IMPROVEMENT OF THE PASTEURISER HEATING SYSTEM TO ENHANCE PRODUCTION EFFICIENCY WITH LIMITED STEAM SUPPLY AT UGANDA BREWERIES

By

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A DISSERTATION SUBMITTED TO THE DIRECTORATE OF RESEARCH AND GRADUATE TRAINING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER'S OF SCCIENCE DEGREE IN ADVANCED MANUFACTURING SYSTEMS ENGINEERING OF KYAMBOGO UNIVERSITY.

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DECLARATION

I, Mulimira Solomon, Reg. No. 22/U/GMEM/425/PE, do hereby declare to the best of my knowledge that the information in this thesis report is my own work and has not been presented to any institution of learning for any academic award.

Signature… Date …

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APPROVAL

We as university supervisors confirm that this body of research was done by Mulimira Solomon Registration number 22/U/GMEM/425/PE under our supervision.

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ABSTRACT

Efficient operation of pasteurizer heating systems is essential for maintaining product quality, minimizing downtime, and improving production efficiency in the food and beverage industry. At Uganda Breweries Limited (UBL), the existing pasteurizer heating system, originally designed for heavy fuel oil boilers, has faced operational challenges under biomass boiler supply, including fluctuating steam pressures, inefficient heat transfer, and frequent downtime. These limitations have significantly affected line efficiency, energy utilization, and production reliability.

The objective of this study was to improve and optimize the pasteurizer heating system to enhance its compatibility with biomass boiler steam supply, improve heat transfer efficiency by at least 20%, stabilize pasteurization temperature within ±1°C in 95% of production cycles, and reduce downtime by at least 30% within one year.

The study employed a mixed-methods approach involving baseline performance characterization, thermal calculations, computational fluid dynamics (CFD) simulations using ANSYS Fluent, and practical modification of the plate heat exchanger. Additionally, the control system was optimized through re-parameterization of the steam modulating valve. Performance data was collected over a continuous monitoring period and analyzed using descriptive statistics, and paired-sample t-tests.

Findings revealed a 22.8% improvement in heat transfer efficiency and a 34.3% reduction in pasteurizer-related downtime after modification. Further analysis showed a strong correlation between steam valve responsiveness and temperature stability, validating the effectiveness of the control system redesign. Financial analysis demonstrated that adding five plates to the TS20MFG heat exchanger was a cost effective solution (UGX 3.25 million) compared to full replacement (UGX 87.3 million).

The study concludes that targeted design and control modifications can significantly enhance the operational efficiency and reliability of pasteurizer heating systems under variable steam supply conditions. It recommends further optimization through automated flow regulation, operation at steam pressures below 1 bar, and exploration of alternative plate designs to maximize energy efficiency.

LIST OF ACRONYMS

ALCS	Annual Life-Cycle Savings
BEST	Biomass Energy Strategy Uganda
CIP	Cleaning In Place
CO	Carbon monoxide
CO2	Carbon Dioxide
DC	Direct Current
EU	European Union
GHG	Greenhouse Gas
GPHE	Gasketed Plate Heat Exchanger
HTST	Higher Temperature Short Time pasteurization
ISI	Iron and Steel Industry
LMTD	Log-Mean Temperature Difference
MEMD	Ministry of Energy and Mineral Development
NHV	Net Heating Value
NPV	Net Present Value
NTU	Number of Transfer Units
NOx	Nitrogen oxides

PE	Partial Equilibrium
PHE	Plate-Heat-Exchangers
PRV	Pressure Relief Valve
PU	Pasteurization unit
PV	Photovoltaic
RES	Renewable Energy Source
SPP	Simple Payback Period.
SRV	Steam Regulating Valve
UBL	Uganda Breweries Limited.
UGX	Ugandan shillings.

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CHAPTER ONE. INTRODUCTION

1.1 Background to the Study.

Pasteurization, first proposed by Louis Pasteur in 1960, is the technique of heating a product to a predetermined temperature and holding it there until all or almost all unwanted bacteria present are killed. This is necessary among other reasons; to make the product safe for human consumption by destroying the pathogenic organism which may be present.(Lindsay R Matthews, 2022) &(James H. Steele, 2000). To improve preservation quality by destroying almost all spoilage organisms and help retain good flavor over a longer period of time such as is the case with beer. Pastuerisation is achieved by ensuring 65°C at the centre of the product for at least 30 minutes, and the longer the exposure time to the higher temperature, the greater the pasteurization value of the product, measured in Pasteurization units (PUs) one PU is defined as exposing a product at 60°C for 1 minute.(Edward Wray, 2025).

Figure 1.1 represents the steam distribution layout of Uganda Breweries limited, showing steam flow from the boiler house to the packaging hall, and into the pasteurizer heating system on line five production line.

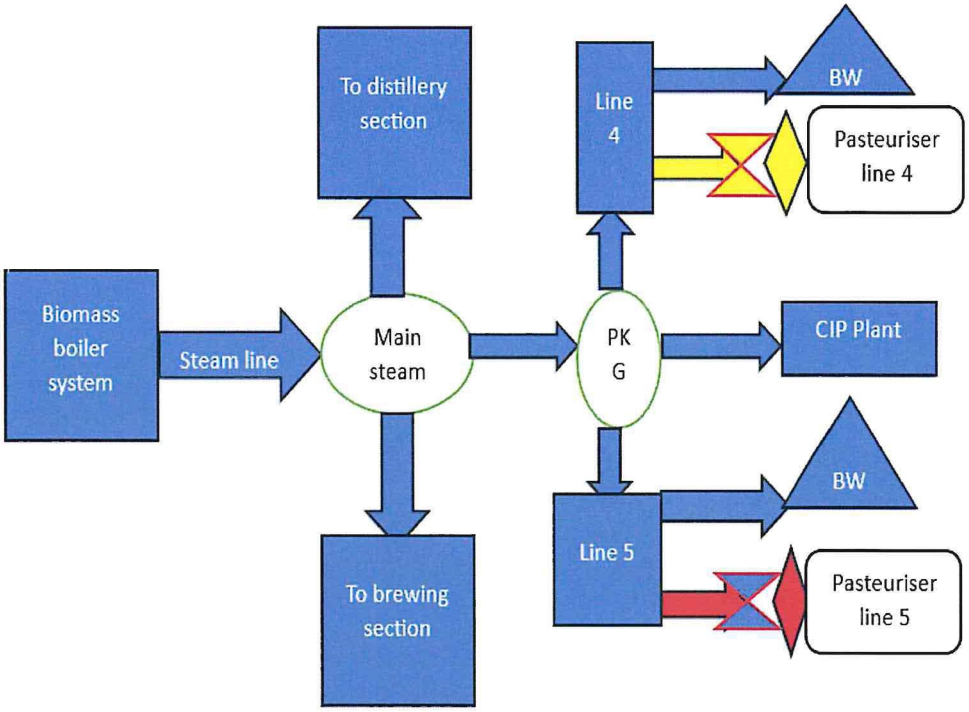


Figure 1.1: Layout of the steam supply at Uganda breweries Ltd

Steam is generated from the biomass boiler system into the main steam line, the steam is distributed to the three major sections of the facility, that is; the distillery, the brewing section and the beer packaging section. Each section has several routine activities that require heating and these were initially factored in during the installation of the boiler system.

However, there are several activities that are not in the normal routines that come in as critical stops, or as requested by the quality team, such as Cleaning in Place (CIP) which is the system used to clean internal sections of machines and pipelines. There are also activities that only happen a few hours during the day and usually require excessive amounts of steam to accomplish such as mashing

in the brew house. These activities out of the routine create abrupt demands on the biomass boiler system, which has a slow response to this kind of load and during the time the system is trying to ramp up and recover, there are sections which get affected and receive lower steam pressures than the minimum set for those particular machine set ups for proper operation.

The biomass boilers are sensitive to the type of fuel supplied and their operation gets affected if the proper fuel ratio is not attainable, the fuel ratio that provides the best performance is 1:1:1, being one bucket of wood chips, one bucket of sawdust and one bucket of bagasse. Poor ratios inhibit steam generation and for the period the poor ratio fuel is burning, the boilers struggle to attain maximum steam pressure.

In the packaging section, there are two lines 4&5 each with two constant consumers of steam during operation that is the bottle washer and the pasteurizer, there's also the CIP plant which requires a large amount of steam to prepare since almost all the time the chemicals required to carry out the cleaning are heated from room temperature to above 80°C. Every time the CIP system is started, steam pressure to the packaging section is affected and the machine most affected is the pasteurizer on line five shown by red color in Figure 1.1. In other sections other than packaging, the processes can afford to wait for the steam pressures to build up with minimum impact on their output, however, in packaging these fluctuations lead to massive losses attributed to shortstops of the machines and loss of production time.

Temperature fluctuations cause inconsistent heating and temperature control within the pasteurizer as shown in line 4 and line 5 in Figure 1.1 can compromise the effectiveness of the pasteurization process, affecting product quality and safety. To curb this occurrence, the operating program of the pasteurizer is set to alarm and stop the machine when certain critical heating conditions are not met. This causes loss of production time, and therefore usage of excess utilities across the entire production line until the heating issue is resolved, when the steam pressure drops frequently and the loss is compounded it amounts to a large portion of the operation cost of the line.

The pasteurizer heating system consists of components mainly the heat exchanger and the modulating valve, plus small others such as flow meters, the pipeline and pressure gauges. This study aimed to modify this heating system by reviewing relevant literature about heat exchangers and modulating valves and their controls, to enable the pasteurizer to adapt to steam fluctuations due to inconsistent biomass boiler supply.

Figure 1.2 presents the components of the heating system for the pasteurizer machine showing main components such as the heat exchanger that is covered in an insulation box to minimise heat loss to the atmosphere and also safe guard operators from heat injuries, the Steam Regulating Valve (SRV) that controls flow of steam through the heat exchanger by opening at different percentages in response to system demand. The Pressure Relief Valve (PRV) serves to maintain maximum pressure of the system as the set point and open when there is excess pressure to avoid damage to system components and avert possible injuries to

users. The system also has a manual shut off valve to isolate the system for maintenance on the steam inlet pipeline, and has a manual condensate pump on the condensate return line.

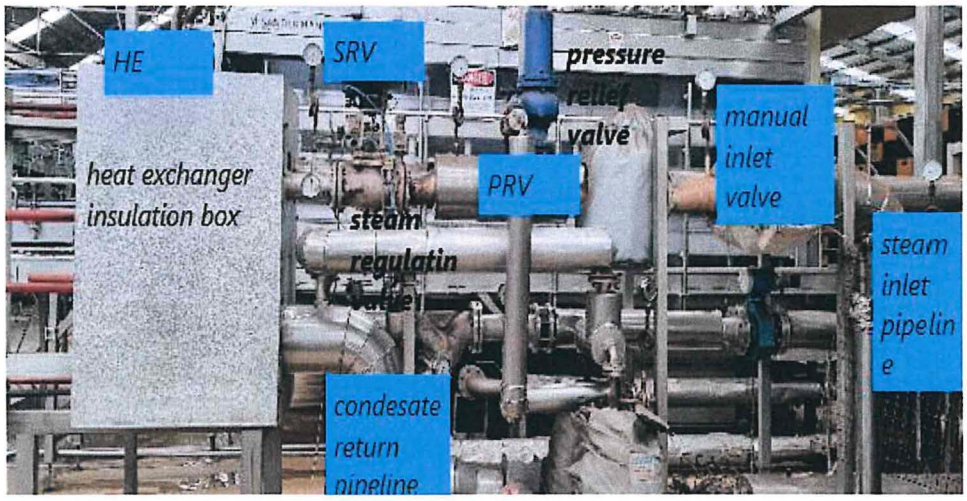


Figure 1.2: Components of the heating system



Figure 1.3: Line monitoring-top losses and line efficiency.

Figure 1.3, is evidence extracted from the Haford packaging line monitoring tool that when the current pasteurizer heating system is coupled with biomass boiler steam supply, issues such as unplanned downtime and increased maintenance costs are experienced due to the arising system inadequacies, affecting overall production efficiency and causing energy inefficiency. The first graph in Figure 1.3 is an excerpt from the line efficiency monitoring system on a day when fuel at the biomass boilers was not up to standard, causing fluctuating steam supply to the line manifesting as rampant short stops. The second graph in Figure 1.3 is poor efficiency as a result of the losses in graph 1.

