movement.

In addition to expansion evaporation the thermal separation process of desorption takes place in the wort. Desorption or stripping in general is the removal of one or several bound gases from a solution. Basically, there are three different kinds of desorption, which can also be found in combination:

- removal of bound gases by expansion of the solution
- removal of bound gases by heating of the solution
- removal of bound gases in the strip gas flow.

The strip gas is an inert gas or vapour. The small vapour bubbles (strip gas) formed in the wort due to flash evaporation provide the required interphases gas/liquid, so that the mass transfer of the volatile substances from the liquid phase to the gas phase is possible and the volatile substances can be removed from the wort with the strip gas. Basis of the mass transfer is Roult’s law and Henry’s law [7].

Dynamic low-pressure boiling uses a temperature range between 100 °C and 103 °C for wort boiling. With the number of pressure build-up intervals, the intensity of the pressure, the rate of alteration of the pressure Hp/Ht, all necessary parameters of wort boiling, like stripping of undesirable flavours, DMS formation, the coagulation process, colour etc., can be influenced in a wide range. With these factors, total evaporation can be reduced to 4 - 5 %. A simplified process sequence of dynamic low-pressure boiling is illustrated in Figure 2.4.

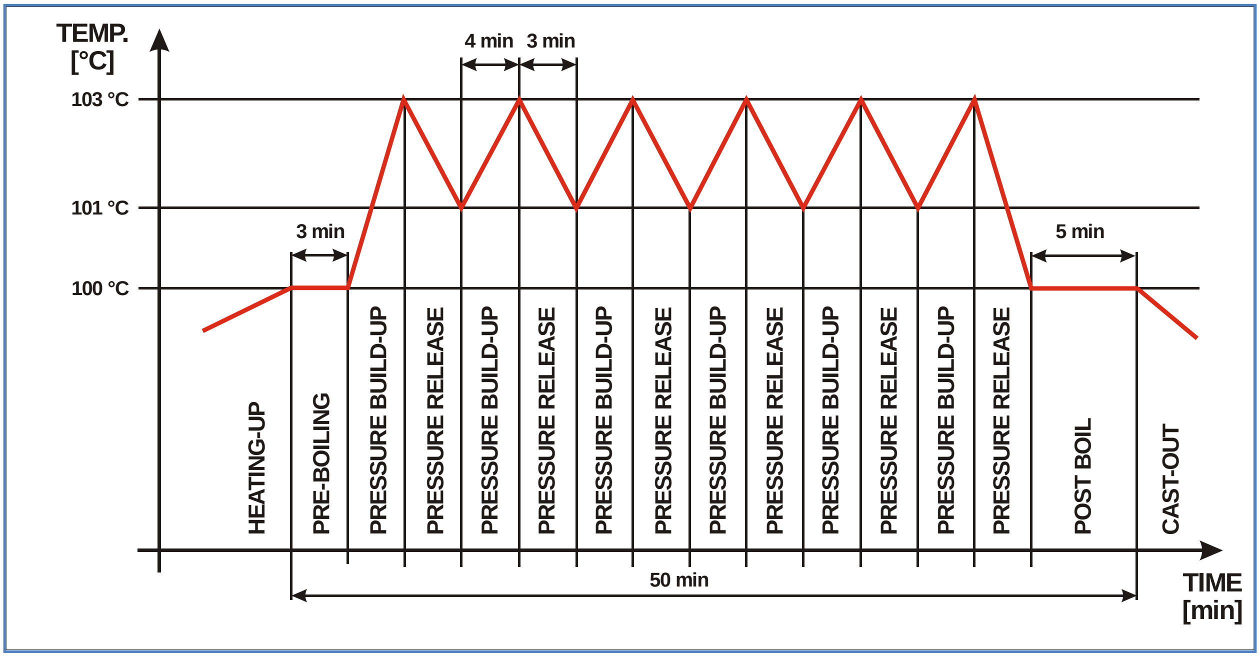


Figure 2.4: Dynamic low pressure boiling [8].

2.4.2 Dynamic low-pressure boiling (LPB) with “fractional” heating

The process of the dynamic low-pressure boiling is divided into three steps:

- Atmospheric pre-boiling serving the purpose of de-aeration of the wort kettle, the pressure regulation system and the vapour condenser,
- Defined pressure build-up in the wort kettle and deliberate pressure release - repetition of this process for 6 times (Fig. 2.4),
- Atmospheric after boiling to achieve the desired cast-out wort concentration.

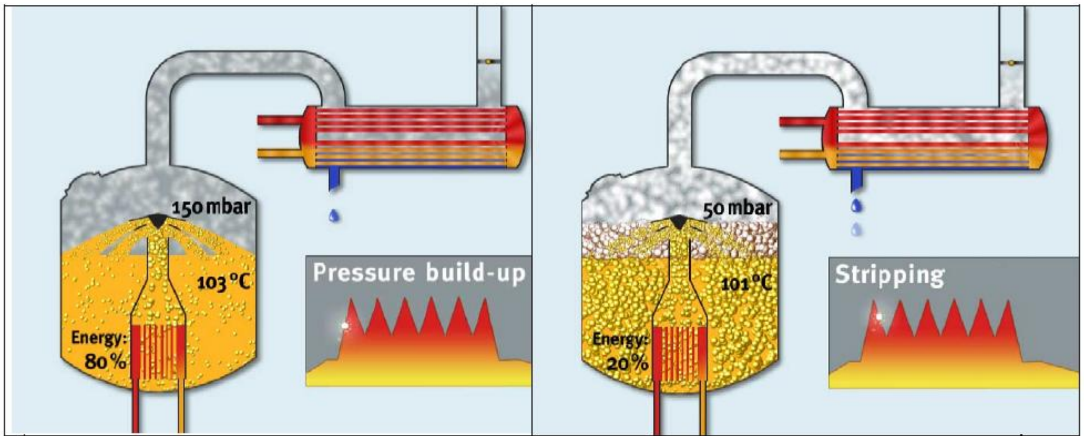


Figure 2.5: Pressure build-up – Stripping [8].

When the set maximum pressure has been reached, deliberate pressure reduction starts. Under defined conditions and with a specified speed Hp/Ht, the pressure in the wort kettle is reduced to 50 mbar. As with the pressure reduction, the corresponding boiling temperature goes down to about 101 °C and steam bubbles are produced in the entire kettle wort volume (figure 2.5). This process is called “flash evaporation”, creates a perfect stripping of volatiles and makes the difference between dynamic low-pressure boiling and other boiling methods [8].

This process “energy supply and pressure build-up“– “pressure release with flash evaporation” is repeated approx. 6 times. In the last expansion step the pressure is reduced to atmospheric conditions again. The next step, “after-boiling” is important to achieve the required cast-out wort concentration. Using this boiling method, boiling time of 45 to 50 minutes can be realized and total evaporation rates of 3.5 to 5 % can be adjusted.

One of the objectives of wort boiling processes relates to a sufficient expulsion of unwanted volatile substances (aroma and staling components) from wort. Such volatile substances can be removed from wort via the gas phase only. In dynamic wort boiling, it is advantageous that the physical basic principle of flash evaporation can be utilized. If a pressurized liquid is depressurized to a lower pressure, the boiling temperature of the liquid is reduced and the energy released thereby is used for formation of steam bubbles (secondary steam) throughout the liquid volume. This results in a vigorous boiling movement in the wort kettle [8].

The stripping gas (steam bubbles) developing in the wort on account of a post evaporation results in volatile substances, predominantly of an organic structure, being expelled from the wort together with stripping gas. In the case of atmospheric boiling with internal or external boilers or also in the case of boiling methods with double-walled heating cones, only the wort which is in contact with the heating surface is at or above boiling temperature.

Experience from recent installations, shows that this proven technology provides superior product quality and that reduced evaporation rates will lead to substantial saving of primary energy and cost [8].

2.4.3 Vapour condenser

Almost exclusively, multi-pass shell and tube heat exchangers in horizontal position are used as vapour condensers. In case of air free wort boiling the vapour is condensed in the shell area. On the tube side water is used to carry off heat and thus to produce hot water for the brewery. In our latitudes the water inlet temperatures are between 20 °C and 25 °C, or in case of operation of an energy storage system 76 °C to 78 °C. With atmospheric condensation the produced hot water reaches water outlet temperatures of up to 98 °C; 80 °C should be the minimum.

Vapour condensers reduce the emissions caused by wort boiling considerably. In practice, 100% reduction of emissions is not possible, neither with atmospheric boiling nor with low-pressure boiling, because wort boiling takes place in batches. Air-free condensation is the precondition for high energy efficiency of the wort boiling plant. In order to realize air-free condensation, vapours have to be released into the open air through the vapour pipe for a few minutes [7]. In addition, pressure relief to atmospheric pressure at the end of the low-pressure boiling process is necessary. This causes mass losses (emission of mainly organic substances), which means a heat loss at the same time.

2.4.4 Energy requirement and hot water preparation

With an energy storage system and dynamic low-pressure boiling with a total evaporation rate of e.g. 4.5 %, based on the cast wort volume, the specific total heat requirement for wort heating to boiling temperature and wort boiling is about 4.2 KWh/hl of cast wort [9]. In wort boiling, no additional excess heat arises which would have to be utilized in the brewery e.g. in the form of hot water. Conventional atmospheric boiling with an evaporative condenser for heat recovery, associated with a technologically required total evaporation rate of 8% based on the cast wort volume, has specific heat consumption for wort heating and wort boiling of about 8.7 kWh/hl of cast wort. Moreover, about 0.63 hl of hot water at 80 °C per hl of cast wort has to be utilized in the brewery in order to completely use up the heat recovered from the evaporative condenser [9]. A comparison of the specific electrical energy consumption shows that, with dynamic low-pressure boiling with an energy storage system, about 1.9 kWh (el) per 100 hl of cast wort are required, the figure for conventional atmospheric wort boiling with an evaporative condenser is only about 0.8 kWh (el) per 100 hl of cast wort.

Energy and environmental advantages of dynamic low pressure boiling

- Minimum total evaporation approx. 3 – 5 %, referring to kettle-full wort
- Maximum heat recovery possible from the wort kettle vapours
    - Saving of fuel
    - Preservation of fossil fuel resources
    - Minimum CO_2 – emissions
    - Minimum vapour emissions into the atmosphere
    - Optimum water balance

Besides economical reasons, reduced evaporation rates will also have a positive impact on our environments. Combined with an energy storage system for wort heating up this particular process will reduce the CO_2-emission from the boiler house.

Compared to standard atmospheric boiling techniques, reducing CO_2-emission up to 50 % is possible: a contribution to meet the emission targets of the Kyoto Conference [9].

2.5 Heat supply with live steam

For reasons of process engineering water vapour is required as heat transfer medium with different thermodynamic conditions (pressure, temperature, steam content). In case of heating processes, however, 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 usage of super heaters or it can be produced during throttling of saturated steam/wet steam from a high pressure to a lower pressure level.

Fire-tube exhaust gas-tube boiler plants (e.g. three-pass boilers), which are used in breweries very often, provide live steam with a steam quality of 95 to 98 % in practice. Live steam from a boiler plant with a boiler operating pressure of e.g. 8 bar (abs.) is reduced to a pressure of e.g. 3 bar (abs.) or less before use in an internal or external boiler.

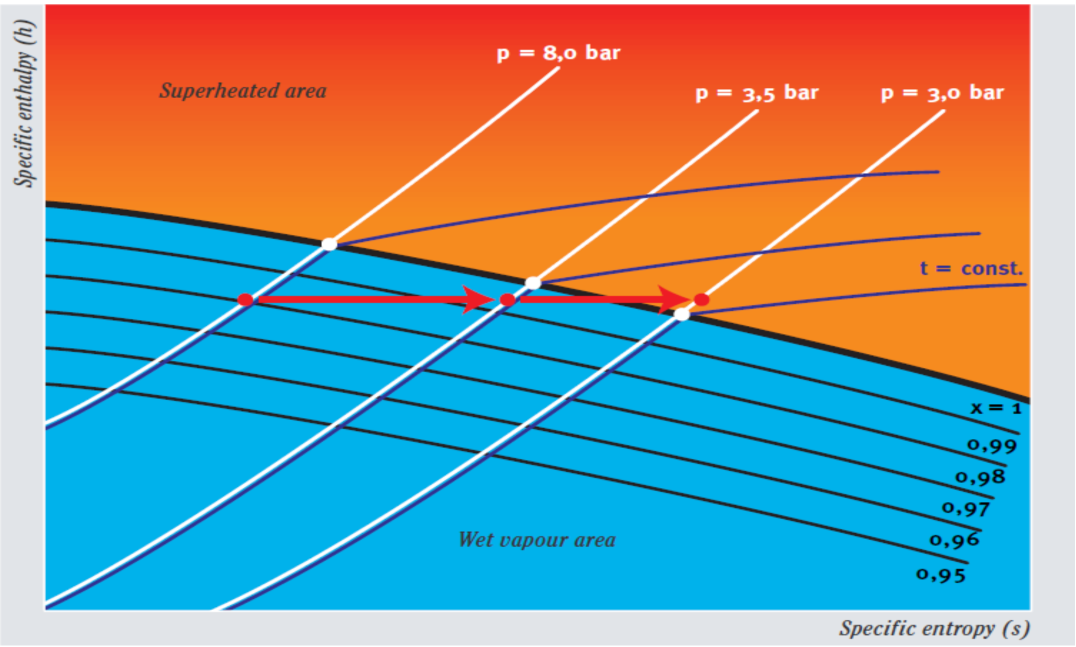


Figure 2.6: Throttling of live steam in the h, s-diagram (x = steam quality, t = temperature) [7].

Figure 2.6 shows a schematic representation of the throttling of live steam. Table 2.3 indicates the temperature and steam quality depending on the pressure of the throttled steam, assuming a boiler operating pressure of 8 bar (abs.) respectively 6 bar (abs.) and a steam quality of 98 % [7].

From table 2.3 it becomes clear that in case of a live steam pressure of 8 bar before throttling, excessive temperatures of the superheated steam occur only in case of steam pressures of less than 2.0 bar after throttling. If a live steam pressure of 6 bar is assumed, then a pressure of the throttled steam of less than 1.5 bar leads to excessive temperatures of live steam. If the superheating temperature after the throttling station remains lower than 10 K, it is possible to do without an installation for steam cooling (injection station). Damage to the product in case of slight superheating can thus be ruled out.

Table 2.3: Temperature and steam quality of the throttled steam [7]

8 bar/0.98	**5.0 bar**	**4.0 bar**	**3.5 bar**	**3.0 bar**	**2.5 bar**	**2.0 bar**	**1.5 bar**
ts in °C	151.8	143.6	138.9	133.5	127.4	120.2	111.4
x	0.990	0.995	0.997	1.000	-	-	-
t in °C	-	-	-	-	132	130	128
Δt in °C	-	-	-	-	4.6	9.8	16.6
6 bar/0.98	**5.0 bar**	**4.0 bar**	**3.5 bar**	**3.0 bar**	**2.5 bar**	**2.0 bar**	**1.5 bar**
ts in °C	151.8	143.6	138.9	133.5	127.4	120.2	111.4
x	0.984	0.989	0.992	0.996	0.999	-	-
t in °C	-	-	-	-	-	123	121
Δt in °C	-	-	-	-	-	2.8	9.6

ts: Saturation temperature

x: Steam quality

t: Temperature of the superheated steam after throttling

Δt: Temperature difference to the saturation temperature

2.5.1 Process Engineering of wort boiling

Wort boiling plants which work according to the principle of dynamic wort boiling (DYN) and which are equipped with an energy storage system are compared with systems which work with atmospheric boiling (ATM) and which use a vapour condenser for heat recovery. With a vapour condenser, ATM boiling plants produce hot process water at 80 °C from cold water, which is taken out of a cold water storage tank at 13 °C (see Figure 2.8). In the following comparison a cast-out volume of 500 hl (hot) per brew is assumed.

Table 2.4 shows important process engineering criteria. With dynamic LPB the average evaporation temperature is 102.5 °C. The total evaporation is referred to the cast-out volume. The heat consumers are supplied with live steam. The de-aeration period serves for the creation of air-free conditions in the wort boiling system and thus for a thermodynamically optimum condensation of wort boiling vapours in the vapour condenser [7].

Table 2.4: Process engineering criteria of wort boiling [7]

	DYN-5	**DYN-6**	**ATM-8**	**ATM-9**
Boiling temperature (°C)	Max. 104	Max. 104	100	100
Total evaporation (%)	5	6	8	9
Boiling time (min)	50	50	70	70
Evaporation rate (%/hr)	6	7.2	6.9	7.7

2.5.2 Energy and environmental comparison of wort boiling

Wort heating and wort boiling

In case of atmospheric boiling (ATM) the wort coming from the lauter tun/pre-run vessel is heated from 72 °C to 100 °C through a heat exchanger by means of live steam. In case of dynamic LPB the wort is heated in two steps. Using the energy storage system the wort is heated from 72 °C to 95 °C during the first wort heating by means of energy storage water with a pre-run temperature of 97 °C. For the second wort heating the dynamic method requires live steam in the internal boiler. Here, it is considered that in the first step the wort is to be heated from 95 °C to the boiling temperature of 100 °C for the pre-boiling phase and then from 100 °C to 104 °C

[7]. Table 2.5 summarizes some results of the energy calculations concerning the different wort boiling plants.