The current pasteurizer heating system design was meant to operate with Heavy furnace oil (HFO) boilers and is not fully compatible with biomass boiler systems, resulting in slow start-up heating, suboptimal performance during operation, and disruptions in the pasteurization process. This has been evidenced by loss of production time to alarms such as low steam supply, low pasteurization units (PUs) on the machine controller interface.

1.2. Problem Statement

As UBL leads the shift towards sustainable practices, the integration of biomass boilers into heating processes has become an attractive option. However, the operational efficiency of tunnel pasteurizers is critical in ensuring consistent product quality, minimizing downtime, and sustaining cost-effective production in the beverage industry. At Uganda Breweries Limited, the pasteurizer heating system currently experiences frequent downtime and unstable temperature regulation due to inadequate heat transfer performance and limitations in steam valve responsiveness under low-pressure conditions. These challenges have led to production interruptions, increased energy consumption, and reduced overall line efficiency. Although plate heat exchangers are widely recognized for their superior heat transfer capabilities compared to conventional systems, their performance is often constrained by design limitations, suboptimal control mechanisms, and pressure fluctuations in biomass-driven steam supplies. The persistent operational inefficiencies at UBL highlight the need for a systematic evaluation and redesign of the pasteurizer heating system. Addressing this problem is essential not only for enhancing production reliability and energy

efficiency but also for contributing to broader industrial efforts in sustainable manufacturing within developing countries.

1.3. Objective of the Study

1.3.1 Main Objective

The main goal of this study was to improve the pasteurizer heating system to enhance production efficiency with unstable steam supply at low cost.

1.3.2 Specific Objectives

1. To modify and optimize the pasteurizer heating system to achieve at least a 20% increase in heat transfer efficiency within 6 months, while maintaining compatibility with biomass boiler steam supply.
2. To implement and validate a steam control system modification that maintains pasteurization temperature deviations within ±1°C given steam pressures below 3bar during 95% of production cycles over a 3-month continuous monitoring period.
3. To reduce pasteurizer-related downtime by at least 30% within the first year of implementing design modifications, as measured through Harford production line efficiency data.

1.4 Research Questions

1. How can modifications to the pasteurizer heating system be developed and implemented to achieve at least a 20% increase in heat transfer efficiency within

six months, while ensuring compatibility with the biomass boiler steam supply at Uganda Breweries Limited?

2. To what extent does the implementation of a steam control system modification maintain pasteurization temperature deviations within ±1°C under steam pressures below 3 bar, during at least 95% of production cycles across a three-month continuous monitoring period?

3. How effective are the applied design modifications in reducing pasteurizer related downtime by at least 30% within the first year of implementation, as measured through Harford production line efficiency data and maintenance records at Uganda Breweries Limited?

1.5 Significance of the Study

The study is significant both to industry and the broader field of scientific research, from an industrial perspective, the optimization of the tunnel pasteurizer's heating system offers a direct pathway to reducing downtime, improving energy efficiency, and ensuring consistent product quality in brewery operations. By demonstrating a 22.8% increase in heat transfer efficiency and a 34.3% reduction in pasteurizer-related downtime, the findings provide practical evidence that targeted design modifications can yield measurable improvements in productivity and operational reliability. These outcomes are particularly relevant for breweries in developing countries such as Uganda, where energy costs, resource constraints, and reliance on biomass boilers demand innovative, sustainable and cost-effective solutions.

The study contributes to the body of knowledge in thermal systems optimization, process control, and applied heat exchanger design. The validation of a steam control system capable of maintaining temperature deviations within ±1°C in over 95% of production cycles demonstrates the value of integrating control theory with practical engineering modifications. Moreover, the research bridges the gap between theoretical models of heat transfer efficiency and their application in industrial food and beverage processing environments, offering a replicable framework for further research in similar energy intensive industries.

1.6 Scope

1.6.1 Content Scope:

The study was focused around the pasteurizer heating system of line 5 at UBL considering existing and modified alternatives.

1.6.2 Time Scope:

The study was conducted between July 2023 to Dec 2024.

1.6.3 Geographical Scope:

The study was conducted at Uganda Breweries Limited, port Bell site in the packaging department.

1.7 Conceptual Framework

1.7.1 Framework.

The project was conducted in three phases as shown in figure 1.8

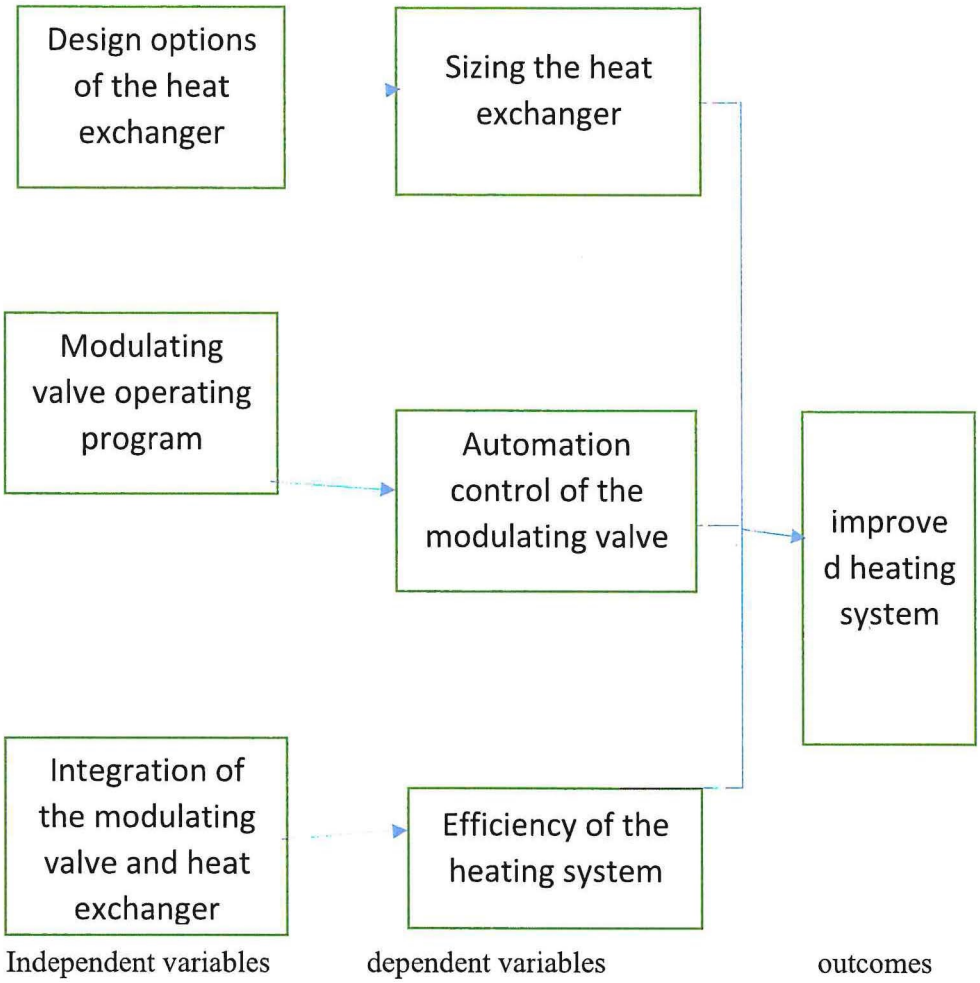


Figure 1.4: Conceptual framework

1.8. Organization of the Thesis

The rest of this thesis is structured to provide a clear and logical flow of information, guiding the reader through the research from introduction of the study to its conclusions. Chapter one introduces the study, outlining its background, objectives, and significance. Chapter two presents a comprehensive

literature review, analyzing existing research and identifying gaps relevant to the study. Chapter three details the research methodology, including data collection techniques and analytical approaches. Chapter four discusses the findings, supported by technical data, graphical representations, and comparative analysis. Finally, Chapter five summarizes the key conclusions and provides recommendations for future improvements. Appendices at the end include additional supporting materials such as the research schedule and budget estimates.

CHAPTER TWO: LITERATURE REVIEW

2.0. Introduction

This study aimed to find a solution to the shortcomings of the pasteurizer heating system that exhibited intermittent heating patterns when coupled with a biomass boiler system. This transition will inform other industry players of the precise requirements needed to set up an efficient production system as the sector attempts to shift towards low cost operations.

2.1. The Principle of a Packaging Line.

A packaging line consists of interconnected machines, each performing specific tasks to produce the final packed product. (D Leer, 2014; FL Härte, 1997; RJ Habets, 2019) discuss that for optimal performance, the line must be designed as a cohesive system, ensuring individual machines are properly specified to work seamlessly together. The speed of the line is ultimately dictated by its slowest machine, known as the bottleneck, usually the filler machine. The bottleneck machine plays a critical role in production efficiency, quality, and cost, and must operate as close to its maximum capacity as possible. To achieve this, upstream machines are intentionally designed to run faster, creating a "V-profile" in the line's operational speeds.

This design ensures the bottleneck machine is consistently supplied with input material and avoids stoppages due to back-ups or lack at infeed. (E Grimes, 2007) observed that conveyors between machines act as buffers, with upstream conveyors filling up before the bottleneck and downstream conveyors remaining

relatively empty, minimizing disruptions. Understanding and implementing this principle allows for better tracking and enhancement of operational efficiency across the production line, making it a cornerstone of effective packaging system design, where, a **core machine** refers to the equipment with the theoretically lowest production capacity, while a bottleneck machine is the one that, in practice, limits the overall output due to operational constraints.(E Grimes, 2007)

For instance, if an Empty Bottle inspector has frequent breakdowns and produces fewer bottles than capacity required at the filler per hour, the empty bottle inspector becomes the bottleneck machine, even though the filler remains the core machine. Losses on the bottleneck machine directly impact the overall line performance since they cannot be compensated by other machines. This knowledge of the V-curve highlights the importance of the pasteurizer to run at rated speed to ensure line performance is not impacted.

2.2. Background to Steam Production in Industry.

Steam Production is a fundamental process in various industries, serving as a versatile and essential source of thermal energy. In industrial settings, steam is generated by heating water in boilers to produce high-pressure steam, which is then utilized for a wide range of applications, including power generation, heating, sterilization, and mechanical work. The importance of steam, (Changchun Liu et al., 2022) and (Dan Einstein et al., 2001) caution, in industry

cannot be overstated, as it plays a crucial role in driving production processes, enhancing efficiency, and ensuring product quality and safety.

In the food industry, steam holds particular significance due to its diverse applications across various stages of food processing and production. One of the primary uses of steam in food manufacturing is for heat treatment processes such as pasteurization and sterilization. Pasteurization, for instance, involves heating food products to specific temperatures to destroy harmful bacteria and pathogens while preserving flavour and nutritional quality. Steam is also utilized in cooking, blanching, and drying processes, as well as in equipment cleaning and sanitation procedures. Additionally, steam is employed in heating and humidification systems within food processing facilities to maintain optimal operating conditions and regulate ambient moisture levels.

2.2.1 Importance of Steam Supply Efficiency in Food Processing.

The relevance of steam in the food industry underscores its critical role in ensuring product safety, quality, and compliance with regulatory standards. Moreover,(Anton Beck et al., 2021) observed that steam-based heating systems offer several advantages, including uniform heat distribution, precise temperature control, and energy efficiency. However, the sustainability and environmental impact of traditional steam generation methods, such as those relying on fossil fuels, have increasingly come under scrutiny. As a result, there is growing interest in exploring alternative and renewable energy sources for steam production, with biomass boilers emerging as a promising solution. By

utilizing biomass materials such as wood pellets, agricultural residues, or organic waste, biomass boilers offer a sustainable and environmentally friendly approach to steam generation, aligning with the food industry's commitment to sustainability and reducing carbon emissions. Therefore, (Peter J Fryer & Cornelis Versteeg, 2014) suggest that understanding the role of steam in food production and the potential of biomass boilers in steam-based heating systems is essential for advancing sustainable practices and enhancing efficiency in the food industry. Based on heat exchange theory, heat is always carried from a hot to a cold medium. There must be a temperature difference between the media. Heat loss by the hot medium equals heat gain by the cold medium, excluding losses to the surroundings. Where steam is used for space heating, a boiler serves as a heat source. In Figure 2.1, the boiler generates steam, which is fed to the heating units via appropriate piping systems. This system will have its peak pressure at the boiler where the steam is generated. The condensed water through a pressure drop system is the delivered back to the boiler as hot feed water, to complete a simple closed loop.

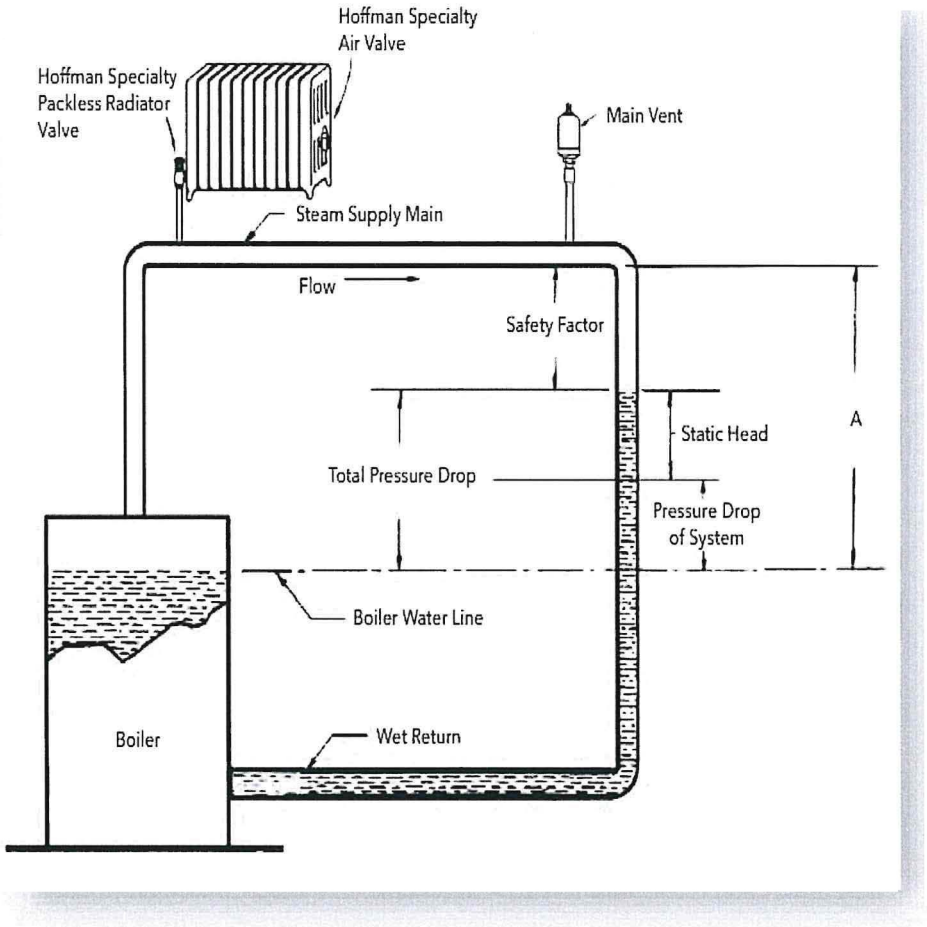


Figure 2.1: Hoffman system example of a steam flow pipe system

Microorganisms are extremely diverse in nature, and they can be both beneficial and dangerous. (G.S Tucker et al.,2002) discuss that pasteurization is a technique that reduces the amount of microorganisms to a point where they are unlikely to cause disease while retaining the product's desired qualities. This procedure inevitably modifies the desired qualities of the product, but frequently it is the only option to be able to preserve products for a specific duration.

2.3 Heat Production Technologies

2.3.1 Combustion; Boilers, dryers, kilns, furnaces, and ovens are common process heat generators. Various types of biomass can provide the entire temperature range required by industrial processes. Some industrial processes demand the continual heating of vast amounts of material, while others require the exact heating of tiny batches. (Yang et al., 2021) noted that "Combustion technologies span, therefore, a wide range of scales, from a few kilowatt to multi-megawatt. The choice of the combustion system depends not only on the energy demand, but also on the fuel characteristics, cost and performance of technologies and legislation."

2.3.2 Direct Heating: Direct heating can fundamentally be defined as the control of thermal energy absorbed or rejected through manipulation of exogenous factors. Certain industrial processes require high temperatures and specific combustion equipment that transfers heat directly from the flue gases to the process. (Abass A. Olajire, 2021) notes that direct heating is also used to produce low or medium temperature heat e.g. in the cork industry.

2.3.3 Indirect Heating: Low and medium temperature heat is often delivered to the process using a heat delivery medium (usually steam). Although biomass is not commonly utilized for process steam production, it has significant potential for producing low and medium temperature steam. The majority of enterprises employ combustion boilers to convert solid biomass into thermal energy. (Yang et al., 2021).

2.4 Types of Flow in Heating Systems

2.4.1 Parallel Flow: When the fluids from the tube and shell flow in the same direction. In this scenario, the two fluids enter the heat exchanger from the same end, but with a significant temperature difference. As the fluids transfer heat from hotter to colder, their temperatures approach each other.

2.4.2 Counter Flow: When two fluids move in opposite directions. Each fluid enters the heat exchanger from opposite ends. Because the cooler fluid exits the counter flow heat exchanger at the same end as the hot fluid enters, it will approach the hot fluid's entrance temperature. (Li-Zhi Zhang, 2020) noted that counterflow heat exchangers are the most efficient of the three types. Unlike the parallel flow heat exchanger, the counter flow heat exchanger can have the hottest cold fluid temperature higher than the coldest hot fluid temperature.

2.5 Pasteurization

Pasteurization is the process of heating a product to a predetermined temperature and holding it until all or nearly all objectionable microorganisms, which may be present are killed. (James H. Steele, 2000) notes that the process aims; to make the product safe for human consumption by destroying the pathogenic organisms which may be present, to improve preservation quality by destroying almost all spoilage organisms and to help retain good flavor over a longer period of time. Pasteurization is performed by maintaining a temperature of 65°C at the product's core for at least 30 minutes. The longer the exposure period, the higher the pasteurization value. The process of killing microorganisms begins at

especially low temperatures, such as 65°C. To reduce the starting number by one decimal point, one must expose the food sample to a temperature of 65°C for a set time, say 20 minutes. (Peter J Fryer & Cornelis Versteeg, 2008) indicated that liquid foods for example beers and fruit juices are pasteurized after filling into containers. Hot water is normally used if the food is packaged in glass, to reduce the risk of thermal shock to the container (fracture caused by rapid changes in temperature). Maximum temperature differences between the container and water are 20°C for heating and 10°C for cooling (Kathryn J. Boor et al., 2017; V.H. Holsinger et al., 1997). The product is then cooled to approximately 40°C to evaporate surface water and therefore to minimize external corrosion to the container or cap, and to accelerate setting of label adhesives. Hot-water pasteurisers may be batch or continuous in operation (John R. Campbell & Robert T. Marshall, 2016) & (EL Crossley, 1954). A continuous version consists of a long narrow trough fitted with a conveyor belt to carry containers through heating and cooling stages.

In practical terms, the functioning of a heating system for pasteurisation relies on the fundamental principles of physics governing heat transfer. (Robert Aranowski et al., 2017) noted that when there's a temperature disparity between two mediums, heat naturally flows from the warmer medium to the cooler one until they reach equilibrium. (Pavel A. Strizhak et al., 2017) indicated that this process occurs in heat exchangers, which are designed to facilitate this transfer of heat energy. For instance, in a biomass boiler system used in a beer brewing industry, heat generated from burning biomass is transferred to water, forming

steam. The steam, now superheated, can then be used to heat water in other sections for various purposes such as pasteurization. This exemplifies how the principles of heat transfer enable the efficient heating of fluids or gases, even when they initially possess minimal energy levels. Moreover, (AB Lidiard, 1966; Filippo Verdolin et al., 2021) state that these principles dictate that there must always be a temperature gradient between the mediums involved for heat transfer to occur. Therefore, understanding these basic rules helps in designing and improving heating systems for enhanced production efficiency, as illustrated in the context of the beer brewing industry.

(Harris N. Lazaridesa, 2011) and (Lijun Wang, 2014) indicate that in the realm of food and beverage production, the need for sustainable and energy-efficient practices has become increasingly prominent. One pivotal stage in ensuring product safety and quality is pasteurization. In response to fluctuating steam demands, biomass boilers, like those installed at Uganda Breweries Limited, do face challenges due to their limited ability to rapidly adjust combustion rates compared to traditional Heavy Furnace Oil boilers, biomass boilers typically have slower response times due to factors such as fuel availability and combustion efficiency. This has resulted in delays and inefficiencies in meeting sudden spikes in steam demand across the entire brewery site, impacting production processes such as by prolonging heating times for the pasteurizer. Despite these challenges, the adoption of biomass boilers aligns with sustainability goals and reduces reliance on fossil fuels, reflecting a broader

industry trend towards environmentally friendly practices in food and beverage production.

2.5.2 Pasteurizer Heating Systems

A Pasteuriser is a tunnel with multiple heating zones. Very small (atomized) water sprays heat the containers as they pass through each zone on a conveyor, resulting in progressive temperature increases until pasteurization is completed. Water jets then cool the containers as they move through the tunnel. Recirculating water between preheat sprays, where it is cooled by the entering food, and cooling zones, where it is heated by the hot products, saves energy and water. 'Steam tunnels provide the advantage of rapid heating, which results in shorter residence times and less equipment. Temperatures in the heating zones are gradually raised by lowering the amount of air in the steam-air mixes. Cooling occurs by the use of fine water sprays or immersion in a water bath.' (M. Indumathy et al., 2022)

2.5.3 Flow Control Valves

The control valve regulates fluid flow by changing the size of the flow path in response to the controller, allowing for direct control of the flow rate. This allows you to control process variables including liquid level, temperature, and pressure. In automatic control terminology, it is known as the last control element. Control valves can regulate fluid flow rates based on input from the controller. Control valves can regulate pressure and/or flow rate automatically, regardless of the pressure used. In some circumstances (as defined by design),

multiple plant systems may operate at pressure and temperature combinations that necessitate Class 300 valves, hence all control valves are typically Class 300 for interchangeability.

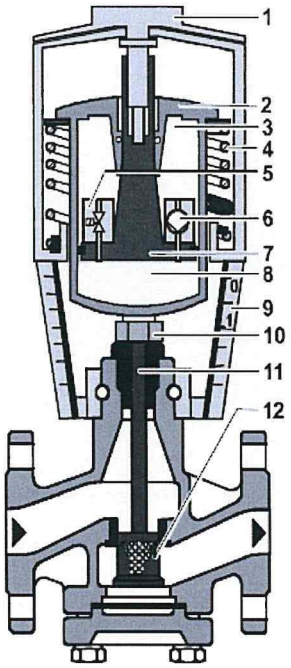
The process control industry employs control valves as the ultimate control element. Control valves adjust fluids, such as water, gas, steam, or chemical compounds, to correct for load fluctuations and keep the regulated process variable as close to the desired setpoint as possible. Control valves in the food processing industry are used to control conditions such as flow, pressure, temperature, and liquid level by fully or partially opening or closing in response to signals received from controllers that compare a "set point" to a "process variable" whose value is provided by sensors that monitor changes in such conditions. "A control valve manipulates a flowing fluid, such as gas, steam, water, or chemical compounds, to compensate for load disturbances and maintain the controlled process variable as close as possible to the desired set point"(Xiaoyan Xiong & Jiahai Huang, 2017)

2.5.4 Valve Sizing

Scholars (Dr.-Ing. Jörg Kiesbauer, 2001) and (Palash K. Bhowmik et al., 2023) observed that control valves may fail to adequately regulate the parameter under their control. Quality difficulties develop when the process is not under control. It is possible to oversize control valves. When precise adjustments are required, an excessively big control valve is insensitive and wastes money. The control valve is typically one to two lines smaller than the pipe. Control valves may have severe lag (reacting too late) if the sensor is located too far away. There could

be a low air supply at the actuator, or air leaks out, resulting in less force available to move the stem. The stem of a control valve may get sticky if the packing is excessively tight or there is a leak. The Motorized Control Valve is slow opening and shutting (approximately 15 to 27 seconds depending on valve size and speed settings), which lessens the risk for liquid velocity shock or "water hammer" commonly observed with speedy opening and closing solenoid valves.