Table 2.5: Results to the wort boiling plants [7]

	DYN-5	**DYN-6**	**ATM-8**	**ATM-9**
Heating up wort phase1 (kWh/brew)	1410	1423	1765	1781
Heating up wort phase2 (kWh/brew)	552	557	-	-
Wort boiling (kWh/brew)	1610	1932	2583	2906
Heat by steam (kWh/brew)	2162	2489	4384	4687

Heat recovery with vapour condenser

If the vapour mass losses and heat losses are taken into account for heat recovery through the vapour condenser, the values indicated in table 2.6 are buffered per each brew. Prerequisite is that the vapour condensate leaves the vapour condenser in boiling condition. Hot process water at 80 °C is produced, from water at 13 °C buffered from cold water storage tank. A provision of generating hot water by cooling down vapour condensate in the vapour condensate cooler is not included.

In case of dynamic low-pressure boiling (see table 2.6) with a total evaporation of 5 %, referring to the cast wort, the heat balance is almost equalized, i.e. the complete heat which was produced by heat recovery and which is stored in the energy storage tank is used for wort pre-heating. With a total evaporation rate of 6 % excess heat is produced in the energy storage tank; this excess heat can be used e.g. for the production of hot process water.

Table 2.6: Heat recovery (without vapour condensate sub-cooling) [7]

	DYN-5	**DYN-6**	**ATM-8**	**ATM-9**
Heat recovery (kWh/brew)	1455	1746	2368	2658
Production of hot water at 80 (°C) (hl/brew)	6	43	313	352

Considering atmospheric boiling in Table 2.6, it can be stated that from an energetic and economical view this boiling system is only appropriate, if high quantities of hot process water per brew can be utilized in the brewery.

Using the dynamic low-pressure boiling method with a total evaporation of 5 % it is not possible to produce hot process water without additional expenditure of fuel heat. For 100 hl hot process water with a temperature of 80 °C about 1,010 kWh of fuel heat, referred to the net calorific value (n.c.v.), is to be additionally expended via the operating boiler [7].

Employing atmospheric boiling with 8 % total evaporation, about 313 hl hot process water per brew are produced by heat recovery in the vapour condenser. This quantity has to be utilized in the brewery in order to exploit the expended fuel heat of about 5,600 kWh (n.c.v.). Even if less than 313 hl hot process water per brew are required in the brewery, about 5,600 kWh (n.c.v.) of fuel heat per brew have to be used in the operating boiler plant for wort heating and boiling [7].

2.6 Overview of energy use and recovery at Study plant

The study plant energy storage system for wort production in the brew house consists of the main components of hot water displacement storage tank, wort pre-heater as plate and frame heat exchanger, vapour condenser, further plate and frame heat exchangers for heat provision, feed pumps, and pipes as well as the necessary safety devices. The main task of the energy storage system is the heating of wort from the temperature out of the pre-run vessel of 72 °C to a temperature of between 92-95 °C. The necessary heat, roughly 8 %-points of total evaporation, comes from the condensation of the wort boiling vapours of the previous brew. The used displacement storage tank serves as short-time heat reservoir, which is sufficiently insulated and mostly atmospherically open and thus has only insignificant heat losses.

2.6.1 Low pressure boiling and atmospheric boiling

As already discussed in section 2.5.2, Wort boiling process in the study plant can be divided in to three main stages. These are:

- Heating up phase 1 (72-92^{o}C), and phase 2 (92-95^{o}C) - referred to as pre-boiling phase.
- Low pressure boiling (LPB) where the vapour pressure is controlled between high and low pressure peaks. This stage takes 45 minutes.
- Atmospheric post boiling which takes about 15 minutes with steam supply at 50% throttled.

At the study plant, among other equipment there are two wort kettles (1and 2), a single vapour condenser, a single energy storage tank, a single wort pre-heater PHE and two wort cooler PHEs. During low pressure boiling, only one kettle at a time is allowed to use the vapour condenser, pre-heater and energy storage tank. The other kettle has to wait for its turn, for low pressure boiling to take place. Hence there is a waiting delay on one wort kettle which can last up to 1.5 hours. This delay has the effect of slowing down production.

Atmospheric boiling is boiling of wort at atmospheric pressure. Here the wort is boiled directly to the required target temperature and time by opening the chimney vent valve, and without utilizing the vapour condenser. Though low pressure boiling is the normal and preferred system of boiling, there are instances that atmospheric boiling is done. Two scenarios that determine use of atmospheric boiling are:

- When the wort pre-heater is fouled or clogged and its efficiency drops. Since the recovered energy from vapour condenser cannot be utilized at the pre-heater, then low pressure boiling is not necessary and is skipped. With no pre-heater and no vapour condenser and energy storage tank, atmospheric wort boiling will be done by direct use of steam energy. This means raising the wort temperature from 72°C to boiling temperature of about 101°C. As demonstrated on section 4.4.3, when the pre-heater is bypassed more steam energy is used during wort boiling.
- During peak season of beer sales, production demand shoots up. Faster throughput in production processes is necessary. The 1.5hrs waiting time at the kettles for low pressure boiling is waived and atmospheric boiling is done. Hence one kettle will be on low pressure boiling while the other will undergo atmospheric boiling.

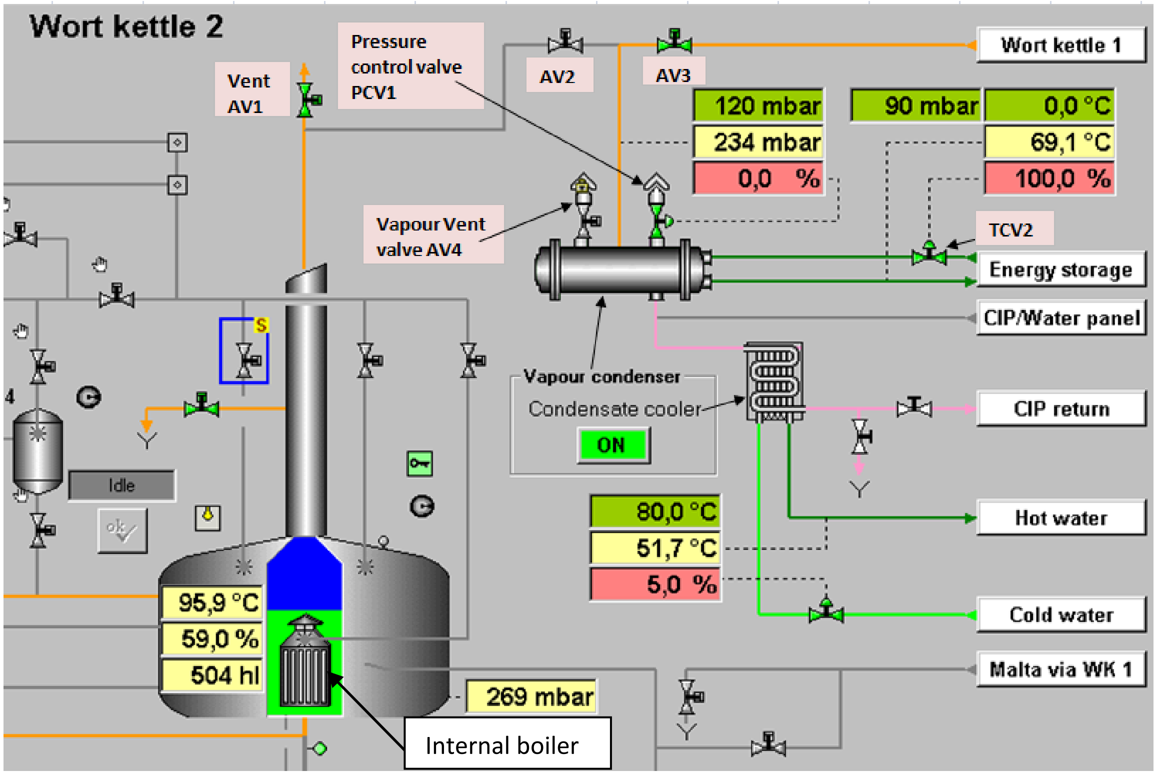


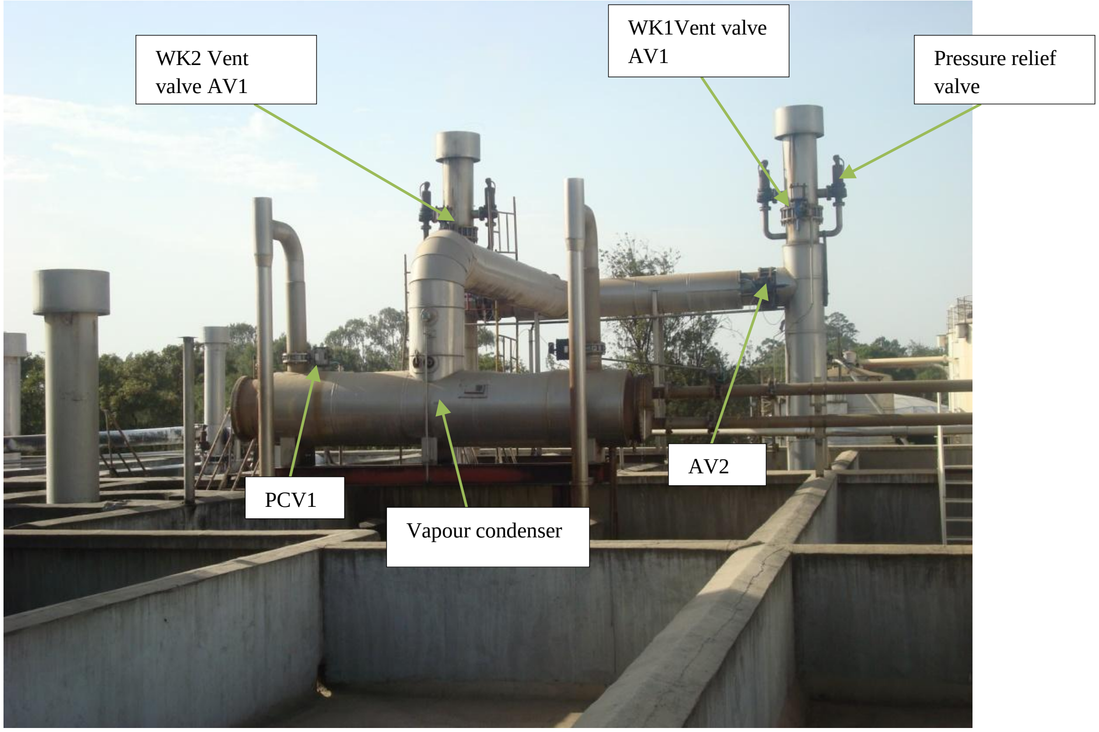
Figure 2.7: Wort kettle and its key energy use components at study plant

Figure 2.7 is a blown view of a scada picture of brew house process showing the wort kettle, vapour condenser, vapour condensate cooler and supply line to and from the energy storage tank.

2.6.2 Wort kettle valves description

AV1 – auto valve at the kettle chimney
AV2 - Auto valve channeling the vapour from wort kettle 2 to the vapour condenser
AV3 - Auto valve channeling the vapour from wort kettle 1 to the vapour condenser
AV4 – Auto valve that opens the vapour condenser to atmospheric pressure
PCV1 – Pressure control valve which controls the vapour pressure
TCV2 – Temperature control valve which controls the water temperature to energy storage tank

If wort kettle 2 is on atmospheric boiling and wort kettle 1 is on low pressure boiling, then AV1 will be open and AV2 is closed. AV3 will be open to enable WK1 to access the vapour condenser. PCV1 is a pressure control valve that regulates the vapour pressure to the required target (pressurizing and depressurizing). AV4 is an auto valve that is called to open after completion of low pressure boiling stage. TCV2 is temperature control valve for water. The water that has been used for pre-heating the wort at pre-heater outlet drops to about 70°C and is channeled back to the vapour condenser for heating up to 95-97°C before it is taken to energy storage tank. Photograph 2.1 shows the vapour condenser and connection to the two wort kettles.



Photograph 2.1: The actual vapour condenser and connection to wort kettle

2.6.3 Wort pre-heater and energy storage tank

From the boiler house, the steam distribution supply is controlled at 8 bars (absolute). The wort boiling requires a steam supply of 3 bar (abs), with reduction being achieved by a pressure reducing valve (PRV). At the time of carrying out the study, the pressure reducing valve on the main steam line to brew house was out of service. Hence the two wort kettles were being supplied with steam at a pressure between 7 and 8 bars.

Several scenarios were considered during wort boiling. These are:

- Effect of different volumes of product per batch or brand
- Energy used when steam supply is varied at different valve settings
- Poor wort pre-heater efficiencies
- Effect of bypassing the wort pre-heater
- Wort boiling with atmospheric only boiling
- Percentage (%) evaporation

Whereas all brands undergo the same process, the raw materials (barley or malt, water, etc) and ingredients are added in different proportions. This has the effect of realizing different product characteristics, one of which is volume. Hence different brands will have different target volumes e.g. target volume for TUSKER is 520hl while for SENATOR it is 730hl per batch.

The steam supply control valve for the wort kettle is automatically controlled to open from 0% (when shut), to 100% (fully open). The amount of steam that flows to the internal boiler can be controlled from 0-100%, depending on the stage of wort boiling. For instance during heating up phase 1 & 2 (target of wort temperature at 95^{o}C), the valve opens to a limit of 75%. During pressure boiling, the valve opens at 50% at pressurizing peak, and opens to 22% at depressurizing phase. Hence, control of valve opening determines the amount of steam energy flow to the kettle and the average evaporation attained on pressure boiling. To inject more steam energy and hence achieve a higher evaporation, the valve settings can be automatically adjusted to realize this.

The wort pre-heater heat exchanger is used to raise the temperature of the wort before entry into the wort kettle. The performance of the wort pre-heater will affect the amount of energy required during heating up phase in the kettle. Heated wort from the pre-heater PHE, should be around

92-93°C. The highest efficiency obtained at per-heater is when the wort temperature is raised from 72°C to 93°C. Fouling of the wort pre-heater is a barrier to its heat transfer efficiency and impedes the flow of heat from hot water to wort. Lowest heat transfer efficiency of the pre-heater due to fouling is when wort temperature is only raised from 72°C to 78°C. This means more steam energy will be required during heating up phase, to raise the temperature from 78 to 95°C. Should the pre-heater require maintenance (to remove fouling) where it has to be bypassed, then even more energy will be required to raise the wort temperature from 72°C to 95°C during heating up at the wort kettle. There will be also no energy recovery at vapour condenser as only atmospheric boiling is carried out.

During dynamic low pressure boiling (LPB), pressure of vapour is controlled by the pressure control valve; PCV1 on Figure 2.7, and the vent valve AV1 is closed at this time. On atmospheric boiling, the wort kettle chimney is open (AV1 open, on Fig 2.7) and hence atmospheric pressure is acting on the wort surface. Atmospheric boiling uses much more steam energy compared with LPB. Figure 2.8 shows the energy storage tank and its features. The heat exchanger shown can also be used to heat make up water for the boiler, though the pipe work installation is not complete.

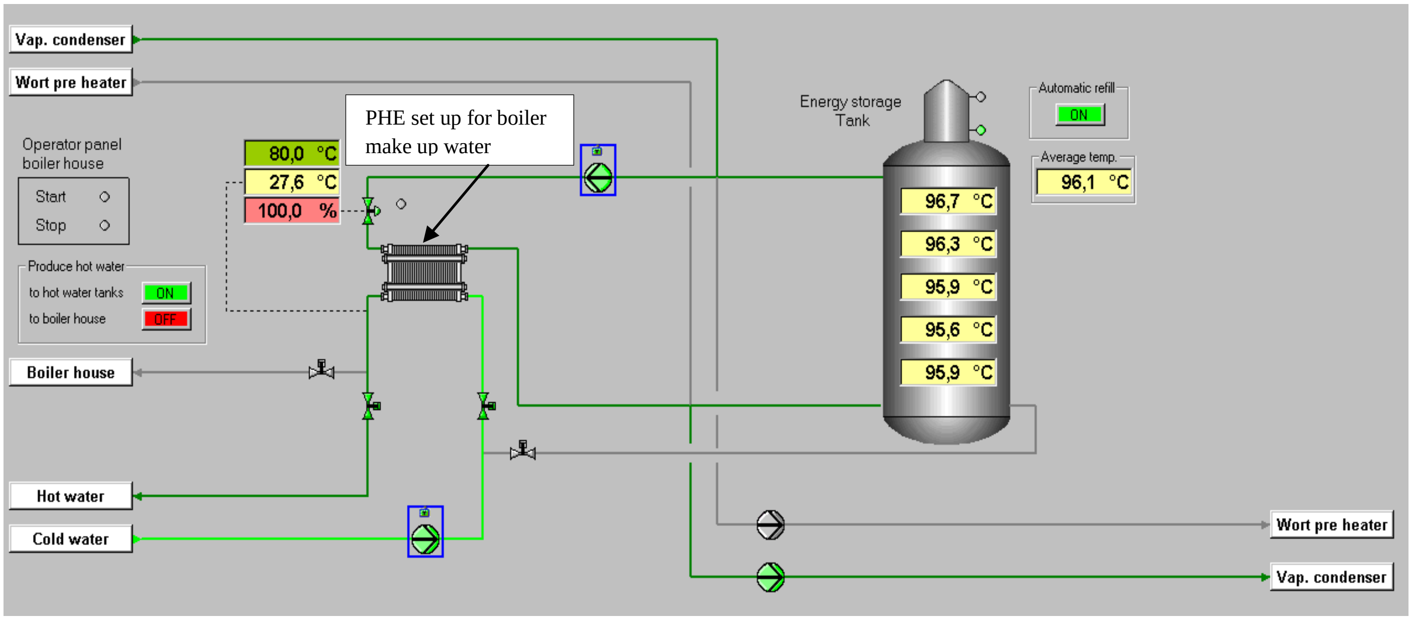


Figure 2.8: Scada screen shot of energy storage tank

2.7 Wort cooling

The wort must be cooled from boiling point to a temperature of 7°C to 12°C to prepare it for fermentation. To avoid contamination with foreign organisms this cooling must be done as quickly as possible. As long as the number of "brews" is less than 16 or 20 there is a large fluctuating load on the refrigeration system. This makes it necessary to store refrigeration (or "cold"). From the point of cost of chilling there are several alternatives depending on the size of the brewery. Normally wort cooling is considered as a separate part of the refrigeration installation aiming to operate at the highest possible temperature to minimize energy costs.

2.7.1 Wort pre-cooling

An additional plate heat exchanger for wort pre-cooling from 98 °C down to e.g. 88 °C during casting into the whirlpool can be integrated. If raw materials are problematic or in the case of one specified total evaporation rate, this will reduce the thiobarbituric acid index (TBI) as compared to a process without wort pre-cooling. It can also be used to reduce renewed formation of dimethylsulphide (free DMS) in the wort [9]. Figure 2.9 is a simplified diagram of a wort boiling plant with an energy storage system and wort pre-cooling.

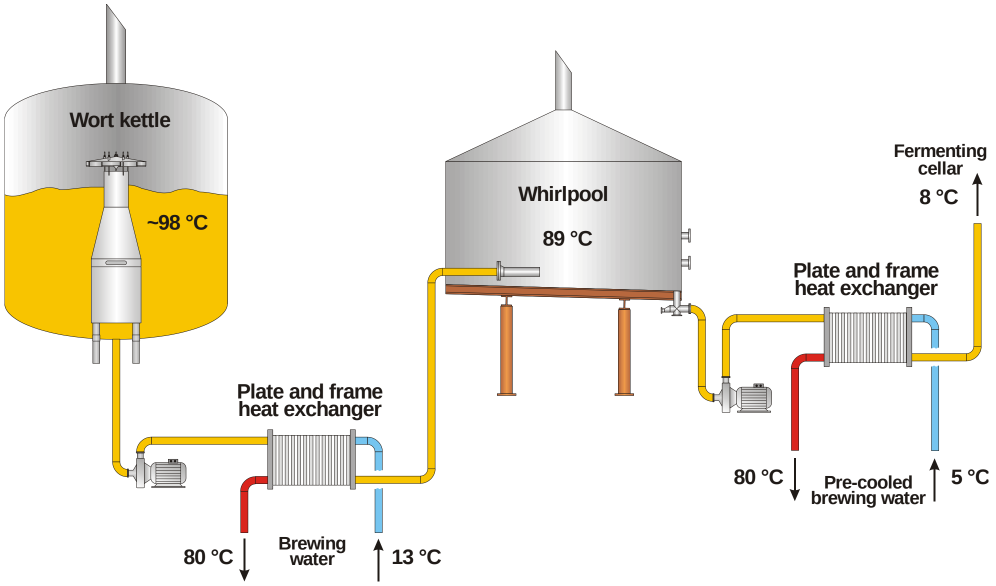


Figure 2.9: Wort boiling with an energy storage system and wort pre-cooling [8].

2.7.2 Single stage wort cooling

After hot trub separation in the whirlpool, the wort is preferably cooled to a temperature of 5°C to 15°C for bottom-fermented beers and to 15 to 18°C for top-fermented beers (pitching temperature). Apart from few exceptions, closed wort cooling systems are used today for cooling. Single-stage plate heat exchangers (PHE) are mainly used as wort coolers, but multi-stage (two/three-stage) versions of PHEs are also in operation [9]. Figure 2.10 shows an illustration of a single-stage PHE. Treated fresh water (=brewing water) is used for single-stage plate heat exchangers for bottom-fermented beer wort cooling; this fresh water is cooled in a cooling plant from the respective fresh water temperature to 3 to 5°C (pre-cooled brewing water) and stored in an insulated brewing water tank [9]. Cooling of the brewing water and filling of the brewing water tank can be implemented during low tariff periods with cheaper electrical energy.

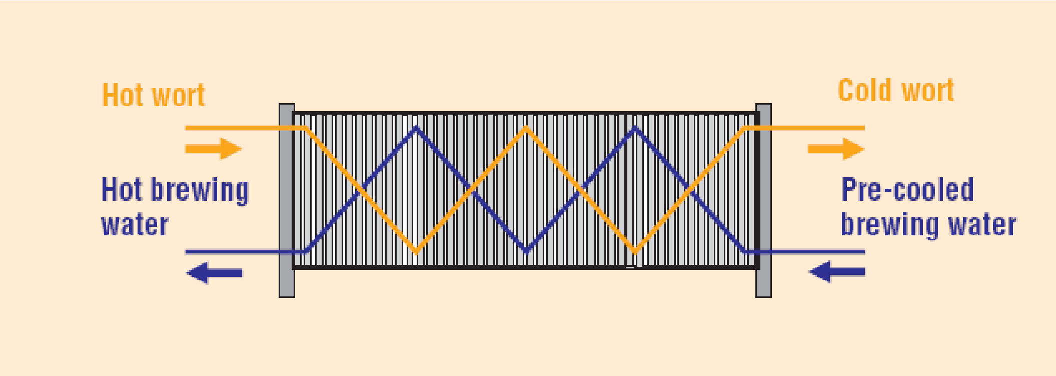


Figure 2.10: Structure of single-stage wort cooler [9]

Wort cooling must be completed for a brew within a maximum of 60 minutes to avoid increased thermal stressing of the wort. Single-stage plate heat exchangers must be designed in such a way that hot brewing water of at least 80°C is generated. Single-stage plate heat exchangers are also used for wort cooling of top-fermented beer.

2.7.3 Two-stage wort cooling

In two-stage wort cooling, the wort is cooled during the first stage of the PHE (pre-cooling section) using non-cooled brewing water. The second stage of PHE (post-cooling section) is either fed with ice water or another refrigerant (e.g. alcohol-water mixture), which is supplied from a heat-insulated refrigerant tank, see Figure 2.11.

Two important criteria for the design of the 1st stage of a plate heat exchanger are the so-called "liquid ratio" calculated from the quotient "heat intake of the brewing water per litre" by "heat delivery of wort per litre" and temperature difference between inlet temperature of the brewing water and transfer temperature of the wort from the 1st stage of the PHE to the 2nd stage.

The following conditions apply:

- Liquid ratio of brewing water to wort: 1.1 to 1.0
- Maximum temperature difference: 4k

Improperly designed pre-cooling sections lead to increased cooling requirements in the post-cooling section and therefore to higher costs for electrical energy. The same conditions apply to the cooling time for a brew and the temperature of the outlet hot brewing water as for the single-stage version.

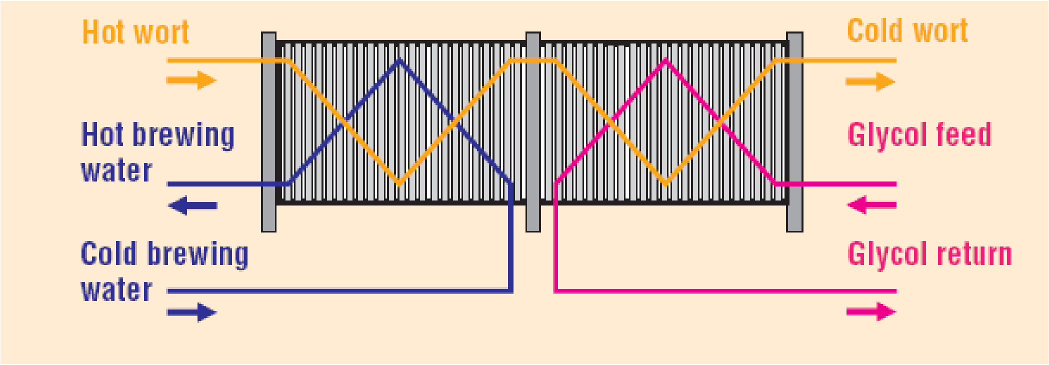


Figure 2.11: two- stage wort cooler with glycol post cooling [9]

2.7.4 Energy consumption during wort cooling/heat recovery

To minimize electrical energy consumption for the proportional provision of cooling using a compression cooling system for wort cooling, the following criteria must be observed, depending on the design of the plate heat exchanger.

The following applies to single-stage PHE:

- High brewing water outlet temperature from the PHE
- High pitching temperatures for the wort.
- Use of storage tanks with pre-cooled brewing water to minimize costs for electrical energy.

The following applies to two-stage PHE:

- Lowest possible wort transfer temperature from pre-cooling to post-cooling section
- Feed temperatures of secondary refrigerant (ice water) as high as possible in the PHE.
- Use of ice water storage systems to balance out peak electric power consumption during high tariff times and fill up the ice water storage tank using low cost electrical energy during low tariff times (only suitable for systems with long brew rhythms)

Table 2.7 shows a comparison of different single and two-stage wort cooling processes. These examples assume a cast wort volume (hot) of 1000hl to be cooled from 96 to 8^{o}C [9]. Treated, uncooled brewing water with a temperature of 13 ^{o}C is available for cooling. The operating refrigerant system uses screw compressors, ammonia as the refrigerant and evaporative condensers with an average condensing temperature of 28^{o}C. In a two-stage wort cooling setup using a refrigerant (e.g. glycol-water mixture) under the specified boundary conditions, proportional electrical energy consumption can be calculated for the refrigerating compressors of 203kWh per brew and 184kWh per brew for direct evaporation of ammonia in a separate plate unit [9].

The basic rule is that an increase in evaporating temperature of 1 Kelvin and constant condensing temperature reduces electrical energy consumption for the refrigerant compressor by approximately 3% [9]. Table 2.7 shows that the proportionate electrical energy consumption for a refrigerant compressor in a single-stage wort cooling process, where the evaporating temperature is -7 ^oC, is 238kWh(el) per brew. In refrigeration systems, which can be operated with two different evaporating temperatures, electrical energy of 192kWh per brew is used at an evaporating temperature of -1^oC [9].

Table 2.7: Comparison of single and two-stage wort cooling process [9]

Process refrigerant Temp. (t_0/t, ^oC)	Cooling Medium/ Refrigerant	Cooling med. Inlet temp. (^oC)	Volume BW (82^oC)	Cooling Demand (MJ/brew)	Electrical Energy (kWh$_{(el)}$/brew)
Single-stage (-7/28)	Brewing water	5	1167	4107	238
Single-stage (-5/28)	Brewing water	5	1167	4107	219
Single-stage (-1/28)	Brewing water	5	1167	4107	192
Two-stage (-7/28)	Glycol/H20	-4	3513		203
Two-stage (-5/28)	Ammonia	-5	3446		184

2.7.5 Cleaning-in-place (CIP)

Cleaning-in-place or CIP; is where production process equipment (vessels/tanks, pipe work, heat exchangers, valves etc) are cleaned by use of a mixture of detergent (NaOH or caustic, acid, etc) and water. The water may be cold or hot and the detergent is usually at low concentration. Cold detergents (caustic and acid) is used for cleaning of tanks and vessels, while hot caustic solution is used in cleaning of product pipes and PHEs used by product (wort cooler and wort pre-heater).

CHAPTER THREE

METHODOLOGY

In this chapter the methods used and the procedures followed are outlined, that includes the various types of tools used.

3.1 Data collection and evaluation

3.1.1 Energy data for process heating systems

The following data was obtained. Sources of the required data are given.

a) Power input ratings

Obtained motor input ratings and pump input ratings.

Data sources: equipment name plates, operating or instruction manuals, equipment drawings, vendor catalogs or other materials supplied by the vendor. Energy input ratings were expressed in a variety of units such as kW, kWh, MJ/hr, etc. The stated value was converted to metric (SI) unit, which is widely used in the plant.

b) Production rate.

Obtained daily, monthly and annual production throughput, i.e. number of brew produced in a given time duration (hl/hr, hl/month, etc), hot water and chilled water flow rates, steam flow rates, etc. These were obtained from: flow meters installed in the plant, plant process or production records, equipment name plates, operating or instruction manuals.

Production units and ratings were expressed in a variety of units such as hectoliter/hour, tonnes (U.S. or metric) per hour, etc.

c) Obtained various process temperatures for: wort at various stages of boiling and cooling, hot water, chilled water, energy storage tank, etc. The temperature readings were obtained by use of temperature sensors (PT100) or by use of glass and digital thermometers. These were expressed in conventional units such as degrees Celsius (°C) or Kelvin (K).

d) Energy use in terms such as kWh, kW/hl, MJ/hl or MW/year.

Obtained energy use at various processes i.e., wort boiling, wort cooling, wort pre-heater, vapour condenser, chilled water and energy storage tank.

Data sources: steam flow and mass meters, electricity energy meters, wort flow meter with counter/totalizer, plant process or production data, and from the vendor-supplied user manuals.

d) Energy cost per unit of energy expressed in units such as Ksh/kWh, any peak charges or demand charges, Ksh/liter of fuel oil, etc. The final cost was calculated to account for energy used and its total cost to the plant.

Data sources: Company monthly electricity bills, fuel oil delivery invoices, Utilities manager's records and accounting department for the plant or the company.

f) Other items included:

(i) type of energy use with appropriate information such as heating value for the type of energy source expressed in appropriate units

(ii) Number of operating hours per year, source of energy, pressure-temperature of the energy source (where applicable), etc.

Data sources: Equipment name plates, operating or instruction manuals, equipment drawings, plant process or production and operating personnel, standard handbooks, or contacts with the vendor/supplier.

Where individual meters were not available, energy use was estimated by using information on operating hours, percentage of the installed or designed equipment heat input rate and equipment up-time or load factor.

For continuous heating processes with little or no variations in loading, energy use was estimated relatively easily, because the different heating zones of the device tend to settle in at certain inputs and remain there. Batch-type operations normally experience wide variations in heating rate over the cycle. One way used to estimate was to check the input at regularly-spaced time intervals and average them over the entire cycle.

3.1.2 Operating Data Collection

For brew house batch processes additional data that was collected include operating cycles, cycle time, number of hours or production shifts the equipment operates, idling time and variations in load sizes and cycle temperatures.

3.1.3 Review of Utility Bills and Costs of Energy types

The utility bills were presented in many different formats and included many parameters such as energy use expressed in terms of kW/month, tonnes/month, etc. with additional charges of various types. The final cost was determined by totaling up all charges and dividing by the units of energy source used to get an average value for a specific period, such as monthly average utility cost. The monthly charges, in turn, were totaled up to get average annual utility rate. In some cases it was necessary to get projected rates.

3.2 Definition of data collection requirements and methods

3.2.1 Measurement, metering and diagnostic equipment used

The following list includes some of the instruments used for measuring and monitoring.

(a) Temperature measurements

For medium temperature (<300°C) process or product temperature measurement, an RTD (resistance thermometer detector), was used to measure temperature. This produced the most accurate results. These are made out of Platinum 100 (PT 100) which have linear temperature/resistance characteristics, and provide a good combination of sensitivity and fast response. Temperature gauges and glass thermometers installed on process lines were also used to estimate the process temperature.

(b) Pressure measurements

For process and steam pressures, a pressure measurement sensor was used. The pressure transmitter Cerabar M measures the pressure of the steam in the heating line of the wort kettle, and other process vessels/lines. Process pressure products range from 1- 15 bar. Fuel oil and compressed air and steam pressures range up to 7 barg or higher. Inexpensive pressure gauges are readily available and are widely used in the plant. They are generally not very accurate and are only used for indicative process pressure, unless they have been specifically calibrated for the assessment.

(c) Flow measurements
For steam supply and distribution, orifice meters and vortex shedding meters were commonly used. For product/process flow of liquids, magnetic flow meters were used. Magnetic flow meters were used where the fluid being measured is a conducting fluid. Mass flow meters were also used extensively in areas that accuracy was needed.

(d) Tank level measurement
For determining the amount of product in a tank, hydrostatic pressure method was used to measure the level or volume. The Endress + Hauser delta pilot level transmitter were used. This involved installing two pressure sensors on top of tank and one at the bottom. The difference in pressure level between the two sensors is a measure of the product level inside the tank.

3.2.2 Other data sources

The required data was derived from following sources.

- Data display on computerized process or equipment control system. For example, process temperature displayed on the computer screen was verified by using a reading of a thermometer located in the pipe work or inside a vessel near the sensor whose reading was displayed on the computer screen.
- Control panels installed near the equipment displaying various measured values. For example, furnace temperature displayed on the control panel.
- Instruments installed on the equipment (e.g., pressure gauge, temperature gauge, differential pressure gauge or manometer).
- Instruments installed or connected to the equipment, or probes especially for use during the assessment. Examples are flue gas analyzers, temperature or pressure probes, flow meters etc.
- Manufacturer supplied information (drawings, manuals, etc.)

Where existing instrumentation or process controls are used as data sources, care was taken to verify their accuracy. The same applies to manufacturers’ drawings, manuals and data sheets.

Process heating equipment is commonly altered over time, and the original documentation may no longer reflect the present construction of the equipment.

3.2.3 Operating conditions during study.

Process heating equipment can be operated at different rates, where the key process parameters could be different from their design values. The operating conditions selected during the study were as close as possible to the conditions at which the equipment is operated most of the time. Equipment operating history was also reviewed and used as a guide.

3.3 Analysis of data from the assessment

3.3.1 Data analysis and energy savings opportunities

Process heating uses energy or heat in a large variety of ways. Data collection, its analysis and energy savings calculations are very much dependent on the equipment and process used. Use of several sources was considered including recommendations from the equipment supplier. The results obtained by use of this method were used to identify energy savings, cost savings and ultimate acceptance or rejection of the suggested energy efficiency projects.

Energy savings opportunities identified in the study were based on considerations such as potential energy savings, practicality of application of the identified opportunity, its effects on other issues, etc. The payback analysis was decided based on available and reliable cost data, current and future business equipment operating predictions, etc. Interaction with the appropriate personnel, including team members was done to get performance data.