2.5.5 Operation of Electro-Hydraulic Actuators



Valve opened

1 Manual adjuster
2 Pressure cylinder
3 Suction chamber
4 Return spring
5 Solenoid valve
6 Hydraulic pump
7 Piston
8 Pressure chamber
9 Position indicator (0 to 1)
10 Coupling
11 Valve stem
12 Plug

Figure 2.2: Parts of a flow control valve

When the valve in figure 2.2 is opened, the hydraulic pump [6] pumps oil from the suction chamber [3] into the pressure chamber [8], causing the pressure

cylinder [2] to move downward. The valve stem [11] retracts when the valve opens. Similarly, the return spring [4] is compressed.

Closing the valve - Turning on the solenoid valve [5] permits oil from the pressure chamber to flow back into the suction chamber. The squeezed return spring pushes the pressure cylinder higher. The valve stem stretches, and the valve closes as discussed by (A. Bhatia, 2014.).

The control valve assembly in figure 2.3 is typically made up of the valve body, internal trim parts, an actuator that provides the motive power to operate the valve, and a variety of other valve accessories such as positioners, transducers, supply pressure regulators, manual operators, snubbers, or limit switches. (B. Kalaiselvi, 2015) observed that control valves can be opened or closed using electrical, hydraulic, or pneumatic systems and positioners may be used to control the opening and shutting of the actuator based on an electrical or pneumatic signal.

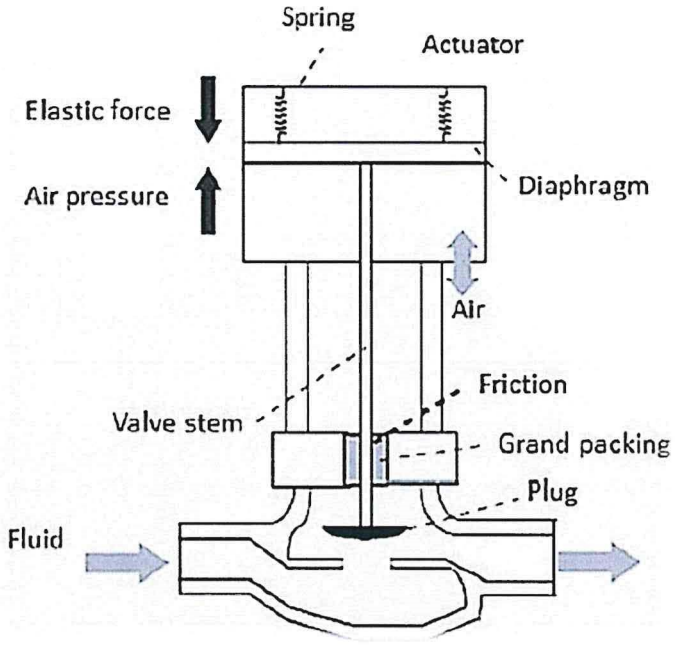


Figure 2.3: Flow control valve structure

2.6 Control Valve Tuning

Tuning the controller controls how the valve responds to a changing process parameter. When a valve requires a correction, tuning determines the speed and strength of the response. The controller has internal circuitry that causes a specified amount of movement in response to an input. Tuning the controller controls how the valve responds to a changing process parameter. When a valve requires a correction, tuning determines the speed and strength of the response. "The controller has internal circuitry that causes a specified amount of movement in response to an input. Once the trim position has been altered, the controller waits for the next measurement from the sensing element to determine the remaining difference to the set point. Valve stems are moved, and the flow

is altered until there is no difference between the setpoint and the actual value of the controlled parameter." (Roberts et al., 2017)

2.6.2 Type of Actuators:

Two types of actuators are common: pneumatic and electric actuators.

Pneumatic actuators use an air signal from an external control device to trigger a control action through a solenoid. These are typically offered in two forms: piston actuators and diaphragm actuators.

Piston actuators are typically utilized when the stroke of a diaphragm actuator is too short or the thrust is insufficient. Compressed air is applied to a solid piston housed within a solid cylinder. Piston actuators can be single or double acting, can sustain higher input pressures, and have smaller cylinder capacities to function at high speeds. Diaphragm actuators apply compressed air to a flexible membrane known as the diaphragm. These actuators are single-acting, which means that just air is supplied to one side of the diaphragm, and they can be either direct acting (spring-to-retract) or reverse acting (spring-to-extend).

2.6.3 Valve Positioner

(A. Bhatia, 2014) stated that a valve positioner is a control device that adds sensitivity to the valve and ensures proper positioning based on a control signal. It receives an electronic or pneumatic signal from the controller and compares it to the actuator's position. If the signal and the actuator position do not match, the positioner transmits the necessary power usually compressed air to move the actuator until the correct position is achieved. Because of its short positioning

time, the valve can be employed in situations where rapid load changes must be adjusted. The valve has no stuffing box, and the stem is sealed by a bellows that requires no maintenance. The valves are single seat straight-through, with a perforated cylinder. By dividing the flow into multiple distinct streams, noise is effectively suppressed. To protect the valve from dirt and grit, it is required to install a fine mesh strainer upstream.

2.7 Heat Exchange

A heat exchanger is a component that allows the transfer of heat from one fluid (liquid or gas) to another fluid. Reasons for heat transfer include among others; to heat a cooler fluid by means of a hotter fluid, to reduce the temperature of a hot fluid by means of a cooler fluid, to boil a liquid by means of a hotter fluid, to condense a gaseous fluid by means of a cooler fluid, to boil a liquid while condensing a hotter gaseous fluid. According to (Peter J. Fryer & Phillip T. Robbins, 2005), a heat exchanger is a vital component used in various industries to facilitate the transfer of heat between two mediums. This equipment comes in different shapes and sizes, depending on the specific application and thermal requirements of the application

(Convalve,2020) noted that there are two main types of heat exchanges: direct heat exchange and indirect heat exchange. Direct heat exchange involves direct contact between both media, resulting in efficient and quick heat transfer. A cooling tower is an example of direct heat exchange, as the water cools directly in contact with the air. In contrast, indirect heat exchange uses a barrier or divided media to separate the two mediums. This technique enables improved

control and optimization of the heat transfer process, leading to increased efficiency and cost-effectiveness.

2.7.1 Shell and Tube Heat Exchanger

A shell and tube heat exchanger like in figure 2.4 comprises a set of tubes contained within a shell structure. The fluid flowing within the tubes is termed as the tube side fluid, while the fluid circulating around the exterior of the tubes is referred to as the shell side fluid. The tube sheet(s) located at the ends of the tubes act as barriers between the tube side and shell side fluids. To ensure a tight seal, the tubes are typically rolled, press-fitted, or welded into the tube sheet. In cases where the two fluids exhibit significantly different pressures, it is common practice to direct the higher-pressure fluid through the tubes, with the lower-pressure fluid circulating on the shell side. This arrangement is economically advantageous since the heat exchanger tubes can be engineered to withstand higher pressures at a lower cost compared to reinforcing the entire shell structure.(Rajiv Mukherjee, 1998).

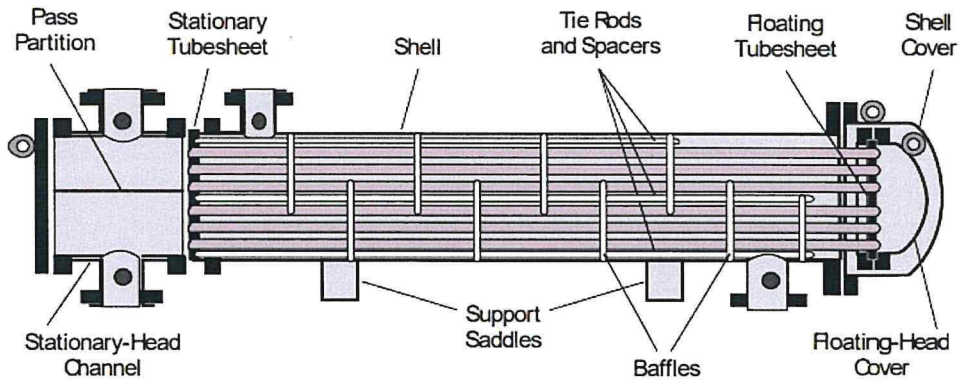


Figure 2.4: Shell and tube heat exchanger ***(Rajiv Mukherjee, 1998)***

2.7.2 Plate Heat Exchanger

A plate heat exchanger operates by utilizing plates instead of tubes to separate the hot and cold fluids. These plates create channels through which the hot and cold fluids alternate. Baffles are employed to regulate the fluid flow between the plates. Due to the expansive surface area of each plate, there is a substantial heat transfer area available for both fluids. Consequently, a plate heat exchanger can facilitate a considerably higher heat transmission compared to a similarly sized tube and shell heat exchanger, primarily due to the larger area provided by the plates. Further more, (Bengt Sundén & R. M. Manglik, 2007) state that plate heat exchangers tend to be more compact than tube and shell counterparts, thanks to the superior heat transfer efficiency of the plates.

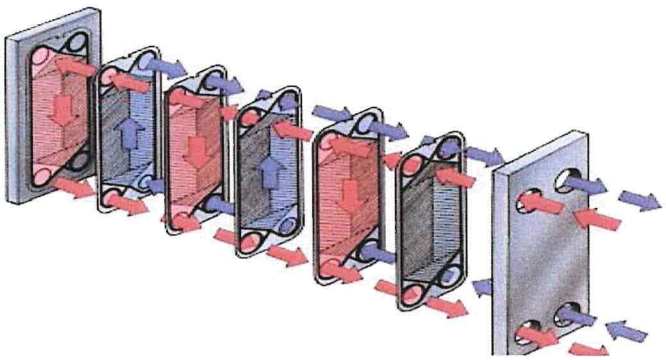


Figure 2.5: Plate heat exchanger

Gasketed plate heat exchangers like in Figure 2.5 provide stable sealing and efficient heat exchange. They use high-quality gaskets to create a secure seal, avoiding heat loss or leakage. These exchangers' flexibility makes them excellent for applications that require precise temperature control and efficient heat transfer.

How does a biomass fuel boiler work? A biomass boiler is a system that generates heat and energy but instead of using natural gas or other fossil fuels, biomass boilers generate energy through biomass combustion. Biomass boiler fuel types include agricultural, forest, urban, and industrial residues. This waste is used to produce heat and electricity with less effect on the environment than fossil fuels. Biomass in the form of wood was by far the largest source of American energy consumption until the mid-1800s when coal became our primary energy source. A biomass boiler system can convert biomass into energy through a few different processes. The most common method for industrial biomass boilers is direct combustion, where biomass burns, releasing heat that can warm buildings, heat water, or generate electricity via steam turbines. Additionally, biomass boilers can use thermochemical processes to create a liquid or gaseous fuels renewable diesel, methane, or renewable jet fuel (Tasneem Abbasi & S.A. Abbasi, 2010)

Biomass boiler uses thermal energy from the combustion of biomass fuel and air to produce superheated steam from feed water. Biomass fuel usually has a high moisture content, which leads to low boiler efficiency. (R. Saidur et al., 2011) argued that the boiler efficiency can be increased by using heat recovery devices to decrease the temperature of flue gas before it is exhausted from the boiler. Three heat recovery devices found in a typical installation of biomass boiler are economizer, air heater, and flue gas dryer. Economizer increases feed water temperature, air heater increases air temperature before combustion, and flue gas dryer decreases the moisture content of fuel. Limited available thermal energy

of flue gas means that a decision must made in selecting the sizes of these devices.

2.8. Food and Beverages Industry

Presently, the industry does obtain much of its energy from heavy Fuel oil (HFO). Yet the sector produces significant amounts of bio wastes that can be converted into energy; however, in most cases, these feedstocks have high moisture content and are unsuitable for thermo-chemical conversion processes. Although some projects are economically attractive, generally, a major barrier for the implementation of solid biomass energy systems in the food and beverages industries are the high investment costs. Also, the supply infrastructure is insufficient or non-existing and biomass availability and security of supply may not be guaranteed. (Malico et al., 2019). Distinct modes/strategies of biomass feeding control influence the CO and NO emissions during biomass combustion in industrial furnaces. This observation suggests that it is possible to improve the performance of these combustion systems by developing and implementing an optimized control algorithm, allowing more suitable biomass feeding into the furnace when under automatic operating mode. (Valente et al., 2020)

The growing world population and economies in transition put more pressure on the food and commodities supply chain. This scenario and environmental concerns necessitate shifting towards sustainable energy sources to mitigate GHG emissions.

The historical energy Due to the energy-intensive nature of the industrial sector, renewable energy resources are not likely to be able to achieve net-zero carbon emissions during plant operations. Unlike buildings, power generation, and transport sectors, the industrial sector is hard to electrify and decarbonize. Hence, technological innovation for the design of energy intensive equipment should be promoted to improve fuel efficiency and compatibility with carbon-neutral fuels such as hydrogen. (Sajid et al., 2022). (Dangprok et al., 2023) noted that however, other factors and costs should be considered before actual generation for best results.

When a manufacturing plant chooses to convert to biomass energy supply, several issues arise and the capacity to change the feedstock used in biomass boilers during normal plant operation is an important aspect in their further diffusion in modern energy systems. This is only achievable with the adoption of advanced control techniques that use knowledge of the state variables and varying fuel qualities. (Lim et al., 2021) state that biomass combustion is critical in the production of heat and power using renewable energy methods. Unlike volatile renewable energy technologies such as solar thermal plants or wind turbines, biomass combustion-based energy systems can produce a consistent and stable thermal or electrical output, in addition to combustion, conventional biomass feedstocks are being used in a growing range of methods for converting biomass into chemicals. This results in conventional biomass feedstocks becoming more expensive. "Hence, a key element in the further distribution of biomass boilers is their capability of utilizing new and alternative biomass"

(Zemann et al., 2020) this has in the past, informed management of UBL to incur installation costs for this technology.

2.9. Heat Exchanger Modelling in a Steam Boiler System

The performance of heat exchangers is pivotal to the efficient operation of pasteurizer heating systems, particularly in optimizing thermal energy transfer from steam to the heating medium. In the context of pasteurization within the food packaging industry, accurately modelling heat exchanger dynamics is crucial for enhancing energy efficiency and ensuring precise temperature control. Such modelling enables engineers to analyse heat transfer mechanisms, temperature profiles, and system performance, offering valuable insights into factors that influence operational efficiency.

For a pasteurizer operating with limited steam supply, understanding heat exchanger behaviour becomes even more critical. By employing heat exchanger modelling, it is possible to identify inefficiencies, optimize heat transfer, and design systems tailored to achieve consistent pasteurization temperatures. This ensures product safety and quality while minimizing energy wastage. Additionally, modelling facilitates predictive analysis, allowing researchers to test various design configurations and operating conditions to determine the most cost-effective solutions.

Incorporating heat exchanger modelling into system improvement efforts can also assist in troubleshooting issues, identifying areas for enhancement, and informing decisions on retrofitting or upgrading the heating system. By

leveraging these insights, this study aims to demonstrate how targeted design improvements in the pasteurizer's heating system can optimize production efficiency, reduce energy consumption, and maintain high standards of food safety. "The heat exchanger system, actuator, valve, and sensor are theoretically modeled based on existing experimental data. The heat flow into the tube is the difference between the heat from the hot liquid entering in and the heat flowing out to the product liquid"(A.A.Emhemed et al., 2017)

"Modelling takes place on two levels. On the local level or cell level, the equations of energy balance in differential form are used."(Kusche & Schulte, 2019) "Viewed from the perspective of dynamic behavior, Heat exchangers have distributed parameters and constantly changing temperatures, making direct Laplace transformation difficult to solve. Double Laplace transformation can lead to numerical issues. There are several options: using a linear or logarithmic distribution, which assumes perfect mixing and immediately drops the temperature to the exit temperature. Alternatively, assuming imperfect mixing and keeping the temperature at the inlet value until it exits the cell, which may feel unrealistic, the basic variables of interest include Density, Viscosity, and Specific heat."(Bobič, 2023) Heat exchanger design is an extremely important issue in industry. The traditional method of solving it is through trial and error techniques, as described in Kern (1950), in which one first guesses the overall heat transfer coefficient, then selects the heat exchanger shape based on the required area, and then recalculates the overall heat transfer coefficient. If the found value is greater than the guessed value, the exchanger design is complete;

otherwise, a new value for the total heat transfer coefficient must be estimated and the cycle repeated.(Coelho Lemos et al., n.d.)

Under given conditions, there are several methods of designing and sizing the correct heat exchanger. (Ezgi, 2017) states that the thermal performance analysis uses four methods.

There are a variety of heat exchanger designs available in industries. "To simulate the heat exchanger, the following assumptions were made: Fluid flows are simplified to a one-dimensional, homogenous flow regime, the inflow and outflow of mass are equal, axial heat conduction of fluids can be ignored, walls have infinite thermal conductivity, meaning the temperature is the same on both sides of a single cell, heat flow to the environment is minimal, fluid kinetic energy can be overlooked, pressure drops within the heat exchanger are overlooked."(Rutgers & Johan Schmaal, 199 C.E.)

(Padhee et al., 2011) noted that the shell and tube heat exchanger system outlet temperature is controlled using a conventional feedback controller. Despite ongoing developments in control theory, the PID control algorithm remains the most widely used approach for industrial process control. This is not just owing to the basic structure, which is conceptually easy to understand and allows for human tuning, but also because the algorithm gives appropriate performance in the great majority of applications. Heating curve switching, a control mechanism that targets exergy losses, essentially uses a heating curve with a higher supply temperature to compensate the exergy losses in production mode. Three control

mechanisms were proposed to solve the flow blocking problem, and all of them were validated as concluded by (Ilya Elizarov et al., 2022)

This study will attempt to improve heat exchanger design by choosing the best material and component design such as the shape and structural layout of each individual plate in the heat exchanger. (Bobič, 2023) notes that although the majority of heat exchanger models on the market use a fish bone sample, it was decided to test the heat exchanger with a microplate sample. The explanation is that heat exchangers with microplates are more efficient since the flow between the plates is more muted and the distribution by plate is generally better, resulting in a 20-30% lower pressure drop or much greater heat transfer than in fish bone structure.

2.9.2. The Frame Plate.

This gives the heat exchanger structural support. And it takes the shape of the individual heat exchanger plates in terms of dimension and construction. **Figure 2.6** shows a frame plate with four flow channels labelled S1, S2, S3, and S4. S3 is the inlet channel for water, and S4 is the outlet channel for water, S1 is inlet channel for steam and S2 is the outlet channel for condensate. This construction allows for counter flow through the heat exchanger and ensures efficient heat exchange.

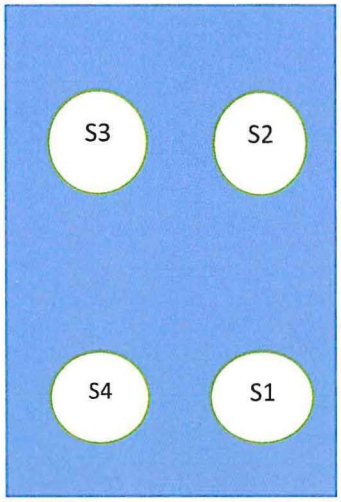


Figure 2.6: Flow pattern of the frame plate

2.9.3. Movable Pressure Plate

The movable pressure provides further structural support to the heat exchanger and holds all the other plates tightly together against the frame plate. Also, this robust design allows for flexibility during maintenance of the unit. The actual positions of the pressure plate and the frame plate on the heat exchanger and their orientation must be maintained in order to preserve integrity of the heat exchanger, this will avoid leakage and fluid blockage or fluid flowing into the opposite side causing direct mixing of the steam and water. This design of the heat exchanger seamlessly allowed for addition of extra plates in order to enhance the surface area of the unit.

2.9.4. Summary of Literature Review and Research Gaps.

Existing studies like (Bengt Sundén & R. M. Manglik, 2007; Rajiv Mukherjee, 1998) and (James H. Steele, 2000; Li-Zhi Zhang, 2020)have emphasized the

importance of optimizing heating systems in the food processing industry to enhance production efficiency and reduce energy consumption. Secondly, while biomass boiler systems hold promise as sustainable alternatives to traditional fossil fuel-based heating systems (Anton Beck et al., 2021; Changchun Liu et al., 2022), limited research has been conducted specifically on their integration with pasteurizer heating systems in food processing facilities. Thirdly, previous research by (Anton Beck et al., 2021; Li-Zhi Zhang, 2020) highlighted the significance of factors such as heat transfer efficiency, temperature control, and system reliability in optimizing the performance of heating systems. However, there is a gap in the literature regarding comprehensive low-cost designs and improvements in pasteuriser heating systems but rather most studies focused on effective operation. There is also limited literature tailored specifically to pasteurizer heating systems coupled with fluctuating steam pressure and inconsistent supply of steam. Summarily, there is a need for further research to explore the potential modifications and benefits of a low-cost improvement to the heating system that's associated with the adoption of fluctuating steam supply systems in the food processing industry. Overall, the literature review provided valuable insights into the current state of knowledge in pasteurization, its associated heating system designs and also identified gaps that the present study seeks to address through empirical research and analysis.

CHAPTER THREE: METHODOLOGY

3.0 Introduction

The project intended to study the existing heating system and identify key parameters to modify in order to sustain the pasteurization process, in order to optimize packaging beer operations for production line efficiency at Uganda Breweries Limited. The study employed a mixed methods design, combining quantitative evaluation, experimental validation, and operational data analysis.

System Characterization: Conducted baseline measurements of steam pressure, temperature profiles, downtime incidents, and heat transfer efficiency over a continuous 6 months period. Recorded production and quality data from Harford and Krones systems for comparison.

Modification and Installation: Implemented low-cost modifications such as installing additional heat exchanger plates and fine-tuning PID control parameters. Calibrated the I/P converter for improved valve responsiveness at lower steam pressures (down to 1.5 bar).

Design Simulation: Used Simulation software to evaluate multiple heat exchanger the new configurations against baseline conditions under fluctuating steam pressures. Evaluated plate designs, flow rates, and pressure drops for optimal performance.

Experimental Validation: Operated and monitored the modified system for at least 5 months. Continuously monitored temperature stability, steam usage, and downtime events.

3.1. Improvement Identification and Optimization of the Pasteurizer Heating System.

The study aimed to identify potential design modifications for the heat exchanger system that can maintain efficiency at low steam pressure levels. To address Objective 1, thermal design calculations and simulation techniques were employed to evaluate modifications to the plate heat exchanger. Exploring concepts such as enhanced heat transfer surfaces and optimized flow patterns to improve heat exchanger and pasteurizer machine performance under varying steam pressure conditions.

3.1.2. Determining the pressure drop through a plate heat exchanger.

Pressure drop represents the resistance to fluid flow across the exchanger, higher pressure drops require more pumping power, which increases energy consumption. Keeping pressure drop within allowable limits ensures the exchanger operates efficiently without excessive pumping costs. A certain pressure drop is necessary to maintain turbulence, which improves heat transfer. Exceeding design pressure drops can cause vibration, gasket failure, or even plate deformation.

The pressure drop in a plate heat exchanger can be estimated using the correlation:

$$\Delta P = \Delta P \text{ ch} + \Delta P_{c_0} \qquad (1)$$

Where;

ΔP = Pressure drop through the exchanger, per side (Pa)

ΔP_{ch} = Pressure drop through the exchanger channels, in between each plate (Pa)

ΔP_{co} = Pressure drop in the inlet/outlet ports of the heat exchanger (Pa)

Allowable pressure drop is noted as 9.9 kPa for steam and 10.2 kPa for water from the existing system.

3.1.3. Determining heat flux through the system

The heat flux (ϕ)can be calculated knowing the flowrate, the in and out temperatures and the specific heat of the fluid, either on hot or cold side.

$$\phi = \dot{m}_c \cdot cp_c \cdot \left(T_{c_0} - Tci\right) \quad (2)$$

$$\phi = \dot{m}_h \cdot CP_C \cdot \left(Th_0 - T_{h_i}\right) \quad (3)$$

Where;

m_c = mass flowrate on cold side (m3/h)

Cp_c = specific heat of cold fluid (J/kg/K)

T_{co} = outlet temperature of cold side (C)

T_{ci} = inlet temperature of cold fluid (C)

m_h = mass flowrate on hot side (kg/h)

Cp_h = specific heat of hot fluid (J/kg/K)

T_{ho} = outlet temperature of hot side (°C)

T_{hi} = inlet temperature of hot fluid (°C)

3.1.4. Approximating the Heat Exchanger Size

It is then possible to approximate the size of the heat exchanger by estimating the overall heat transfer coefficient H.