3.3.2 System data analysis

The assessment data analysis required “translation” of the raw data collected during the assessment into useful information such as;

- Steam energy input at wort kettle during dynamic low pressure boiling, with different flow settings.
- Recovered heat at vapour condenser and energy storage tank
- Heat transfer at pre-heater and the effect of fouling to its efficiency
- Wort cooling and electrical energy use to generate chilled water

- useful energy going into the product, heat lost in several areas (wall losses, opening losses, cooling, etc.).

The analysis method depended on the type of equipment (heat exchanger), process and degree of detail required. Calculation methods were developed using standard formulas, equations and graphs. Results of the analysis were presented in the form of a table or in pictorial form.

CHAPTER FOUR

RESULTS & ANALYSIS

In this chapter results of the study are presented. This study was carried out at Kenya Breweries Ltd (KBL), at Tusker Breweries plant in Ruaraka. The energy consumption for all the brew house processes of wort boiling, wort pre-heater, vapour condenser, wort cooling, energy storage tank, heat recovery from vapour condensate, chilled system and hot water tanks are discussed. Thermal energy used in the processes is tabulated and heat transfer calculations presented. Energy losses are identified and illustrated and energy conservation measures (ECMs) are suggested. Comparisons are made of measured energy consumption for wort boiling vs. calculated values based on actual plant performance.

4.1 Energy consumption figures at the study plant

Table 4.1 shows site ward energy consumption of energy for a period of two years i.e. 2010 and 2011 [3]. The table follows the KBL financial year which runs from July to June. For example financial year 2010 (F10), runs from July 2009 to June 2010. It shows production in hectolitres (hl) and corresponding energy use of heavy fuel oil (HFO) for the boilers in MJ, and electricity in kWh. The table shows monthly production of beer in hectolitres and energy consumption (both electricity and fuel energy) for the two years. Monthly energy consumption figures for the two years are tabulated, and the total energy use per year, for the two years is shown. Both monthly and annual energy index (in MJ/hl) are also shown for the two years.

Energy consumption has been converted to energy units of MJ using the following conversions where the total energy is shown in the last column in MJ/hl.

1 kWh = 3.6 MJ Electricity energy
1 litre of HFO = 42.67 MJ fuel energy (Grade 180)

Annual production in year 2010 was 4.48 million hectolitres. The production for year 2011 was 4.55 million hectolitres of beer, which was a 2% increase over year 2010 [3]. The

Overall energy consumption (fuel energy and electricity) for the site in year 2010 was 697,851,015 MJ. The energy consumption dropped to 676,657,925 MJ in year 2011, which represented a 3% drop. This drop was noticeable for both electricity and fuel energy in the same year.

Table 4.1: Two year Energy consumption profile (HFO and Electricity), at study plant [3]

Month	**Monthly Production (hl)**	**Heavy fuel oil (litres)**	**Fuel-energy (MJ)**	**Electricity energy (kWh)**	**Electricity energy (MJ)**	**Total site energy (MJ)**	**HFO Energy intensity (MJ/hl)**	**Electricity Energy intensity (MJ/hl)**	**Total energy intensity (MJ/hl)**
Jul-09	350,425	1,031,639	44,020,036	3,703,687	13,333,272	57,353,308	125.62	38.05	163.67
Aug-09	392,217	1,130,669	48,245,646	4,061,864	14,622,712	62,868,358	123.01	37.28	160.29
Sep-09	370,459	1,050,818	44,838,404	3,991,322	14,368,761	59,207,165	121.03	38.79	159.82
Oct-09	395,247	1,058,795	45,178,783	3,618,992	13,028,369	58,207,152	114.31	32.96	147.27
Nov-09	395,601	1,114,950	47,574,917	3,824,083	13,766,699	61,341,615	120.26	34.80	155.06
Dec-09	378,727	1,002,090	42,759,180	3,445,536	12,403,929	55,163,110	112.90	32.75	145.65
Jan-10	362,004	1,042,291	44,474,557	3,403,905	12,254,057	56,728,614	122.86	33.85	156.71
Feb-10	335,809	973,884	41,555,630	3,354,120	12,074,832	53,630,462	123.75	35.96	159.71
Mar-10	389,087	1,103,314	47,078,408	3,625,240	13,050,864	60,129,272	121.00	33.54	154.54
Apr-10	377,422	1,121,188	47,841,092	3,539,179	12,741,045	60,582,137	126.76	33.76	160.52
May-10	388,444	1,129,923	48,213,814	3,699,618	13,318,626	61,532,440	124.12	34.29	158.41
Jun-10	345,460	918,766	39,203,745	3,306,566	11,903,636	51,107,381	113.48	34.46	147.94
Jul-10	396,882	1,059,434	45,206,049	3,407,525	12,267,088	57,473,137	113.90	30.91	144.81
Aug-10	370,283	978,656	41,759,252	3,547,529	12,771,105	54,530,356	112.78	34.49	147.27
Sep-10	428,496	1,144,084	48,818,064	3,851,960	13,867,056	62,685,120	113.93	32.36	146.29
Oct-10	421,175	1,080,135	46,089,360	3,839,177	13,821,036	59,910,396	109.43	32.82	142.25
Nov-10	396,282	1,098,555	46,875,342	3,828,504	13,782,614	60,657,955	118.29	34.78	153.07
Dec-10	398,337	950,591	40,561,718	3,435,360	12,367,296	52,929,014	101.83	31.05	132.87
Jan-11	370,694	1,039,128	44,339,592	3,544,690	12,760,884	57,100,476	119.61	34.42	154.04
Feb-11	348,022	885,561	37,786,888	3,047,057	10,969,406	48,756,294	108.58	31.52	140.10
Mar-11	357,197	987,162	42,122,203	3,034,070	10,922,652	53,044,855	117.92	30.58	148.50
Apr-11	370,377	1,069,353	45,629,293	3,620,609	13,034,193	58,663,485	123.20	35.19	158.39
May-11	374,037	1,032,766	44,068,125	3,620,609	13,034,193	57,102,318	117.82	34.85	152.66
Jun-11	319,350	986,353	42,087,683	3,254,676	11,716,835	53,804,518	131.79	36.69	168.48
SUM F10	4,480,901	12,678,327	540,984,213	43,574,112	156,866,802	697,851,015			
SUM F11	4,551,131	12,311,778	525,343,567	42,031,766	151,314,358	676,657,925			
AVG F10	373,408	1,056,527	45,082,018	3,631,176	13,072,233	58,154,251	121	35	156
AVG F11	379,261	1,025,982	43,778,631	3,502,647	12,609,530	56,388,160	116	33	149

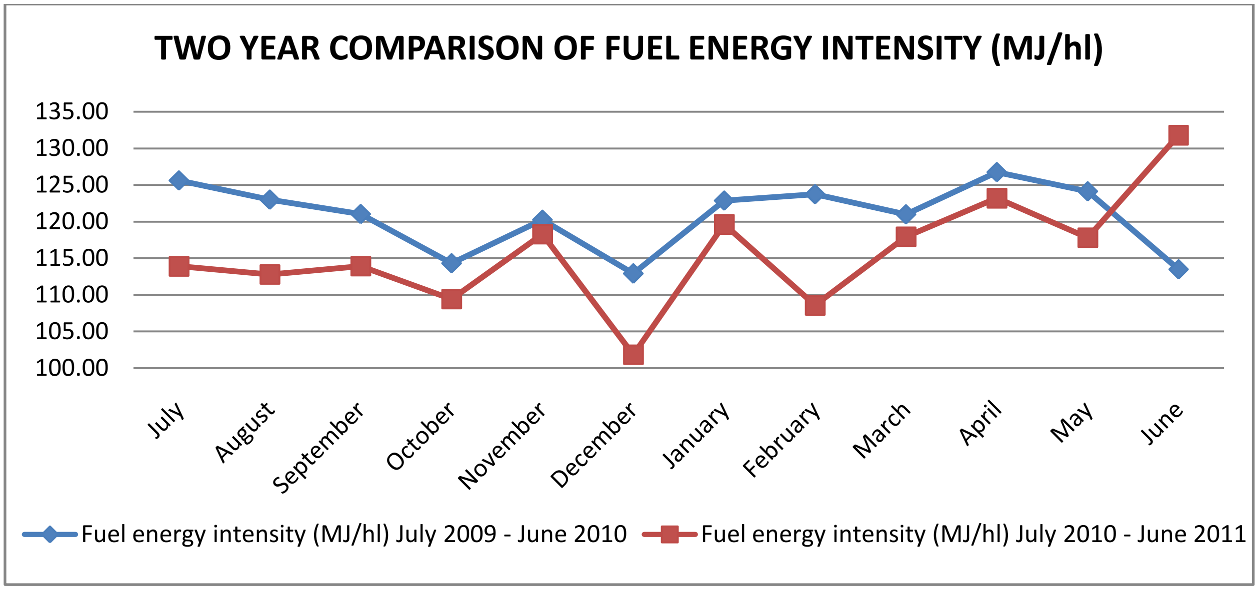


Figure 4.2: Two year comparison of fuel energy intensity

Figure 4.2 shows the monthly fuel oil energy use per hectolitre of beer produced. In 2010 for every hectolitre of beer produced, 121 MJ of fuel energy was used. This translated to 45,082,018 MJ monthly average of fuel energy used in that year. In 2011, there was a reduction of average fuel energy consumed with increased production at the study plant. For every hectolitre of beer produced, 116 MJ of fuel energy was consumed. This was equivalent to monthly average of 43,778,631 MJ, of fuel energy. From the monthly average, daily fuel energy for year 2010 was 1,502,734 MJ or 417,426 kWh and 1,459,288 MJ or 405,358 kWh in year 2011.

<u>To determine the utilization of steam capacity at study plant</u>

Monthly average of fuel energy in year 20112473

was 43,778,631MJ, equivalent to 12,160,731kWh

Steam raised by 1kWh of energy [10] = 1.1 kg

Actual monthly steam consumed = $\frac{12{,}160{,}731 \text{ x } 1.1}{1000}$ = 13376.8 tonnes of steam

Capacity of three steam boilers at study plant = 48 tonnes/hr

Monthly capacity = 48 x 24 x 30 = 34560 tonnes

Utilization = 13376.8/34560 = 0.387, or 38.7%

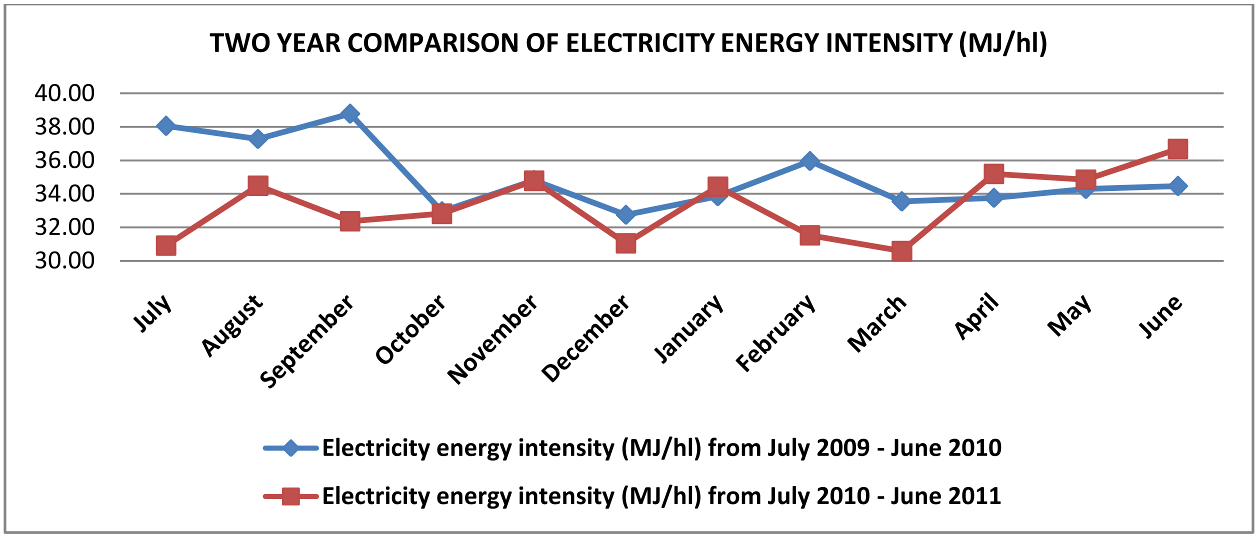


Figure 4.3: Two year electricity energy intensity monthly trends

Figure 4.3 shows a relationship of electricity energy intensity trends for two years. In the year 2010, it took an average 35.04 MJ of electricity per month to produce one hectolitre of beer. This translated to a monthly average consumption of 13,072,233 MJ of electricity in that year. The average monthly electricity consumption value for the year 2011 was 33 MJ for every hectolitre of beer produced. This translated to a monthly average of 12,609,530 MJ of electricity.

In both the HFO and electricity use trends, there are significant variations observed in the energy intensities due to variations observed in monthly production of beer for the two years.

The total energy use intensity trend for two years is captured in figure 4.4. In the year 2010, the total monthly average energy used per hectolitre of beer produced was 155.8 MJ/hl. It was 149.1 MJ/hl in 2011, which represents an average drop of 6.74 MJ/hl or 4.3%. The total combined energy (HFO and electricity) used for the year 2010 was 697,851,015 MJ, while that of the year 2011 was 676,657,925 MJ. There was a drop of 21,193,089 MJ of energy used in 2011. This represents 3% drop of total energy and was attributed to low energy use on both HFO and electricity. Electricity contributes 22% of the total energy in both years.

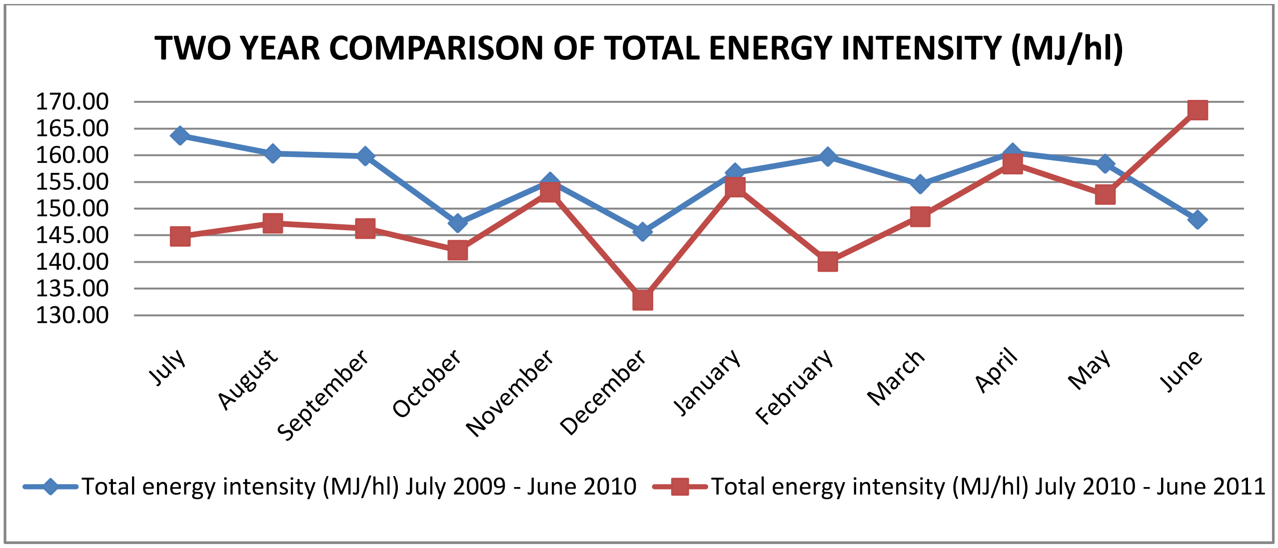


Figure 4.4: Two year total energy intensity (HFO and electricity) monthly consumption trend

4.2 Steam boiler plant

The steam generating plant has four steam boilers arranged so that they feed steam to a common header. Three boilers are rated at 18 tonnes/hr and the 4th one is rated at 12 tonnes/hr. For 3 years that covered the study period, one of the 18 tonnes/hr boilers has been on major overhaul. Hence, only 3 boilers are run at any particular time with total capacity of 48 tonnes/hr.

Saturated steam is generated at approximately 9 bar. The duty and sequence of operation for each boiler is automatically controlled. Depending on the steam demand, the boilers will be fired in sequence to meet the load. Modulation controls are set to operate between 8.5 and 9.5 Bar. Hence when one or two boilers are in operation and the outlet steam pressure goes below 8.5 bar gauge, then the 3rd boiler is fired to meet the load demand. Each individual boiler (boilers no 1-3) will be on duty 1 for one week, in a rotating schedule.

Total capacity of boilers = 48 tonnes/hr

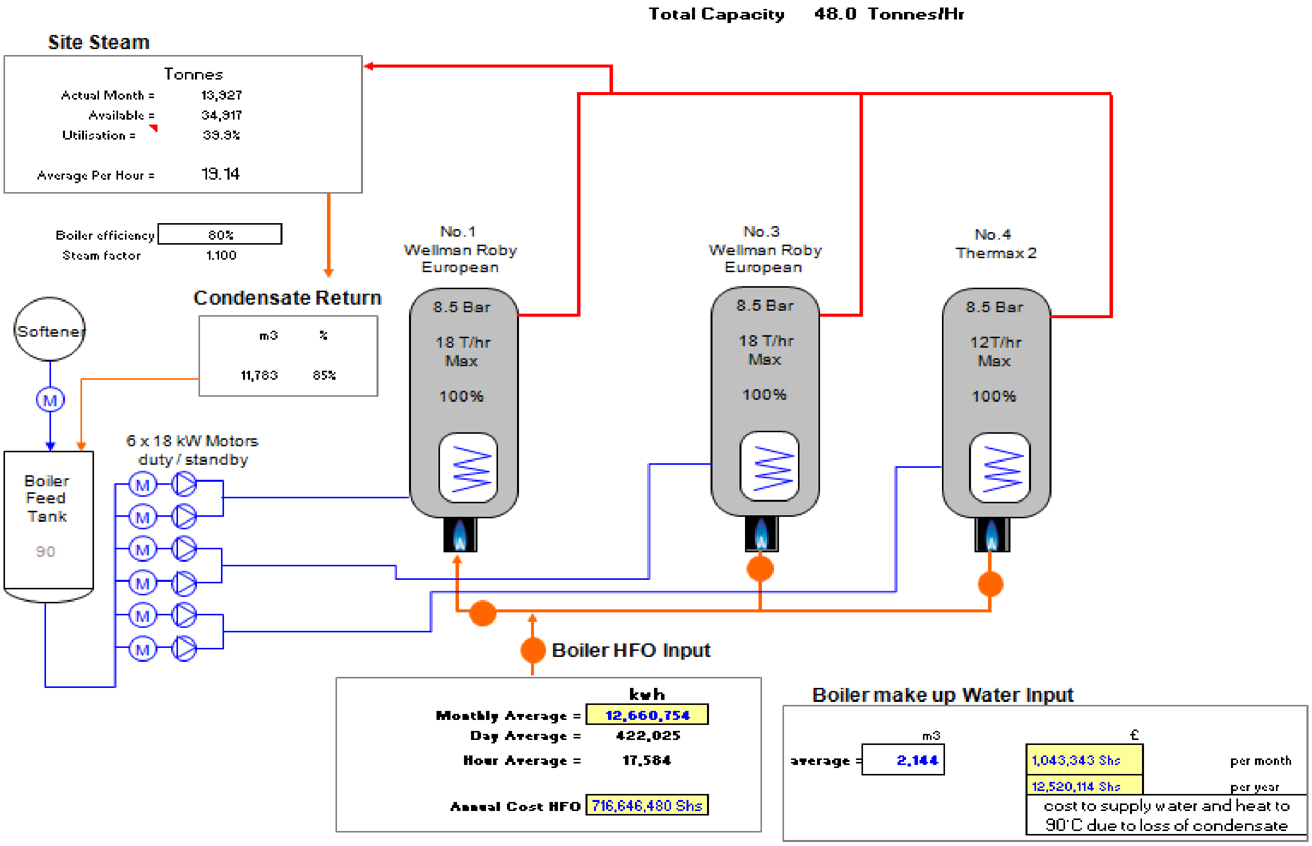


Figure 4.5: Illustration of Boiler layout and its interconnected system [10]

Figure 4.5 shows the illustration of interconnection of the three boilers at the study plant. The values illustrated are from Camco audit report done at the boiler plant in 2009 [10]. Boiler feed water is from a feeding tank that contains recovered condensate and make up water. Makeup water is from the water softener plant near the boiler room. Boiler feed water is fed to a common line to supply all the boilers. All the boilers have level monitoring system through sensor detection that ensures that required water level in the boilers is maintained.

The water is fed through an automatic system comprising a control valve and a pump. The temperature of the feed water is about 85 °C. Heavy fuel oil is fed to the boilers from the bulk storage tank that is situated approximately 40 meters from the boiler room. For safety of personnel and equipment, the tank is situated in an isolated area that is free from any human activity. It is pumped to a small holding tank from where it is fed to the boiler furnaces.

4.2.1 Steam distribution system

The Steam that is generated from the three boilers is channelled to a common header, from where it tapped and distributed to several user points in Brewing and Packaging.
Steam distribution to Packaging is through four main lines, supplying four different beer packaging lines. Three of these are bottled beer lines and the fourth is for packaging keg barrels. The main application of steam in packaging plant is for Bottle washer and pasteurizing machines, through heat exchangers.

The main application of steam in Brewing is heating of product through heat exchangers. The products involved are wort, water and heating of detergents used for cleaning (CIP) of beer lines or vessels. These vessels used for process are equipped with steam coils/jackets. Steam is passed through the jacket and heat is passed to the product being processed. The temperature of the product is raised as per the requirement. Some of the vessels are wort kettles, mash tun vessels, hot water storage tanks etc. In the plate heat exchangers, steam is used to heat detergents and process hot water and storing in a storage tank. Other application for steam in Brewing is at the yeast drier, which is a machine for drying wet/liquid yeast by use of steam. The dried yeast is then crushed/milled and packaged in to 60kg packets and sold as animal feed.

4.2.2 Condensate Return

The amount of condensate return was calculated based on the difference between the boiler feed water and the makeup water usage (in cubic meters) from the softener plant. The result was tallied in Table 4.2. The Data was taken for a period of one month from 19th Sept, 2010 – 18th Oct, 2010 [11]. The monthly percentage for condensate contribution was tabulated.

Table: 4.2: Distribution of boiler feed water (BFW) [11]

Water Meters	Unit	Reading 1 19/09/2010	Reading 2 18/10/2010	Monthly Usage	Daily Total
Boiler 1 Feed Water	m³	178,636	189,190	10,554	352
Boiler 2 Feed Water	BOILER ON OVERHAUL				
Boiler 3 Feed Water	m³	33,151	38,671	5,520	184
Boiler 4 Feed Water	m³	458,918	461,950	3,032	101
Total Boiler Feed Water	m³				637
Softener Makeup Water	m³	104,597	106,741	2,144	71
Condensate Return	%				**89%**

$$\% \text{ condensate return} = \frac{(\text{Total Boiler Feed Water} - \text{Softener Makeup Water})}{\text{Total Boiler Feed Water}} \text{ x } 100\%$$

$$\% \text{ condensate return} = \frac{(637 - 71) \text{ x } 100\%}{637} = 88.9\%$$

On average condensate contributes 85-90% of total boiler feed water.

4.2.3 Estimation of boiler blow down

All steam boilers must blow down to reduce the amount of total dissolved solids (TDS) in the boiler water [12]. Continuous Blow down is done automatically on all the boilers. The thermal energy in the blow down water is not recovered. Blow down is set for all the boilers at 3000ppm. The controls system tries to maintain the TDS level below 3000ppm.

The quantity of blow down required to control boiler water solids concentration is calculated by using the following formula [12]:

$$\text{Boiler BD } \% = \frac{\text{Feed water TDS x } \% \text{ Makeup water}}{\text{Max permissable TDS in boiler water}}$$

Measured Feed water TDS (from softener plant) = 180 ppm

Percentage of Makeup water is = approx 15% (of BFW)

$$\text{Hence BD } \% = \frac{180 \text{ x } 15}{3000} = 0.9\%$$

The Selected Boiler capacity (from specification) is 18000kg of saturated steam per hour.

$$\text{Hence Blow down rate at full load} = \frac{18000 \text{ x } 0.9}{100} = 162 \text{ kg/h}$$

4.3 Measured results on steam energy utilization

4.3.1 Energy used when steam supply flow is changed

Table 4.3 represents the data with normal settings for the steam flow control valve (see FCV1, Fig 2.7), during the pressuring and depressurizing peaks. The valve was set to open at 50% during pressurizing phase and 22% during depressurizing phase. The valve automatically controls to the set target (e.g. 22% and 50%) with a signal from the programmable logic controller (PLC). The PLC uses mathematical algorithms and PID (proportional, integral and derivative) values to determine the actual signal sent to valve.

Table 4.3: Energy consumed at wort boiling with steam valve settings of 22% and 50%.

BRAND	BRAND REF no	VOLUME OF BATCH (hl)	TYPE OF WORT BOILING (LPB or AB)	ACTUAL MASS OF STEAM CONSUMED (Kg) PER BATCH	ACTUAL STEAM ENERGY USED (MWh) PER BATCH	MASS OF STEAM PER UNIT VOLUME Kg/hl	ENERGY PER UNIT VOLUME (kWh/hl)
TUSKER	1849	589	AB	13962	10.72	23.7	18.2
SENATOR	1991	495	LPB	7202	5.51	14.5	11.1
TUSKER MALT LAGER	2007	543	LPB	7972	7.98	14.7	14.7
BELL	1852	541	LPB	6099	4.74	11.3	8.8
BELL	1853	526	LPB	7190	5.53	13.7	10.5
GUINNESS	1855	464	LPB	8521	6.55	18.4	14.1
TUSKER	1869	591	LPB	7886	6.05	13.3	10.2
SENATOR	1867	502	LPB	6810	5.22	13.6	10.4
SENATOR	1871	537	LPB	7008	5.39	13.1	10.0
MALTA GUINNESS	1988	512	LPB	8832	6.76	17.3	13.2

From Table 4.3, it can be noted that brand TUSKER with reference no. 1849 has the highest steam consumption than the rest i.e. 10.72 MWh of steam heat energy. This is because it was subjected to atmospheric only boiling for the entire boiling phase. Comparing this with a similar product, brand TUS with reference no.1869 (with almost same batch volume) which had a steam consumption of 6.05 MWh of steam heat energy. For the two similar brands TUSKER 1849 and 1869, steam heat energy used per unit volume of wort was; 18.2 MWh/hl and 10.2 MWh/hl respectively. The batch on atmospheric boiling used 8.0 MWh/hl more heat energy than a similar batch on low pressure boiling. This represents 78.4% more energy consumed.

From section 4.1, the average daily steam supply from boiler house in 2010 was 405.4 MWh. From Table 4.3, the batch on atmospheric only boiling took 10.72 MWh of steam energy. In one day with 20 brews, the energy consumed per day would be 10.72 x 20 = 214.4 MWh.
As a percentage of total steam generated per day, this is 52.8%.
From table 4.3, the average steam consumption for the brews done on low pressure boiling (LPB) was 6.0 MWh. In one day with 20 brews produced, the total consumption at wort kettle will be 6 x 20 brews = 120 MWh. As a percentage of total steam generated per day, this is 29.6%. Hence atmospheric boiling consumes an additional 97 MWh of steam energy per day compared with low pressure boiling.

One of the key reasons for using Atmospheric boiling is that it shortens the process idle times and hence more batches (brews) are produced in a given day compared with LPB. Whereas this satisfies the production demand, the energy costs associated are enormous. The steam consumption by each individual brand still varies from brew to brew due to the variations in the volumes (brew lengths) in brew house, which has a direct effect on evaporation rates attained.
To avoid atmospheric boiling as a result of fouling, CIP of the wort pre-heater must be done after the recommended eight brews are processed. CIP should be considered as part of normal production and not as an activity that can be postponed. This will ensure minimum steam usage for wort boiling, as the recovered energy from wort boiling will be used to pre-heat the wort.

Table 4.4 represents the data collected after varying the steam control valve during pressurizing and depressurizing peaks, for each vessel. The valve was set to open at 40% during pressurizing peak and 20% during pressure release (depressurizing). Data was then collected for each batch (brew) processed.

Table 4.4: Energy use with steam control valve setting at 20% and 40%

BRAND	BRAND No.	BATCH VOLUME (hl)	WORT KETTLE IN USE	WPH / WK INLET TEMP (^oC)	ACTUAL MASS OF STEAM USED IN kg PER BATCH	ACTUAL STEAM HEAT ENERGY USED (MWh) PER BATCH
TUSKER	2965	567	1	85	8785	6.75
PILSNER	2974	468	1	86	6730	5.18
GUINNESS	2976	509	2	86	8765	6.74
PILSNER	2975	503	1	90.3	6352	4.8
GUINNESS	2963	504	2	90.3	5892	4.03

As expected, the data compiled in table 4.4 clearly shows that with lower settings of the steam control valve for each vessel, there is less consumption of steam compared to table 4.1. Less steam energy will translate to low evaporation rates, which ultimately have an effect on the amount of recovered heat energy at the vapour condenser. There has to be a balance between amount of steam supply to wort kettle and the recovered heat at vapour condenser, otherwise the energy storage water may not be able to pre-heat wort to the required 92-93^oC at the pre-heater.

Table 4.4 shows the temperature of pre-heated wort ranging from 85^oC to 90.3^oC. Hence, the overall steam energy supplied per brew at the kettle has to be higher to compensate for this low wort temperatures from pre-heater i.e. up to 8785 kg mass of steam used at wort kettle.
It can also be noted that when we attain high wort temperatures at the pre-heater, the steam consumption at the wort kettle is less than when we attain low wort temperatures at pre-heater.

4.3.2 With pre-heater out of service

If the pre-heater is not cleaned regularly (by CIP) then fouling will build on the pre-heater PHE which has the effect of reducing heat transfer. This has a negative impact on the pre-heater efficiency. To improve the efficiency, the pre-heater has to be unboxed and manual cleaning of the plates is carried out. This may take up to four days depending on the extent of fouling. When the pre-heater is out of service (bypassed), there is no wort pre-heating, and direct steam energy at the kettle is then used to raise the temperature of wort from 72^oC to 95^oC at the wort kettle, with atmospheric boiling.

Figure 4.8 shows a model representation of the pre-heater that will be used for heat transfer determination for all heat exchangers.

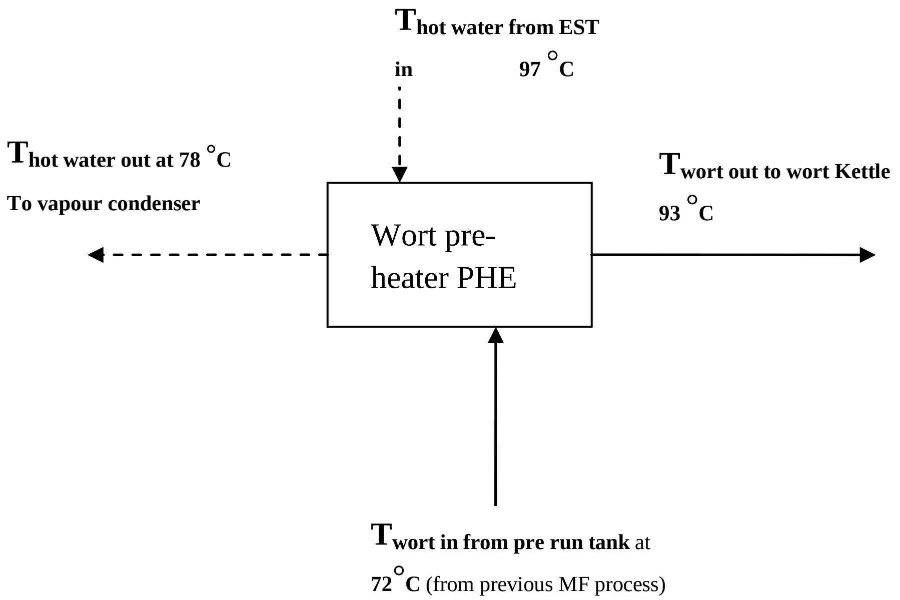


Figure 4.8: Model block diagram of wort pre-heater plate heat exchanger (PHE)

Table 4.5: Energy use at wort kettle when pre-heater is bypassed

BRAND	BRAND No	WORT KETTLE IN USE	ACTUAL MASS OF STEAM USED (kg) PER BREW	ACTUAL STEAM HEAT ENERGY USED (MWh) PER BREW
TUSKER	3032	1	10084	8.19
TUSKER	3033	1	9287	7.28
SENATOR	3036	2	9730	8.03
GUINNESS	1854	1	9280	7.12
GUINNESS	1856	1	10271	7.89
SENATOR	1865	1	9980	6.89
SENATOR	1868	1	11103	9.3
SENATOR	1870	2	9880	7.6

This means more steam energy will be used, as a result of atmospheric boiling which is carried out when pre-heater is bypassed or out of service. Also no more energy can be recovered from wort boiling and energy storage system will not be in use. Table 4.5 above represents data taken for various brews produced, when the pre-heater is out of service or bypassed. As can be seen the highest steam energy use recorded i.e. 11,103 kg (for Senator Brand), occurred when the pre-heater was not in use. This represents close to 3,000 kg (or 42%) more steam consumption per brew, when the pre-heater is bypassed compared to consumption data on Table 4.3, for Senator Brand. Thus bypassing the wort pre-heater or utilizing it at low efficiencies increases the steam consumption for the wort boiling process. This can be avoided by regular cleaning (CIP) of the pre-heater. The recommended cycle of cleaning from the equipment supplier is after 8 brews.

4.3.3 Performance of wort Pre-heater

A determination of wort Pre-heater efficiencies at the different temperatures attained during normal operation was made. The temperatures used were for wort receiver holding temperature (pre-run tank), wort kettle filling (wort pre-heater outlet) temperature and energy storage upper temperature.

Table 4.6: Determination of pre-heater efficiencies from temperature and effect of CIP

Brand	Batch ref no	Batch Volume (hl)	Batches (or brews) done after last CIP	Pre-heater wWort Temperatures		Energy storage Tank Temperature
				Inlet (T_2') °C	Outlet (T_2'') °C	
GUINNESS	2326	506	1	75.3	89.7	92
SENATOR	2327	506	2	75.4	77.6	92
PILSNER	2328	463	3	75.6	91.3	92
SENATOR	2329	500	4	75.9	92.3	88
GUINNESS	2330	472	5	75.3	77.8	92.1
SENATOR	2331	528	6	75.6	78.1	90
GUINNESS	2332	464	7	75.5	77.8	92

Table 4.6 shows batches produced at different times with consideration given to when the last CIP of the pre-heater was done. The wort outlet temperature T_2'' is an indication of the efficiency of the pre-heater. High T_2'' temperature signifies that the pre-heater is not clogged due to fouling. Lower T_2'' values indicate lower pre-heater efficiencies and deterioration of heat transfer due to fouling. As shown in table 4.6, highest efficiency is on the 3rd and 4th batches produced after last CIP (i.e. PILS 2328 and SEN 2329). From the 5th to 7th batch, wort outlet temperature T_2'' drops and stays at around 78°C, signifying that heat transfer efficiency of the pre-heater has dropped due to fouling of the PHE plates. The target for CIP is after 8 brews/batches are processed. From

wort outlet temperatures (T_2'') shown in Table 4.6, CIP target of 8 brews should be reduced to 5 brews, to maintain high efficiencies required at the pre-heater.