H for plate heat exchanger is often in between 2 to 7 $kW.m^2.K^{-1}$.

$$\phi = H \cdot S \cdot \Delta Tm_l \quad (4)$$

Where;

H = overall heat exchange coefficient ($kW.m^2.K$-1)

S = area of the heat exchanger (m^2)

ΔTm_l = Log mean temperature difference (LMTD) (K)

These calculations were compared to baseline system data to verify achievement of at least a 20% increase in efficiency within a 6-month implementation timeframe.

3.1.5. Improvement Identification and review.

Based on the literature review findings, potential design modifications for the heat exchanger system that can maintain efficiency at low steam pressure levels were explored using concepts such as enhanced heat transfer surfaces, optimized

flow patterns, and innovative materials to improve heat exchange performance under varying steam pressure conditions.

Identification of Key Parameters: Begun by identifying key parameters affecting heat exchanger performance. These parameters include surface area, flow velocity, material properties, and geometry of the heat exchanger components.

3.1.6. Heat Transfer Rate Calculation

The overall heat transfer rate (ϕ) in a heat exchanger is given by

$$\phi = H \cdot S \cdot \Delta Tm_l \tag{4}$$

Log Mean Temperature Difference (LMTD) for a counter flow heat exchanger.

$$\Delta Tm = \frac{(T_{h,in} - T_{c,out}) - (T_{h,out} - T_{c,in})}{In(\frac{T_{h,in} - T_{c,out}}{T_{h,out} - T_{c,in}})} \tag{5}$$

Where;

$T_{h,in}$ = Hot fluid inlet temperature (°C)

$T_{h,out}$ = Hot fluid outlet temperature (°C)

$T_{c,in}$ = Cold fluid inlet temperature (°C)

$T_{c,out}$ = Cold fluid outlet temperature (°C)

Comparison of overall heat transfer coefficient (U-values)

Typical overall heat transfer coefficients (U) for different heat exchangers:

- Shell-and-tube heat exchanger (SHE): 500–1500 W/m²·K
- Plate heat exchanger (PHE): 2000–6000 W/m²·K

Since $U_{PHE} > U_{SHE}$ the plate heat exchanger will transfer more heat per unit area.

3.1.7. Surface Area Requirement

To achieve the same heat duty Q, the required surface area is:

$$A = \frac{Q}{U\Delta Tm_l} \tag{6}$$

For the same Q, since PHE has a higher **U**-value, the required area for a plate heat exchanger is significantly smaller than for a shell-and-tube heat exchanger.

3.1.8. Heating Water for Pasteurization

- **Hot fluid:** Steam at 120°C, exiting at 90°C
- **Cold fluid:** Water entering at 20°C, exiting at 85°C
- **Required heat duty:** Q = 500 kW

From equation (5)

$$\Delta Tm = \frac{(120 - 85) - (90 - 20)}{In(\frac{120 - 85}{90 - 20})} \tag{5}$$

$$\Delta Tm = 50.4K$$

Now calculating required surface area:

- For **shell-and-tube** with U = 1000W/m²·K

From equation 6

$$A = \frac{Q}{U\Delta Tm_l} \quad (6)$$

$$A = \frac{500 \times 10^3}{1000 \times 50.4}$$

$$A = 9.92m^2$$

For **plate heat exchanger** with U= 4000 W/m²·K:

$$A = \frac{Q}{U\Delta Tm_l} \quad (6)$$

$$A = \frac{500 \times 10^3}{4000 \times 50.4}$$

$$A = 2.48m^2$$

From the calculations conducted to evaluate different configurations and types of heat exchangers, the results obtained indicated that the plate type heat exchanger offers higher heat transfer rates and efficiency compared to the traditional shell and tube design since the plate heat exchanger requires 75% less surface area than the shell-and-tube exchanger for the same heat duty. This improvement is attributed to the larger surface area available for heat exchange in the plate type configuration. This study therefore was focused on developing a plate heat exchanger with dimensions fit to purpose in the existing system of the line five pasteuriser heating system. This system has a default requirement of mean temperature difference of 83.5K, temperature requirement of 85 degrees Celsius and heat transfer coefficient of 2.893W/(m^2.K)

3.2. Implementation and Validation of Steam Control System Modification.

To address Objective 2, the steam modulating valve and control logic were analyzed and optimized. In order to understand the requirements for the improvement to be achieved, operation data was studied and relevant parameters were collected and compared with plausible theoretical adjustments.

The water moving through the heating system is circulated by means of an electrically powered pump, from a machine reservoir called the hot buffer, for efficient operation of the machine, the temperature of the water in the hot buffer has a minimum set point as shown in **Figure 3.1**, the set point is constantly monitored throughout machine operation by use of temperature transmitters and a PLC (Programmable Logical Control). When the temperature at the hot buffer falls below the set point, a signal is sent to the steam control valve to open and allow for an equivalent compensation through the heat exchanger. The level transmitter at the hot buffer communicates the amount of water in the reservoir at any given moment, if this falls below the set point a pneumatic valve is opened to let in fresh water. Addition of fresh water affects the temperature of the system and therefore the temperature sensor signals for compensation as discussed previously. The signal exchange is discussed further later in this chapter.

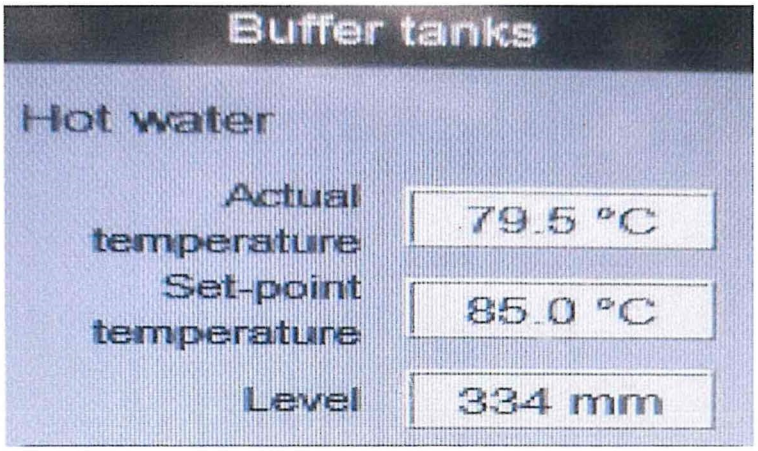


Figure 3.1: System temperature set points

The main operating parameters of the existing system were found to be,

1. Steam pressure, the minimum allowable steam pressure of the system is set at 3.5 bars, and a maximum of 7 bars, this is monitored by use of a regulating valve installed with pressure and temperature gauges on the supply line.
2. Surface area; the heat exchanger requires to have sufficient surface area to enable efficient heat transfer through the system. This is ensured through-out the design of the unit and the dimensions of the component parts.

Figure 3.2 is a picture of gauge readings for the temperature and pressure of steam flowing through the heating system at the given moment. These analog gauges are very vital to help an individual to verify the digital reading displayed at the machine interface, usually when the machine signals a steam deficiency, these are used to understand if the alarm is genuine or its due to an internal

machine fault. This can then be rectified to restore optimum production conditions.

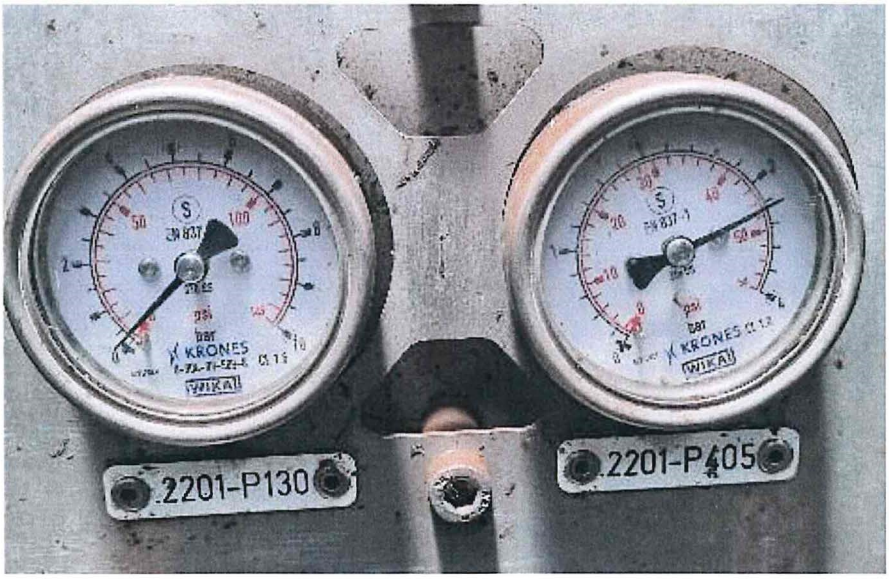


Figure 3.2: Pressure and Temperature gauges

Heat transfer area stated at $1200m^2$, this represented by the existing heat exchanger, which is advantageous due to its compact nature, is not limited by low surface area for heat transfer. Flow rate of water from the machine through the heat exchanger to the hot buffer of the machine, this is sustained by a pump through an enclosed pipeline fitted with flow meters. Optimum flow rate for the line five heating system is set at a minimum of 32 m^3/h. the flow rate is observed to be relatively stable since the pump runs at a constant speed, unless there is a blockage is the system such as caused by a clogged strainer. **Figure 3.3** is a picture of the water flow meter which is mounted at the inlet pipeline of the heat

exchanger and it measures, displays and communicates the actual flow rate of water through the heating system.

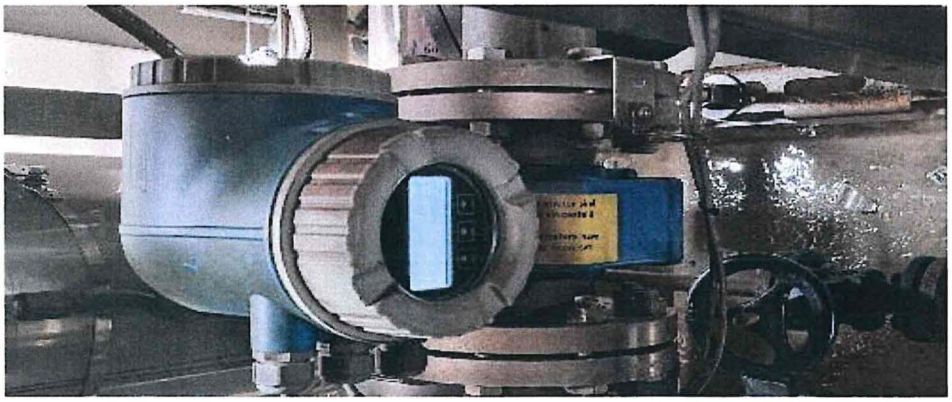


Figure 3.3: Water flow meter

As a governing rule, the pressure drop in the system should not exceed the maximum allowable pressure drop of the heat exchanger, otherwise the system becomes inefficient and wastes a lot of useful energy. The maximum allowable pressure drop in the system should therefore be of a higher value that of the existing unit for the system to be able to cope under fluctuating steam pressure conditions.

3.2.2. Control and Operation Modification

The study evaluated potential control and operation modifications necessary to improve the system's response to fluctuating steam pressure. This involved implementing advanced control algorithms, integrating sensors for real-time monitoring, and adjusting operating parameters to optimize performance during transient conditions. Temperature control mechanisms play a crucial role in ensuring optimal performance of the pasteurizer heating system.

PID controllers were implemented to regulate fluid flow rates and maintain precise temperature levels during pasteurization processes. The effectiveness of the PID control in achieving tight temperature control with deviations is well within acceptable limits. The control and operation of the steam regulating valve was altered by adjusting the machine set point to allow process continuation at lower steam pressures of up to 1.5 bar, this was achieved by installing an I/P converter (current/pressure converter) that communicates the effective process value, as the position of the stem of the steam regulating valve, the PID controller then compares the set point value against the process value and determines the magnitude of deviation. The PLC is then set to send a respective command signal equivalent to the prevalent deviation. The command signal is a small current ranging from 4mA and 20mA.

3.2.3. Process value (PV) - Set point value (SP) = Deviation(D)

For values of D $\geq$0, the command current generated is set at 4mA. This does not send any pneumatic pressure to the diaphragm of the regulating valve and thus it remains closed. For values of D< 0 ;command current of 20mA the system opens the regulating valve to 100% by use of a compressed air signal. At 8mA the valve opens at 25%, at 12 mA the valve opens at 50%, at 16Ma the valve opens at 75%, this range enabled the valve to respond effectively to the fluctuating steam conditions.