<u>Effect to Production of reducing Pre-heater CIP targets from eight to five</u>

Reduction of CIP targets from eight to five will have an impact on the daily production throughput at brew house. CIP of pre-heater takes about an hour. In 24 hrs the target production is 20 brews as per current capacity.

With the current target of CIP after 8 brews;
In one day, 20/8 = 2.5 CIPs are done.
If target is changed to CIP after 5 brews;
In one day this is equivalent of 20/5 = 4 CIPs done.
The difference is 1.5 CIPs more, will be required per day.

The pre-heater CIP cycle takes about an hour; hence the additional time required for CIP will be 1.5 hrs.

24 hrs = 20 brews

For 1.5 hrs = $\frac{1.5 \text{ X } 20}{24}$ = 1.25 brews lost in a day

This will have to be hived off the normal production plan/targets. In terms of production loss in a month this is equivalent to loss 39 brews, and in a year this translates to 468 brews. Hence, whereas it saves energy to have high pre-heater efficiencies when CIP is done after 5 brews, a production loss of 39 brews in a month is quite huge to contemplate. As a start the CIP target can be revised to 7 brews and the performance of pre-heater monitored.

When the pre-heater is bypassed there is no energy recovery from wort boiling. Since there is no pre-heating, all the energy required to raise the temperature of the wort at the kettle must come directly from steam supply. This means high steam consumption at the wort kettle. There will be no recovery of energy from the vapour condenser, as none can be utilized by wort pre-heater, and atmospheric boiling will have to be done. The impact of this to the wort kettle is that the steam consumption at the kettle tends to be high by an additional 26 MWh of steam energy per day (from calculation values in section 4.4.3). In section 4.4.3, an analysis of energy loss when the pre-heater is out of service is outlined, with cost implications.

4.4 Estimate of energy loss with wort pre-heater out of service

Abbreviations

T_s= temperature of steam

T_w= Temperature of wort

T_{hw}= Temperature of hot water

T_{cw}= Temperature of cold water

T_c= Temperature of condensate at vapour condenser

T_{oil}=Temperature of Heavy Fuel Oil

$\rho_{w=}$ Average density of wort (before boiling) = 1054 kg/m^3

Average density of wort (after boiling) = 1065 kg/m^3

$\rho_{s=}$ Density of steam

C_{ps}= Specific heat of steam

C_{pw}= Specific heat of wort = 3.98kJ/kg°C

$C_{p\ oil}$= Specific heat of Heavy Fuel Oil

m_s=Mass flow rate of steam

m_w=Mass flow rate of wort

VC = Vapour condenser

Q= Energy flow rate

Latent heat of evaporation for water = 2257 kJ/kg [15]

Assumptions

- There is no heat loss of steam in the system or surrounding on the heat exchangers
- Highest temperature attained after pre-heating is 93 °C.
- Constant volumetric and mass flow rates.
- Constant pressure of steam at 7 bar.

Brew size

The average size of a brew before boiling in the wort kettle, is 530hL

The actual evaporation rate during dynamic low pressure boiling (DYN LPB) is approximately 8%, based on full kettle wort volume. Water in the wort will evaporate after boiling.

The volume evaporated = 8/100 x 530 = 42.40 hl

Therefore volume at end of LPB = 530 – 42.40 = 487.6 hl

Sugar extract (solution) is added to the wort at the end of LPB. The amount introduced is normally dependent on the brand being produced (brewed). Wort is then transferred to the next stage of production – wort cooling.

4.4.1 Heat transfer of various heat exchangers

a) Wort pre-heater

To find the heat energy required to raise the temperature of wort from 72°C to 93°C, using hot water from the energy storage tank (EST), consider the block diagram below.

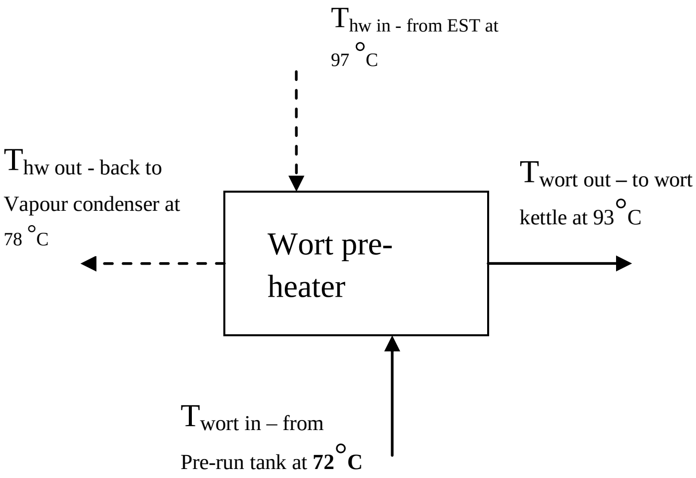


Figure 4.9: Block diagram of wort pre-heater plate heat exchanger (PHE)

$T_{w\ in}$ = 72°C

$T_{w\ out}$ = 93°C

C_{pw} = 3.98 kJ/kg°C

Density of wort, ρ_w = 1054 kg/m^3

Volume of wort per batch = 530hL = 53m^3

Therefore mass of one batch of wort = ρ_w x V

= 1054 x 53 = 55,862 kg

Heat transfer required [14], Q = $m_w C_{pw} \Delta T$

= 55,862 x 3.98 x (93–72)

= 4669 MJ

b) <u>Internal boiler at Wort Kettle</u>

For fluids, heat conduction, energy storage, motion and mixing of fluid at different temperatures result in net transfer of internal energy from one zone to another [13]. Saturated steam is supplied at a pressure of approximately 7 bar, from the engine room.

For LPB, the wort temperature reaches an average of 102.5°C.

Volume of wort evaporated at an evaporation rate of 8% was found to be 42.4 hl.

Mass of 42.4 hl = 1054 x 4.24 = 4,469 kg

Latent heat of evaporation of water = 2257 kJ/kg [15]

Heat quantity required to evaporate 42.4 hl is given by;

Q = 4,469 kg x 2257 kJ/kg

= 10,086 MJ

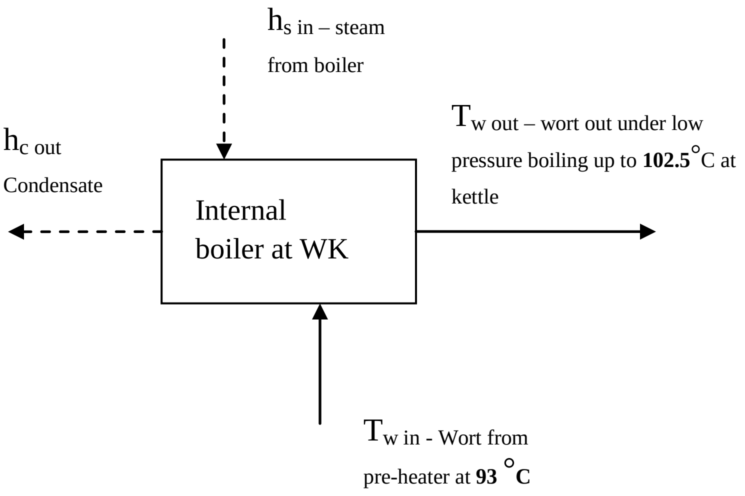


Figure 4.10: Block diagram of wort kettle internal boiler (shell & tube heat exchanger)

Heat energy from steam required to raise wort at a temperature of 93°C to 102.5°C, is given by

$$Q = m_w C_{pw} \Delta T$$

$$= 55{,}862 \times 3.98 \times (102.5-93)$$

$$= 2{,}112 \text{ MJ}$$

c) <u>Vapour condenser</u>

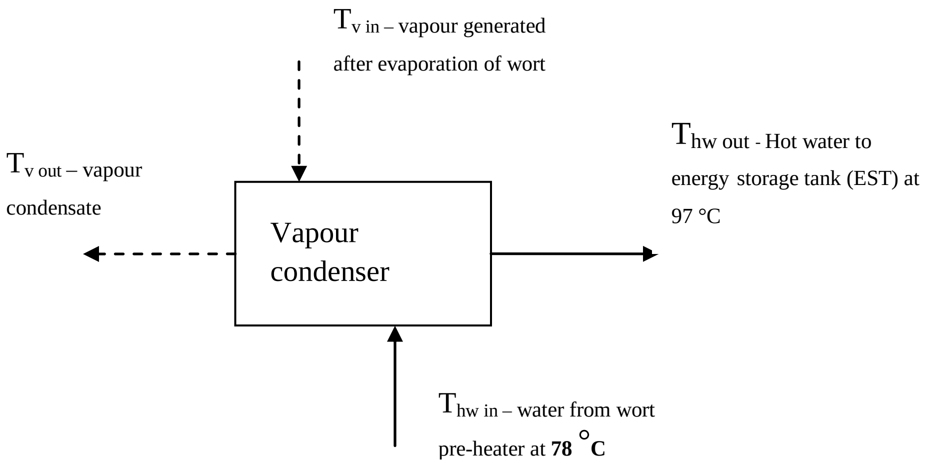


Figure 4.11: Block diagram of vapour condenser shell & tube heat exchanger

Heat required to raise 1 kg of hot water from the energy storage tank, at 78°C to 97°C is given by;

4.2 x (97-78) = 79.8 kJ/kg

Assuming the volume of hot water generated at vapour condenser per one brew is approx 300 hl.

Mass of 300hL of water = 30000 Kg

Hence Heat required = 30000 x 79.8

= 2,394 MJ

d) Vapour condensate heater

Condensate from the vapour condenser is routed to heat cold water through a heat exchanger, where cold water at room temperature is raised to 75-80°C. This water is transferred to the hot water tank.

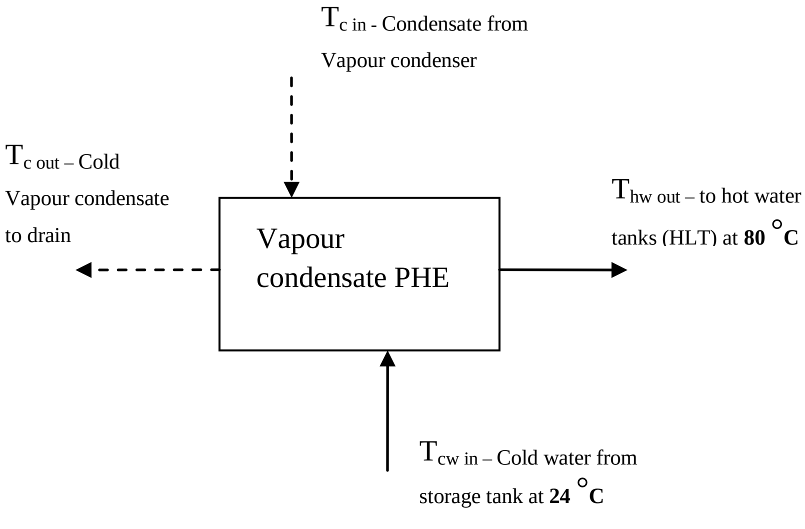


Figure 4.12: Block diagram of vapour condensate cooler heat exchanger

Heat transfer for 1kg of cold water $Q = (m_{w\ out} \times Cp_{w\ out} \times \Delta T)$

$= 1 \times 4.2 \times (80-24) \quad = \quad 235.2$ kJ/kg

Assuming the volume of hot water generated by condensate at vapour condenser per one brew is approx 150 hl

Mass of 150hL of water = 15000 kg

Hence Heat required = 15000 x 235.2
= 3,528 MJ

4.4.2 Efficiency of energy storage system

Heat generated due to evaporation of wort during boiling is used to heat water at energy storage tank to 97 °C. This hot water is utilized at the wort pre heater to raise the temperature of wort from 72 to 93°C.

Heat generated by evaporation of wort at a rate of 8% per brew = 10,086 MJ

Heat transferred to the wort at pre-heater per brew= 4,669 MJ

Ratio of heat quantity for wort pre-heating to heat quantity of evaporation:

$$\frac{4669 \text{ X } 100\%}{10086} = 46.3\%$$

Heat transferred to cold water by the vapour condenser condensate = 3,528 MJ

Total heat utilized (recovered) from evaporation = 4669 + 3528 = 8,197 MJ

Heat that is not recovered = 10086 – 8197 = 1,889 MJ

As a % of the total heat generated,

$$= \frac{1889 \text{ X } 100\%}{10086} = 18.7\%$$

Hence the energy storage system effective utilization is at

100-18.7 = 81.3%

4.4.3 Energy cost implication when the wort pre- heater is out of service

From time to time due to continuous production and if the wort pre-heater PHE cleaning schedule is not adhered to, we get severe product deposit carry over to the plates of the wort pre-heater which is known as fouling. Fouling is the increased resistance to both heat transfer and fluid flow caused by deposits on a heat transfer surface. This makes the pre-heater to be out of service for up to one week, to enable manual cleaning and removal of the sticky compounds.

As already calculated, the heat required to heat the wort from 72 to 93°C = 4,669 MJ
This heat is provided by the energy storage tank water at 97°C.
If the pre-heater is out of service, the additional heat required to raise the temperature of wort will come from steam at the wort kettle.
4,669 MJ of steam is equivalent to $\frac{4669}{3.6}$ kWh = 1,297 kWh per batch/brew

Considering there are 20 brews per 24 hrs, this translates to;

1,297 x 20 = 25,939 kWh of steam energy per day.

Hence it takes additional 26 MWh (or 93,380 MJ) of steam energy per day at the wort kettle, to meet the shortfall created when pre-heater is bypassed. It takes about three days to manually clean the pre-heater once it is clogged. Considering the pre-heater is out of service twice in one month i.e. 6 days in a month. This translates to a total no of days in a year = 72 days

Therefore energy loss in a year;

= 25,939 x 72

= 1,867,600 kWh per year

Calculated Cost of steam is Ksh 6.2/kWh

Hence in one year the loss for not using the wort pre-heater;

= 1,867,600 x 6.2

= Ksh 11,579,120

Considering that it costs about Ksh 9.5 million for a new wort pre-heating PHE, then simple payback period:

$$= \frac{9{,}500{,}000}{11{,}579{,}120} = 0.82 \text{ years or 10 months, say 1 year.}$$

A new pre-heater can be installed as a standby to be used whenever the efficiency of the pre-heater has gone down or it is clogged by fouling. Since it takes up to 4 days to manually clean the pre-heater, then the effect of this PHE being out of service will not be felt. The energy storage and recovery during wort boiling will operate efficiently.

4.4.4 Wort Pre-heater efficiency

Calculated pre-heater efficiency is given by [13];

$$\epsilon = \frac{\mathbf{M}\text{water } \mathbf{Cp}\text{water (T(in) water – T(out) water)}}{\mathbf{M}\text{water } \mathbf{Cp}\text{water (T(in) water – T(in) wort)}}$$

$$= \frac{(255)\ (4.2144)\ (97-78)}{(255)\ (4.2144)\ (97-72)} = 76\%$$

4.5 Wort Coolers

Figure 4.13 shows the wort cooler PHE where chilled water (pre-cooled brewing water) is used to cool the wort from approximately 95°C to fermentation temperature target, which is between 10 and 20°C depending on the brand.

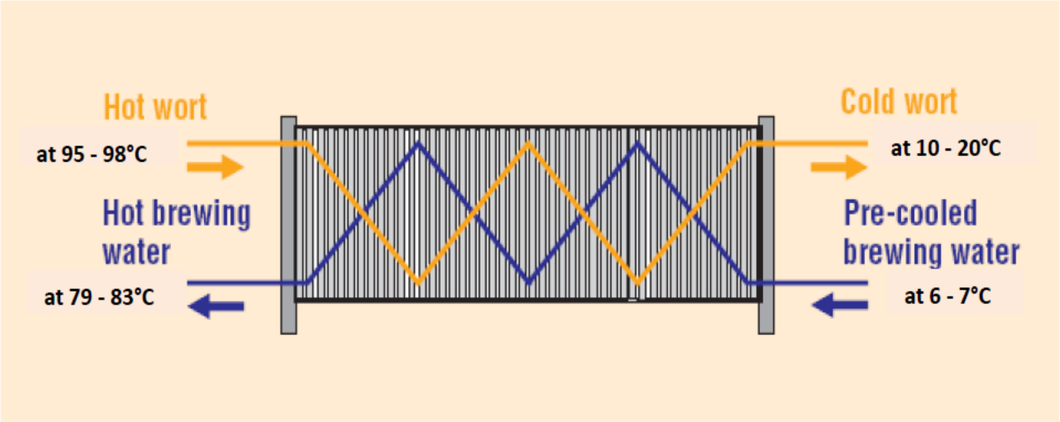


Figure 4.13: Wort cooler plate heat exchanger (PHE) [9]

4.5.1 Results of wort cooler efficiencies

Table 4.7 Wort cooler efficiencies

Brew	Brew Ref. no	Brew No after CIP	Wort in Temp °C	Chilled Water Temp in °C	Wort out Temp °C	Hot water Temp °C	Wort flow throughput (hl/hr)
SEN	2219	1	95.1	6	12.3	82.1	600
GNS	2222	2	95.6	6	13.5	80.3	550
SEN	2223	3	95.4	6	14.3	79.4	400

From Table 4.7 above, it can be concluded that the wort flow throw through the wort cooler is negatively affected by fouling caused by trub build in the PHE. This affects the overall production time, in that it takes longer to transfer the wort through the wort cooler. The 3rd batch transferred after the last CIP shows a drop in flow to 400 hl/hr (or 33% drop). The equipment supplier recommends CIP after three brews or batches.