Figure 3.4. shows a signal exchange diagram through the heating system indicating the different components that read and transmit system data and how the system responds towards the information. It includes both mechanical and

electrical parts as indicated in the table 4.5. Steam from the biomass boiler at the packaging supply valve flows through the Flow meter (FM) the digital reading is displayed on the machine interface, and steam then flows through the steam regulating valve (SRV) whose opening is based on conditions discussed above, and on into the heat exchanger

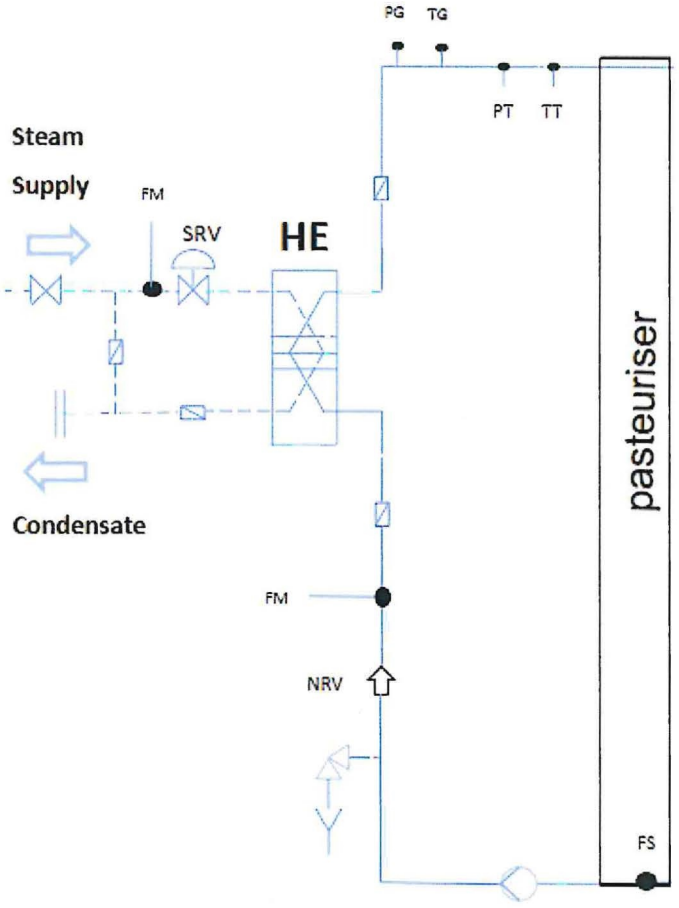


Figure 3.4: Control drawing for the heating system

Table 3.1: Key for the control flow diagram

Symbol	Name
FM	Flow Meter
SRV	Steam regulating valve
HE	Heat Exchanger
TT	Temperature transmitter
PT	Pressure transmitter
PG	Pressure gauge
TG	Temperature gauge
NRV	Non return valve
FS	Flow switch
	Pump

3.3. Downtime Reduction Analysis.

To address objective 3, methodology focused on linking design improvements to measurable operational outcomes.

3.3.1. Machine Records Review

Secondary data about pasteurizer down time for the machine was retrieved from available records at in the packaging hall archives. This data was extracted from Harford and Krones software archives and their effect on production,

maintenance cost and efficiency losses caused by breakdowns was summed up and tabulated. This was further cross referenced with similar data as reported by production managers per shift for the past three years.

Data extracted included;

(1) Major breakdowns at pasteurizer related to heating system and time taken to restore machine for production

(2) Time lost related to heating system failure or build up and frequency of occurrence.

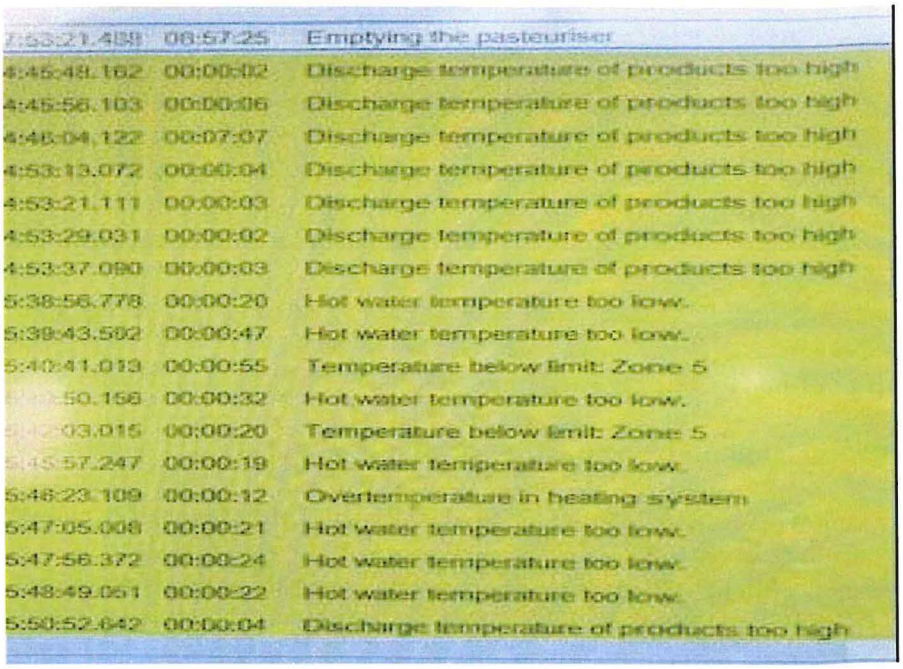
Control System Design: The modulating valve operation program was re-parameterized to achieve ±1°C temperature stability in 95% of production cycles.

Experimental Validation: A 5-month continuous monitoring program was conducted, using installed PLC sensors, thermocouples, and flow meters to validate the effectiveness of the modification.

3.3.2. Sources of Data:

Primary data was collected through observation. Collected through direct observation and capability studies, focusing on cycle times, machine stops, and valve responsiveness, the related machine availability losses, performance losses and quality losses that directly affect packaging line five efficiencies as observed in **Figure 3.5**. Secondary data was obtained by reviewing the available records

on packaging beer line performance, Harford production efficiency reports and maintenance logs from the past three years were reviewed.



7:53:21.489	00:57:25	Emptying the pasteuriser
4:45:48.162	00:00:02	Discharge temperature of products too high
4:45:56.103	00:00:06	Discharge temperature of products too high
4:46:04.122	00:07:07	Discharge temperature of products too high
4:53:13.072	00:00:04	Discharge temperature of products too high
4:53:21.111	00:00:03	Discharge temperature of products too high
4:53:29.031	00:00:02	Discharge temperature of products too high
4:53:37.090	00:00:03	Discharge temperature of products too high
5:38:56.778	00:00:20	Hot water temperature too low.
5:39:43.592	00:00:47	Hot water temperature too low.
5:40:41.019	00:00:55	Temperature below limit: Zone 5
[illegible]50.156	00:00:32	Hot water temperature too low.
[illegible]03.015	00:00:20	Temperature below limit: Zone 5
[illegible]57.247	00:00:19	Hot water temperature too low.
5:46:23.109	00:00:12	Overtemperature in heating system
5:47:05.008	00:00:21	Hot water temperature too low.
5:47:56.372	00:00:24	Hot water temperature too low.
5:48:49.061	00:00:22	Hot water temperature too low.
5:50:52.642	00:00:04	Discharge temperature of products too high

Figure 3.5: Historical alarm list for the pasteurizer

3.3.3. Measurement of Downtime Reduction

Downtime was calculated as

$$DR\% = \frac{BD - PMD}{BD}\% \tag{7}$$

Where;

DR is down time reduction

BD is baseline down time

PMD is post modification downtime

The Target achievement was defined as ≥30% downtime reduction within 12 months of implementation.

3.4. Research Tools/ Instruments

During observations, stop watch (timer) and data gathering work sheets were used to collect data. Stop watch was used to measure the amount of time spent for the duration of a particular activity in minutes.

Data gathering work sheets were used to note readings taken from stop watch after observing a particular activity from start to finish. Then the information was used to tabulate total downtime per shift, production time, machine speed, heating efficiencies, etc. This data was used to identify patterns, trends, and areas for improvement in efficiency and responsiveness to fluctuating steam pressure. Data was collected on the pre-current operation of the pasteurizer heating system, including steam pressure profiles, temperature variations, energy consumption, and downtime incidents and complied through observation and active planned participation. The heating process on the pasteurizer was examined to understand how the process affects packaging beer into bottles and their movement time on the assembly line. The function of packaging beer line is to pack the right beer brand into bottles at right time in the right amount in sequence at minimum production cost.

3.5. Data Analysis

Descriptive statistics and comparative analysis were applied to baseline and post-modification data. Statistical validation employed paired-sample t-tests to

confirm whether observed improvements in heat transfer efficiency, temperature stability, and downtime reduction were significant.

3.6. Ethical Considerations

Permission to access production data was obtained from Uganda Breweries Limited (UBL). All company operational data was anonymized, and findings were reported strictly for academic purposes without disclosure of sensitive commercial information.

CHAPTER 4. RESULTS AND FINDINGS

This chapter presents findings and discussions of the findings that were discovered during data collection on the study of optimization of heating system of the pasteurizer on packaging operations for beer production line at 5 UBL. These are presented by first analyzing financial implication, then identifying bottlenecks to steam supply, determining efficiency loss caused by steam fluctuations and desired modification to improve line efficiency. The interpretation of graphs is based on history of the packaging beer line performance and this data was used to identify patterns, trends, and areas for improvement in efficiency and responsiveness to fluctuating steam pressure.

4.1.1. Operating System Data.

The **table 4.1**, shows fluid properties such as viscosity and specific heat of the two main important fluids in the system that is; steam and condensate on the hot side and water on the cold side.

Table 4.1: Fluid properties

Fluid properties	**Hot side**	**Hot side**	**Cold side**
	Liquid phase	Vapour phase	Liquid phase
Viscocity (cP)	0.198/0.200	0.0135	0.801/0.353

Specific heat: kJ/(kg.K)	4.29	1.9	4.18

(a). Inlet and Outlet Temperature of Each Fluid.

The **Table 4.2**, shows temperatures of the different fluids at the inlet and outlet of the heat exchanger, the data in the table represents the heat lost and gained by different fluids through the system. Steam is introduced at high temperature and exits at a lower temperature, while water is introduced at relatively low temperature and exits the heat exchanger at high temperatures.

Table 4.2: Fluid inlet and outlet temperatures.

fluid	**Inlet temperature**	**Outlet temperature**
Steam °C	150	130
Water°C	30	85

(b). Inlet Pressure of Fluids

The **table 4.3**, displays pressure of the different fluids at the infeed of the heat exchanger and at the outlet of the heat exchanger, the data represents the drop, in pressure through the heat exchanger. The data indicates that both fluids experience a pressure drop through the heat exchanger.