A drop of up to 50% in wort flow is observed for subsequent batches transferred, if CIP is not done after 3rd batch. This will cause serious production delays which will affect the daily production targets. Hot water generation at the wort cooler will also be affected as the temperature of recovered water will be less than the targeted 80°C. Unlike the pre-heater, the wort cooler is not bypassed, as it is absolutely critical to attain the target fermentation temperatures per brand.

4.5.2 To determine the heat transfer at wort cooler

(i) Wort specification

Product Flow (wort)	550 hl/hr
Density Beer	1.05 kg/litre
Mass Flow	16.04 Kg/Sec
T_{in}, Temp into Cooling Zone	95 °C
T_{out}, Temp out Cooling Zone	14 °C
$\Delta T = (T_{in} - T_{out})$	81°C
Specific Heat Capacity Beer	4.182 kJ/kg/°K
Heat Extraction	16.04 kg/Sec × 81°C × 4.182kJ/kg/°K
	= 5,434 kW……………………………… (4.1)

(ii) To determine chilled water specification;

Heat Extraction	5,434 kW
T_{in}, Temp into Heating Zone	6 °C
T_{out}, Temp out Heating Zone	85 °C
$\Delta T = (T_{in} - T_{out})$	79 °C
Specific Heat Capacity Water	4.182 kJ/kg/°K
Mass Flow	16.32 kg/Sec
Density Water	1.00 kg/litre
Chilled Water Flow	580 hl/hr…………………………………… (4.2)

4.5.3 Recovered Heat from the wort cooler

The wort must be cooled from boiling point to a temperature of 10°C to 20°C (depending on brand) to prepare it for fermentation.

Treated fresh chilled water (brewing water) is used for single-stage plate heat exchangers for bottom-fermented beer wort cooling; this fresh water is cooled in a cooling plant from the respective fresh water temperature to 2 to 7^{o}C (pre-cooled brewing water) and stored in an insulated brewing water tank. Hot brewing water recovered is transferred to the hot water tank, for use on other brewing processes.

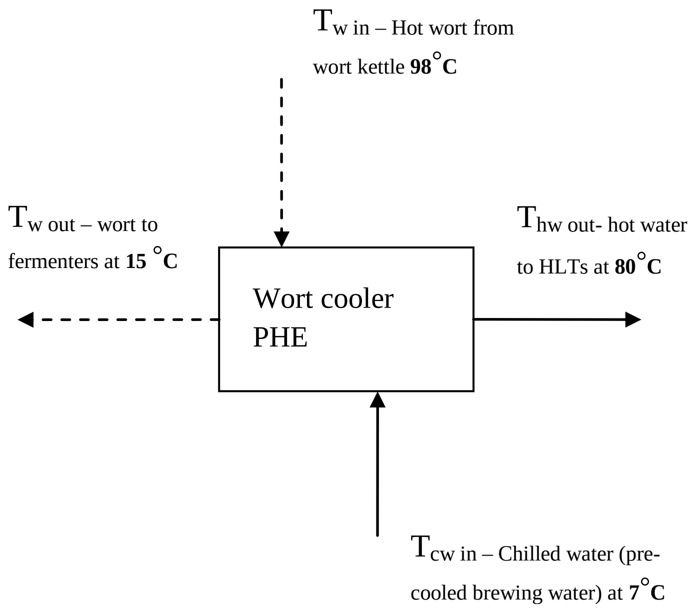


Figure 4.14: Block diagram of wort cooler PHE

4.6.4 Heat loss for hot wort at wort cooler PHE

Wort volume at end of boiling approximately $54m^3$

Density of wort after boiling is 1065 kg/m^3

Target density of wort before fermentation is 1050 kg/m^3. This adjustment is achieved by blending the wort with water to attain the required density or gravity.

Hence the density of wort before cooling is 1050 kg/m^3

Mass of wort = 1050 x 54 = 56,700 Kg

Heat loss for wort through the PHE = heat required to raise the water from 7 °C to 75-80°C.

$$Q = (m_{\text{wort out}} \times Cp_{\text{wort out}} \times \Delta T)$$

$$= 56700 \times 3.98 \times (98-15) = 18{,}730.3 \text{ MJ}$$

$$= 5{,}203 \text{ kWh}$$

4.5.5 Wort cooler efficiency

Calculated wort cooler efficiency is given by [13];

$$\epsilon = \frac{\mathbf{M}\text{water x } \mathbf{Cp}\text{water (T(in) water – T(out) water)}}{\mathbf{M}\text{water x } \mathbf{Cp}\text{water (T(in) water – T(in) wort)}}$$

$$= \frac{(255)\ (4.2144)\ (79.5-6.6)}{(255)\ (4.2144)\ (97-6.6)} = 81\%$$

4.6 Chilled water system

During collection, wort is cooled to a temperature suitable for yeast pitching. From equation 4.1, the calculated chilled water flow is 580 hl/hr which mainly depends on the temperature at which the chilled water is at. This affects the makeup load due to fact that when the temperature is below 4°C, it tends to lower the makeup load and the system experiences low water levels at HLTs. The ideal temperature to operate is 6°C since we are able to achieve higher volumes being fed into the HLT 7.

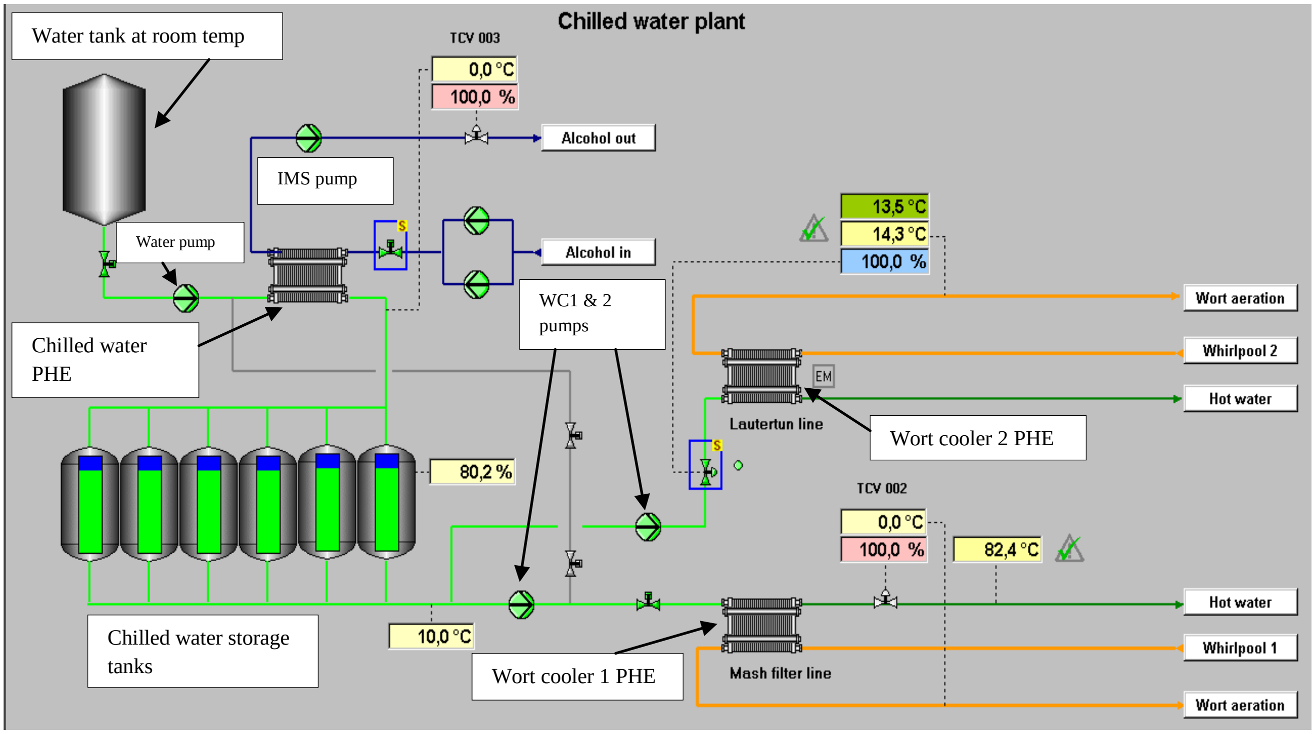


Figure 4.15: Scada screen shot of chilled water system and interconnection to wort coolers.

Chilled water is supplied to the wort coolers (WC1 and 2). Figure 4.15 shows the layout and interconnection of the plant. The generated chilled water is stored in the chilled water storage tanks. From the storage tanks, the water is pumped to the wort coolers whenever required. Table 4.8 shows the electricity cost of generating the chilled water. Four pumps are considered, and their running hours in a year used to calculate the annual cost of running the pumps.

Table 4.8: Annual electricity cost of running the chilled water plant pumps

Motor Description	Make of motor/pump	Motor rating (kW)	Motor current (Amps)	RPM	Operating Hours per Year	kWh / Year	Cost / Year Ksh
Water pump	ABB	11	20	2930	8136	89,496	1,591,239
IMS pump	VEM	11	21.5	1450	8136	89,496	1,591,239
WC1 pump	ABB/ Alfa- Laval	18.5	32	2920	6611	36,358	646,441
WC2 pump	VEM	5.5	10.1	2880	6611	122,294	2,174,392
Total						337,644	6,003,310

Electricity cost = Ksh 17.78 per kWh

Total kWh / Year	337,644
Total Cost / Year (Ksh)	6,003,310

4.7 Hot water balance in brew house

4.7.1 Hot water overview

Hot water is used in almost all brewing processes. Several tanks are used to store the hot water generated or recovered. The entire system capacity of the hot water, as shown in Table 4.9 is 6436 hl [10] given by the capacity volume design of hot liquor tanks (HLTs). All the hot water tanks are insulated and covered at the top to maintain the water temperature as shown on HLT 5, Photograph 4.1. HLT 7 which overflows or feeds HLT 6 has a heating loop with a PHE utilizing steam. The heating loop is to maintain the water temperature at 80^{o}C. Most of hot water is utilized for mashing, sparging, flushing and cleaning of vessels and process lines (CIP).

Table 4.9: Total capacity of hot water holding vessels (HLTs) [10]

VESSEL	CAPACITY (HL)	TOTAL (HL)
HLT 7	2080	6436
HLT 6	1540	
HLT 5	1540	
HLT 2	638	
HLT 1	638	

Table 4.10 gives the breakdown analysis of hot water usage by brew at each stage of production in brew house [10]. The average operating temperature of water collected to the HLTs is 80°C. For water requirements at lower temperatures e.g. 48 and 50°C, hot water at 80°C is blended (through a mixer) with cold water at room temperature i.e. 24°C, to attain the required temperature targets.

Table 4.10: tabulation of ideal process hot water usage of a single brew [10]

PROCESS	TEMPERATURE OF WATER (°C)	VOLUME OF WATER USED (hl)
Mash in	48°C	250
Mash rinsing	50°C	5
Sparging	78°C	255
Mash filter rinsing	50°C	5
Wort kettle rinsing	80°C	5
Whirlpool rinsing	80°C	5
Wort cooler sterilize	80°C	25
Collection	50 °C	50
TOTAL		**605**

As can be seen, the biggest use is during mashing-in and during sparging at the Mash filter [10].

Table 4.11: Daily hot water usage in brew house per number of brews done [10]

BREWS	TOTAL LIQUOUR USED (hl)	CIP DAILY USAGE (hl)	TOTAL (hl)
18	10890	360	11250
20	12100	360	12460
22	13310	360	13670

The brew house rated capacity is 22 brews. Due to operational performance or whenever there is a breakdown to equipment, the daily output can drop to 18 brews per day. Cleaning in place (CIP) estimated usage is 360 hl. This is shown in Table 4.11 above.

Photograph 4.1: Hot water storage tank (HLT 5)

4.7.2 Estimation of hot water generated and consumed

(i) Wort side parameters

From equation 4.1, the heat extraction is 5,434 kW.

(ii) Daily throughput

Product Flow	550 hl/hr
Brews per day	18
Wort cooler CIP's per day	6
Wort Cooler throughput per brew	552 hl
Estimated daily production	9,936 hl
Ave Processing time per day	15.4hrs
Heat Extracted	5434 x 15.4 = 83,913 kWh

(iii)Water side parameters

Heat Extraction	5,434 kW
Temp Into Heating Zone	6 ^{o}C

Heat Exchanger Efficiency	98%
Heat Recovered	5325 kW
Temp Out Heating Zone	80 ^{o}C
Delta T	74 ^{o}C
Specific Heat Capacity Water	4.182 kJ/kg/ ^{o}K
Mass Flow	16.32 kg/Sec
Density Water	1.00 kg/litre
Water Flow	619 hl/hr

(iv) Daily throughput

Processing time	15.4 hrs
Hot water generated per Brew	550 hl
Hot water generated	619 hl/hr x 15.4 hrs = 9,566 hl

(v) Daily Hot water Usage & Balance

Hot water generated	9,566 hl
Hot water usage for Brews	10,548hl
Hot water usage CIP	360hl
Total hot water usage	10,908hl
Hot water overflow	0hl
Hot water Tanks Capacity	5,896 hl

Buffer as % of daily liquor generated = $\frac{5896 \text{ X } 100\%}{9566}$ = 62%

Table 4.12: Wort cooler throughput

Chilled water Flow through wort cooler	500 hl/hr
average collection time	1.08 hours
through put for 18 brew	10692 hl
through put for 20 brew	11880 hl
through put for 22 brew	13068 hl

The entire system is at balance i.e. there is a balance between the hot water makeup (generated) and hot water consumed in various processes. The system is able to replenish when brew house is in operation since makeup load of hot water during wort collection process, can meet hot water demand (consumed).

The wort coolers and the hot liquor usage are theoretically in balance, however if they are out of sequence then overflows could occur. For example at the end of runs when cooling is taking place but no new mashes are being done. Keeping the balance will be difficult because the effective buffer is relatively small. Topping up the tanks with fresh water should be avoided where possible as all this does is to consume buffer. Table 4.12 shows the chilled water usage per daily production throughput. Photograph 4.2 shows the hot water distribution pipes to various process areas in brew house. The pipes had not been lagged, and this wastes a lot of heat.

Photograph 4.2: Hot water distribution pipes and valves

CHAPTER FIVE

DISCUSSIONS

In this chapter the results of the study are discussed highlighting specific observations and findings in relation to energy use.

5.1 Historical data

The average electricity consumption for the year 2010 was 3,631,176 kWh and 3,502,647 kWh in the year 2011. This represented energy intensities of 9.73 kWh/hl in year 2010, and 9.25 kWh/hl. There was a decline in the overall electricity energy use in 2011.

1,056,527 litres of HFO was used at the boilers in year 2010 while 1,025,982 litres of HFO was used in 2011. The HFO intensity declined from 120.8 MJ/hl in year 2010, to 115.8 MJ/hl in the year 2011. There was a marginal increase in Production output in the year 2011 compared with 2010, i.e. 373,408 hl of beer was produced in year 2010 compared with 379,261 hl of beer produced in the year 2011. The increase in production output for 2011 managed to lower the energy intensity of the previous year, though there was better utilization for the two main types of energy. It was observed that several energy conservation initiatives that were implemented in 1st half of year 2011 yielded some positive results e.g. better management of condensate recovery system. This meant less HFO was required.

The total monthly average site energy consumption stood at 156 MJ/hl in 2010 and 149 MJ/hl in the year 2011. Electricity contributed an average of 22% of total monthly site energy consumption for the two years.

5.2 Steam generation and distribution

The study established that optimization of boiler operations can reduce the monthly usage of Fuel oil (HFO). Stored hot water at the energy storage tank can be used to heat the boiler make up water. There is a PHE available for this use and considerable savings made on HFO. On average condensate contributes about 85-89% of total boiler make up water. This can be improved by 10% by metering major condensate points and ensuring all condensate return station are well maintained. The study shows that up to 162 kg of steam per hour for one boiler is blown down. A heat recovery unit can be installed to recover the heat that is blown down the drain. This can be used for boiler make up water or any other use to heat water. Most of the steam distribution lines and accessories have been lagged. However poor lagging in some steam distribution areas and condensate recovery lines were noticed. Hot unlagged surfaces with temperature in excess of 145^{o}C were observed. Lagging of hot surfaces needs to be undertaken to reduce the temperature to current existing standard of 37 ^{o}C for lagged surfaces.

5.3 Wort boiling process considerations.

The study has shown that the total Heat generated due to evaporation of wort during boiling is used to heat water at energy storage tank to 97 °C. This hot water is utilized at the wort pre heater to raise the temperature of wort from 72 to 95°C. The calculated heat generated by evaporation of wort at a rate of 8% per brew was found to be 10,086 MJ.
Heat transferred to the wort at pre-heater per brew was calculated as 4,669 MJ, which represent 46.3% of the total heat generated. Hence the recovered heat used at pre-heater is nearly half of heat generated from evaporation of wort.

Several scenarios were considered during wort boiling, and their impact on energy consumption. Wort Pre-heater PHE is an integral component of energy recovery during wort boiling. The study shows that high steam consumptions were experienced when the pre-heater was out of service. In some instance this represents close to 3000 kg (or 42%) more steam supply required per brew, when the pre-heater is bypassed. There is therefore a need to ensure that low pressure boiling (LPB) with energy storage/recovery system is used at all times during wort boiling. As already seen, it is worthwhile to consider buying and installing a second wort pre-heater to be on standby. Considerable savings are possible and the payback takes less than two years.

The study has shown that due to clogging and fouling, CIP of all the heat exchangers i.e. pre-heater, wort coolers and the wort kettle internal boiler will ensure higher thermal efficiencies. The recommended CIP schedules of the various PHEs need to be followed at all times. Skipping of scheduled CIP due to production demands only increases the energy consumption per brew and causes poor thermal efficiencies of the PHEs. The study shows that 18,730 MJ of heat is recovered in the form of hot water at 80°C, when the efficiency of the wort cooler is at 81%. Operating the wort cooler at higher efficiency therefore increases the heat recovered.

The study showed that there is need to optimize the current hot water usage and storage capacity (HLTs). The average daily hot water generated at required standard of 80°C, is 9,566 hl against a daily demand of 10,908 hl (including CIP). The combined storage tanks capacity is 5,896 hl, which acts as a buffer when brew house is in operation. The wort coolers and the hot liquor usage are theoretically in balance, hence a monitoring system should be put in place to ensure that they are not out of sequence, otherwise overflows could occur.

5.4 Energy Conservation Opportunities and Measures

<table>
<tr><td>Item</td><td>Energy conservation Opportunity</td><td>Utility</td><td>Water,
HFO,
Electricity</td><td>Total Operating Hrs</td><td></td></tr>
<tr><td>1</td><td>Measuring, Monitoring & Targeting</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="11"></td><td rowspan="11">
Photograph 5.1: Measurement of steam supply to wort kettle</td><td>Total Water Consumption</td><td></td><td>Operating Cost</td><td>1,303,133,444</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Saving Potential %</td><td>4%</td><td>Saving Potential</td><td>52,000,000</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Estimated implementation Cost (Ksh)</td><td>12,500,000</td><td>Payback (Yrs)</td><td>0.24</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Description</td></tr>
<tr><td colspan="4">Currently effective monitoring and targeting is carried out on all main utility supplies on a weekly and monthly basis.
Additionally, effective sub metering, setting targets and monitoring key sub metering will generate considerable savings, through better understanding of site processes, quicker identification of problems and the ability to track and target effectively. Examples of measures that should be in place include; boiler condensate recovery, fridge plant energy consumption, hot liquor made and used, bottle washer and pasteurizer water consumption.</td></tr>
<tr><td colspan="4">Actions Required</td></tr>
<tr><td colspan="4">Purchase of additional sub metering, use of an effective monitoring process and target setting</td></tr>
</table>

<table>
<tr><th>Item</th><th>Energy conservation Opportunity</th><td>Utility</td><td>Water,
HFO,
Electricity</td><td>Total Operating Hrs</td><td></td></tr>
<tr><td>2</td><td>Install a standby wort pre-heater PHE</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="10"></td><td rowspan="10">

Photograph 5.2: Wort pre-heater PHE</td><td>Equipment Size</td><td></td><td>Operating Cost</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Saving Potential %</td><td></td><td>Saving Potential</td><td>13,304,606</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Estimated implementation Cost (Ksh)</td><td>17,500,000</td><td>Payback (Yrs)</td><td>1.4</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Description</td></tr>
<tr><td colspan="4">The wort pre-heater is currently prone to clogging due to fouling if CIP is not done after the recommended 8 brews. This leads to poor efficiency of the pre-heater and if this persists then pre-heater is taken out of service. This causes the energy storage and recovery system not to be operational, as atmospheric boiling is conducted.

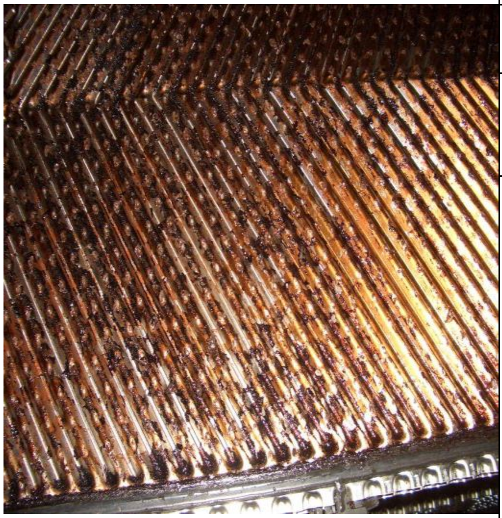
A new pre-heater can be installed as a standby to be used whenever the efficiency of the pre-heater has gone down or it is clogged by fouling. Since it takes up to 4 days to manually clean the pre-heater, then the effect of this PHE being out of service will not be felt. The energy storage and recovery during wort boiling will operate efficiently.</td></tr>
<tr><td colspan="4">Actions Required</td></tr>
<tr><td colspan="4">Purchase a new pre-heater PHE</td></tr>
</table>

<table>
<tr><th>Item</th><th>Energy conservation Opportunity</th><th>Utility</th><th>Water, HFO, Electricity</th><th>Total Operating Hrs</th><th>6,611</th></tr>
<tr><td>3</td><td>Re-plate / Optimize 2 off Wort Cooler PHEs</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="7"></td><td rowspan="7">
Photograph 5.3: Wort cooler PHE</td><td>Equipment Size</td><td></td><td>Operating Cost</td><td></td></tr>
<tr><td>Saving Potential %</td><td></td><td>Saving Potential</td><td>4,544,225</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Estimated implementation Cost (Ksh)</td><td>6,500,000</td><td>Payback (Yrs)</td><td>1.4</td></tr>
<tr><td colspan="4"><u>Description</u>

The wort coolers currently are prone to blinding/clogging and are also inappropriately designed leading to poor cooling profiles / heat exchange. This generates an excess of hot liquor at a lower than optimum temperature.

Redesign / plating of the wort coolers will be an effective way to reduce blinding, improve product cooling consistency and also increase the temperature and consistency of the hot liquor generated. Meters need to be installed on the chilled water feeds to the coolers and the hot liquor tank out feeds (brew house and brew house CIP). This will enable an effective hot liquor balance to be calculated and aid effective management.

Estimated savings of 0.5 brews worth of HLT overflow per day (729/2 = 365hl). Estimated cost Ksh 6.5M</td></tr>
<tr><td colspan="4">Actions Required</td></tr>
<tr><td colspan="4">Get the PHE manufacturer (Alfa-laval) to provide design calculations and a proposal</td></tr>
</table>

<table>
<tr><th>Item</th><th>Energy conservation Opportunity</th><td>Utility</td><td>Water, HFO, Electricity</td><td>Total Operating Hrs</td><td>4,368</td></tr>
<tr><td>4</td><td>Investigate Whirlpool effectiveness and its effect to wort coolers</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="6"></td><td rowspan="6">
Photograph 5.4: Wort cooler PHE plate showing effect of fouling</td><td>Equipment Size (KW)</td><td></td><td>Operating Cost</td><td></td></tr>
<tr><td>Saving Potential %</td><td></td><td>Saving Potential</td><td>5,778,435</td></tr>
<tr><td>Estimated implementation Cost (Ksh)</td><td>0</td><td>Payback (Yrs)</td><td>0.0</td></tr>
<tr><td colspan="4"><u>Description</u>
Currently trub is carried over into the Wort coolers and causes considerable blinding of the heat exchange surface. This means that the wort coolers have to be CIP'd every 3 brews.
The blinding causes variance in cooler performance and increases the quantity of hot liquor generated. It also means a lot of water is consumed due to CIP.
Investigating if whirlpool performance is optimized and changing to a concentrated type hops would potentially reduce the amount of trub carried over. The frequency of CIP's could then be reduced saving hot liquor.</td></tr>
<tr><td colspan="4">Actions Required</td></tr>
<tr><td colspan="4">Investigate whirlpool performance, continue to a trial with concentrated hops</td></tr>
</table>

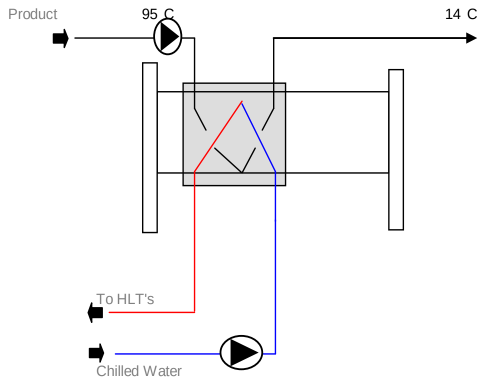
<table>
<tr><td>Item</td><td>Energy conservation Opportunity</td><td>Utility</td><td>HFO, water, Electricity</td><td>Total Operating Hrs</td><td></td></tr>
<tr><td>5</td><td>Hot liquor tanks (HLT) Management</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="4"></td><td rowspan="4">

Figure 5.1: An illustration of wort cooler</td><td>Equipment Size (KW)</td><td></td><td>Operating Cost</td><td></td></tr>
<tr><td>Saving Potential %</td><td></td><td>Saving Potential</td><td>4,544,225</td></tr>
<tr><td>Estimated implementation Cost (Ksh)</td><td>1,850,000</td><td>Payback (Yrs)</td><td>0.1</td></tr>
<tr><td colspan="4"><u>Description</u>
The brew house model shows that the wort Coolers and the liquor usage are theoretically in balance, however if they are out of sequence then overflows could occur from the HLT's. For example at the end of run when cooling is taking place but no new mashes are being done.
Keeping the balance is difficult because the effective buffer in the HLT's is relatively small - circa 50% of a day's mash.
Actions
- Topping up the tanks with fresh water should be avoided where possible to maximize available buffer in the HLT's. Trials should be conducted on how low the tank level can be left at a start up.
- Effective metering is imperative to the success of this activity. We have specified meters to be installed on the wort cooler hot liquor out feed and the two out feeds from the hot liquor tanks to brew house and brew house CIP.
Estimated savings of 0.5 brews worth of HLT overflow per day (729/2 = 365hl). Estimated cost is to improve metering</td></tr>
</table>

Item	**Energy conservation Opportunity**	Utility	Steam/ Hot Water	Total Operating Hrs	8,760
6	**Lagging improvements across site**				
	 Photograph 5.5: Unlagged hot water pipes	Annual Usage (KW)		Operating Cost	677,765,605
		Saving Potential %	2%	Saving Potential	13,555,312
		Estimated implementation Cost (Ksh)	6,500,000	Payback (Yrs)	0.5
		Description One example of unlagged pipes is the main valves off the boiler header. This has an area of approximately 5m² exposed to ambient air, and convection currents. Temperature differential is 170 - 25 = 145°C. Annual heat loss calculated at 400,000 kWh. Other instances of unlagged pipe were observed. A structured approach to pipe lagging maintenance is to be adopted, by site, with opportunities to be logged, and repairs to be carried out. Savings estimated as 2% of boiler fuel			

<table>
<tr><th>Item</th><th>Energy conservation Opportunity</th><td>Utility</td><td>Water, wort,</td><td>Total Operating Hrs</td><td>8,760</td></tr>
<tr><td>7</td><td>**Motor Management Policy**</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="6"></td><td rowspan="6">
Photograph 5.6: Chilled water plant pump motors</td><td>Annual consumption (kWh)</td><td>40,387,510</td><td>Operating Cost</td><td>545,231,385</td></tr>
<tr><td>Saving Potential %</td><td>2%</td><td>Saving Potential</td><td>10,904,628</td></tr>
<tr><td>Estimated implementation Cost (Ksh)</td><td>13,000,000</td><td>Payback (Yrs)</td><td>1.2</td></tr>
<tr><td colspan="4">**Description**
The basic steps include:
1. Creation of a motor survey and tracking program.
2. Development of guidelines for proactive repair/replace decisions.
3. Preparation for motor failure by creating a spares inventory.
4. Development of a purchasing specification
We suggest almost 95% of the power is consumed on site in an electric motor. A large proportion of the motors are attached to a mechanical drive. Drives include gearboxes, belt & pulley combinations and couplings. Electric motors are used across the plan.
All standard motors should be replaced as they burn out with premium efficiency motors, rather than rewinding them. The price premium for higher efficiency motor is an excellent investment because the operating cost of a motor is many times more than its</td></tr>
<tr><td colspan="4">**Actions Required**</td></tr>
<tr><td colspan="4">Replace Standard Motors with High Efficiency Motors instead of rewinding at burn out.</td></tr>
</table>

Item	**Energy conservation Opportunity**	Utility	Condensate	Total Operating Hrs	8,760
8	**Improve Condensate recovery**				
	 Photograph 5.7: Unlagged Condensate return pipes	Condensate Loss (%)	15%	Operating Cost	12,520,114
		Saving Potential %	10%	Saving Potential	8,263,275
		Estimated implementation Cost (Ksh)	1,950,000	Payback (Yrs)	0.2
		Description The condensate recovery rate is currently estimated at 80 to 85% depending on method of calculation. It is supposed that site could improve condensate return by 10%, by returning pipes which currently go to drain. One example is the condensate return from the oil heaters, which are located directly next to the boilers.			

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

In this chapter conclusions of the study observations and results are made. Highlights of the observations in energy are presented and proposed ECM is shown. Further recommendations are made on energy conservation opportunities observed.

6.1 Conclusions

The following conclusions can be drawn from this study;

The main source of energy is HFO with energy content 42.67 MJ/litre, and electricity supplied from 66 kV and stepped down to 11 kV and 415V.

The average HFO use was 121MJ/hl of beer production in the year 2009. This was shown to decrease with an increase in production in the year 2010, to 116 MJ/hl. Electricity contributes 22% of the total energy in the study plant.

The available capacity of steam generation at boiler plant is 48tonne/hr. From section 4.1, it was calculated that the average monthly utilization of boiler plant is only 38.7%.

Wort boiling process was observed to consume between 30% and 52% of the total steam energy from the boiler plant. The type of boiling (atmospheric-only boiling or low pressure boiling) determines the actual steam energy consumption. Low pressure boiling was observed to consume 97MWh less energy per day compared with atmospheric boiling. Two main considerations for undertaking atmospheric-only boiling at the study plant are:

a) When the pre-heater is not in use and hence the whole energy recovery system is immobilized. It is only possible to undertake ATM boiling and not LPB.
b) Due to production demands, and since there is only one pre-heater and two wort kettles, it is possible to have half the daily production done on ATM boiling, and the other half on LPB. This way it is possible to produce more brews in a given day.

The amount of energy consumed during wort boiling is dependent on the performance of the wort pre-heater. Fouling (or precipitation of compounds) at the heat exchangers plates greatly impairs their heat transfer performance. Proper cleaning-in-place (CIP) of the wort pre-heater when required eliminates the fouling material. The recommended CIP of the pre-heater is after 8 batches/brews. From data collected, it was observed that after 5 brews, the heat transfer performance of the pre-heater drops sharply.

When the pre-heater is not in use as a result of fouling and subsequent blockage of its wort flow path, then an additional 1,297 kWh per brew or 26 MWh per day of steam energy will be required for wort boiling. The study established that if CIP is not done correctly and timely, then the pre-heater will be out of use for a minimum of 72 days in a year. The effect of this is that an additional 1,867 MWh steam energy will be required.

During LPB it was observed that up to 81% of heat energy recovered from evaporation of wort is effectively utilized, at the wort pre-heater and vapour condensate heater. In most cases the energy recovery performance was quite low depending on other factors such as; performance of pre-heater and actual boiling time at wort kettle, and variations in steam supply from boiler house.

The calculated heat extracted at the wort cooler was 5,203 kWh per brew, which is used to generate hot water at 80 ^{o}C into the hot liquor tanks (HLTs), from chilled water. The chilled water is supplied at the wort cooler at a temperature of between 4^{o}C and 6^{o}C. Annual electricity energy consumption of running the chilled water plant pumps was calculated as 337,644 kWh.

Hot water is used in almost all brewing processes. Hot water is generated mainly at the wort coolers and to a smaller extent from the energy storage tank. The entire system capacity of the hot water is 6436 hl. The average operating temperature of water collected to the HLTs is 80^{o}C. On a single day 12100hl of hot water is for production processes and 360 hl of hot water used for CIP. The existing buffer (HLTs) can only hold 62 % of daily liquor generated.

Several ECM’s to conserve energy have been recommended in this study. These include the following;

- Measuring, Monitoring & Targeting – with a payback of 0.24 years
- Install a new standby wort pre-heater PHE – with payback of 1.4 years
- Re-plate / Optimize Wort Cooler PHEs - with payback of 1.4 years

- Investigate Whirlpool effectiveness and its effect to wort coolers – house keeping with no capital expenditure expected
- Hot liquor tanks (HLT) Management - with payback of 0.1 years
- Lagging improvements (steam, condensate 7 hot water) across site - with payback of 1.4 years

6.2 Recommendation

This study has established that there are several energy saving opportunities at the KBL brew house plant and wort boiling process. The main contributor of unnecessary high energy consumption is the wort pre-heater. An additional 20% of the total site steam energy is required to meet the shortfall created by pre-heater being out of service. The study has found that;

A standby pre-heater can be purchased and be installed to be used when the one on duty is fouled or under CIP. The ROI as earlier determined will be less than one year. The current CIP target of the pre heater can then be reduced from 8 to 5, and be done consistently.

Current utilization of energy storage system (recovered energy) is at 81%. The energy storage system can be optimized by introducing heating of boiler make up water in the recovered energy loop. This will mean purchase and installing a heat exchanger.

It is recommended that a further study of hot water mapping for the study plant processes is required to cater for future requirements. The current system is out dated and due for replacement. This will ensure adequate storage capacity is provided and the hot water usage accounted for.

The identified energy conservation measures suggested could be implemented in phases. Most of these have payback periods of less than two years. This can be implemented as an overall site energy or environmental initiatives that are centrally driven.

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