Table 4.3: Fluid Inlet and outlet pressures

Fluid	Inlet pressure	Outlet pressure
Steam	3.5 bar (minimum)	2.2bar
Water	10	9

4.1.2. Determining Heat Flux Through the System

The heat flux ϕ can be calculated from equations (2) and (3);

$$\phi = \dot{m}_c \cdot cp_c \cdot \left(T_{c_0} - Tci\right) \quad (2)$$

$$\phi = \dot{m}_h \cdot CP_C \cdot \left(Th_0 - T_{h_i}\right) \quad (3)$$

m_c 50000 (kg/h)

$Cp_c = 4.18$(J/kg/K)

T_{co} =85(°C)

T_{ci} = =30(°C)

$m_h = 4680$(kg/h)

$Cp_h = 4.29$(J/kg/K)

$T_{ho} = 130$ (°C)

$T_{hi} = 150$ (°C)

$$\phi = 2900 \cdot 5KW$$

For new design

$m_c = 154.7$ (m3/h)

$Cp_c = 4.18$(J/kg/K)

$T_{co} = 95$(°C)

$T_{ci} = = 30$(°C)

$m_h = 3046.9$(kg/h)

$Cp_h = 4.29$(J/kg/K)

$T_{ho} = 140$ (°C)

$T_{hi} = 150$ (°C)

$$\phi = 15340KW$$

Table 4.4: Heat flux through the old and new system

variable	Old design	New design	units
m_c	50000	154.7	kg/h
Cp_c	4.18	4.18	J/kg/K
T_c	85	95	°C
T_{ci}	30	30	°C
m_h	4680	3046.9	kg/h
Cp_h	4.29	4.29	J/kg/K
T_{ho}	130	140	°C

T_{hi}	150	150	°C
ϕ	2900.5	15340	KW

4.1.3. Approximating the Heat Exchanger Size

Accurately estimating the size of the plate heat exchanger is crucial for optimizing the pasteurizer heating system in a cost-effective manner. The heat exchanger's surface area directly impacts heat transfer efficiency, steam utilization, and overall system performance. A properly sized PHE ensures that the pasteurizer reaches and maintains the required temperature efficiently, reducing downtime and energy waste. Determining the correct PHE size allows for strategic modifications, such as adding extra plates to improve performance without replacing the entire unit

From equation (4);

$$\boldsymbol{\phi = H \cdot S \cdot \Delta T m_l} \qquad (4)$$

H = overall heat exchange coefficient ($kW.m^2.K\text{-}1$)

S = area of the heat exchanger (m^2)

$\underline{\Delta T_{ml}\,(K)}$

H = 2.893 ($kW.m^2.K\text{-}1$)

$\underline{\Delta T_{ml}\,(K)=0.835}$

value of S can thus be calculated, as a 1st approximation of the heat exchanger size.

$$S=\frac{2900.5}{0.835\times2.893}$$

S = area of the existing heat exchanger=1200 (m^2)

For the new design

$$S=\frac{15340}{0.835*2.893}$$

$$=6350.2\ m^2$$

4.1.4. Calculating the Number of Plates Required.

With references from Alfa Laval an international supplier, a plate size and design were chosen, and calculated the number of plates required as follows,

$$\mathbf{N = S/s} \qquad \textbf{(5)}$$

Where;

N = number of plates required=50

S = total heat exchange area =1200(m^2)

s = size of a single plate=24 (m^2)

$$S = 1200(m^2)$$

$$s = 24\ (m^2)$$

$$N=\frac{1200}{24}=50\text{plates}$$

To calculate the number of channels : n = (N-1)/2=24.5.

For the new design

$S = 6350.2\ (m^2)$

$s = 113.4\ (m^2$

$N = \frac{6350.2}{113.4} = 56$ plates.

4.1.5. Modification and Optimization of the Pasteurizer Heating System

ANSYS Fluent software was used to simulate fluid flow and heat transfer within the plate heat exchanger under both baseline and modified designs. Boundary conditions included inlet steam pressure at 3 bar, water inlet at 25°C, and flow rates consistent with brewery operations. Results are shown in **Table 4.5** and illustrated in graph in **Figure 4.1** below, indicating a clear enhancement in overall heat transfer coefficient.

Table 4.5: Simulation results for heat transfer after modification.

Scenario	Heat Transfer Coefficient ($kW/m^2 \cdot K$)	Improvement (%)
Baseline	2.89	-
Modified Design	3.55	22.8
Simulation Validation	3.52	21.8

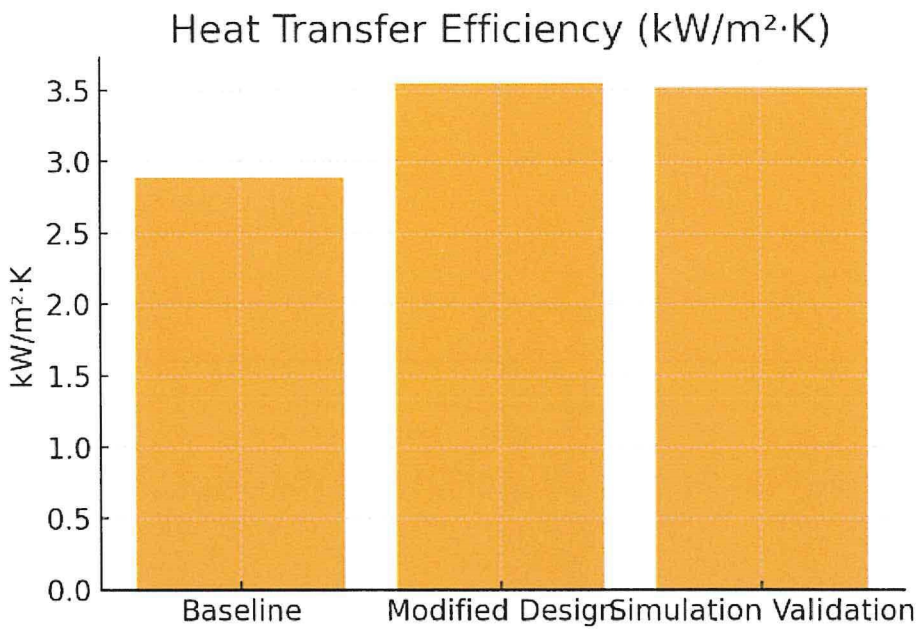


Figure 4.1: Graphical representation of heat transfer simulation results

Post-modification thermal analysis indicated a measurable improvement in heat transfer efficiency, **Table 4.6** indicates the quantitative improvement in heat transfer efficiency of the heat exchanger as a result of adding additional identical plates.

Table 4.6: Baseline efficiency verses Post modification efficiency.

Parameter	Baseline	Post-Modification
Heat Transfer Efficiency (kW/m²·K)	2.89	3.55

Percentage Improvement		22.8%

4.1.6. Financial consideration

A practical and cost-effective solution for enhancing the performance of the TS20MFG heat exchanger was the addition of 5 identical plates, rather than purchasing a completely new unit. According to the sales quotation from a heat exchanger manufacturer (**Appendix A**), acquiring a new unit would cost over €22,809, including freight to Kampala. By comparison, adding 5 plates at €170 each (totaling €850) represented a significantly lower expense. This approach not only minimized capital expenditure but also utilized the existing design, which allows for additional plates without altering the setup. From a technical standpoint, the added plates increased the heat exchanger's surface area, enhancing its ability to transfer heat efficiently. This improvement was particularly critical in handling lower steam pressures down to 1 bar while significantly reducing the heating time during start-up. The modification addressed inefficiencies caused by fluctuating steam supply, ensuring the pasteurizer can maintain a stable temperature and reduce time lost to delays during operation. Calculations conducted earlier confirm that this adjustment aligned with the system's requirements and was able to deliver tangible performance benefits. Additionally, the installation of the new plates does not require external labor, as the task can be completed by in-house personnel,

saving time and additional costs. Constraints such as limited space and the relatively new condition of the existing heat exchanger further supported this decision. Installing a new unit would not only incur higher costs but also potentially require additional adjustments to fit the existing system layout, leading to longer downtimes.

4.2.0. Steam Generation Efficiency

Assessing the steam generation efficiency of the biomass boiler system as the primary source of steam for the brewery. Experimental data collected during boiler operation indicate that incorporating biomass fuel rationing, adding wood chips with high calorific value leads to increased steam generation rates and thermal efficiency.

Table 4.7 showing average time taken by the biomass boiler to generate and build maximum pressure of 10 bars when the different available fuels are fed to the furnace, and the observations made during the process.

Table 4.7: Different biomass fuels time to generate maximum pressure

Fuel	Time taken to build 10bars(minutes)	Observation during operation
Bagasse	60	Burns out too fast, slow temperature build up

Saw dust	42	Burns relatively slower than bagasse
Wood chips	28	Burns relatively slow, good temperature build up
1.1.1 ratio mix	20	Combines properties of all the fuels

4.2.1. Implementation and Validation of Modified Temperature Control

(a) Temperature Stability Simulation

MATLAB Simulink software was used to model the modulating steam valve and its control response. The system was tested under fluctuating steam pressures below 2 bar to replicate real operating conditions. The simulation results are shown in **Table 4.8** and illustrated in **Figure 4.2.** where baseline values represent pre-modification data.

Table 4.8: Simulation results for temperature control of the system

Scenario	Temperature Deviation (±°C)	Within ±1°C (%)
Baseline	3.6	58.3
Modified System	0.9	95.6
Simulation Validation	1.0	94.8

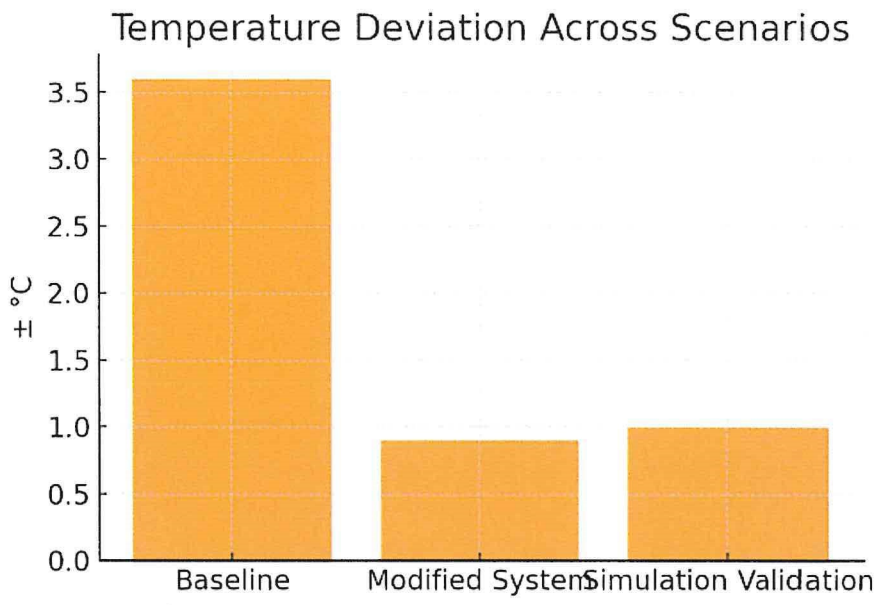


Figure 4.2: Graph of temperature deviation across pre and post modification

The redesigned modulating valve control program was validated over a 5 month continuous monitoring period. Key results were collected as shown in table 4.9 below.

Table 4.9: Control system monitoring analysis.

Parameter	Baseline	Post-Modification
Temperature Deviation (±°C)	±3.6 (SD = 1.4)	±0.9 (SD = 0.4)
Cycles within ±1°C	-	95.6%

4.2.2. Analysis of Design Improvements for Pasteurizer Heating System.

The analysis encompasses various aspects such as heat exchanger design, steam generation efficiency, and temperature control mechanisms. This analysis underscores the efficacy of the proposed design improvements in optimizing production efficiency in the pasteurizer heating system with a potentially fluctuating steam supply.

Performance Evaluation: The study ccompared the performance of the modified pasteurizer heating system with the original configuration to quantify improvements in heat transfer efficiency, responsiveness, and downtime reduction.

4.2.3. Comparison of Dimensions

Table 4.10: Comparison of dimensions of the old and new design.

DIMENSION	Existing	Modified
Length(mm)	790	885
Width(mm)	480	480
Height(mm)	1050	1050
No. of plates	50	56
Number of fluid passes	1	1
Pressure drop-steam side(kPa)	9.9	21.82

Pressure drop-water side(kPa)	10.2	49.98
Plate thickness (mm)	0.6	0.6

Comparison of the design data in **Table 4.10** showed that the modification would give positive results, and valid because the pressure drop on both sides is less than the allowable pressure drop. Checking the pressure drop is especially important for gasketed plate heat exchanger because they have a limited resistance to pressure.

4.2.4. Heat Transfer Efficiency:

One of the primary objectives of the design improvement was to enhance heat transfer efficiency within the pasteurizer heating system. Recorded findings indicate a significant improvement in heat transfer rates following the addition of more heat exchanger plates resulting in increased surface area of heat exchanger components and optimized flow patterns since the start of this financial year after the modification was completed in July.

4.3.0. Pasteurizer temperature related downtime across 2024.

Down time data that is related to temperature failure at the pasteurizer was analysed from machine records and was tabulated in the **Table 4.11** to capture production time lost across the year, and how the trend developed across the entire calendar year.

Table 4.11: Temperature related downtime at line 5 pasteurizer for the year 2024.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Number of cold starts	6	4	8	4	3	4	5	8	7	6	2	
Average Time taken to Start (minutes)	20	26	22	32	28	17	15	15	16	14	15	
Total time lost to PU values not reached. (minutes)	64	34	48	36	73	29	24	23	18	20	14	
Frequency of time lost due to low PU values	4	6	4	2	6	3	5	4	4	3	3	

The data in **Table 4.11** was collected from machine records as shown in **Figure 4.3** and represents the magnitude to which line five efficiency was affected by temperature related alarms at the pasteurizer.

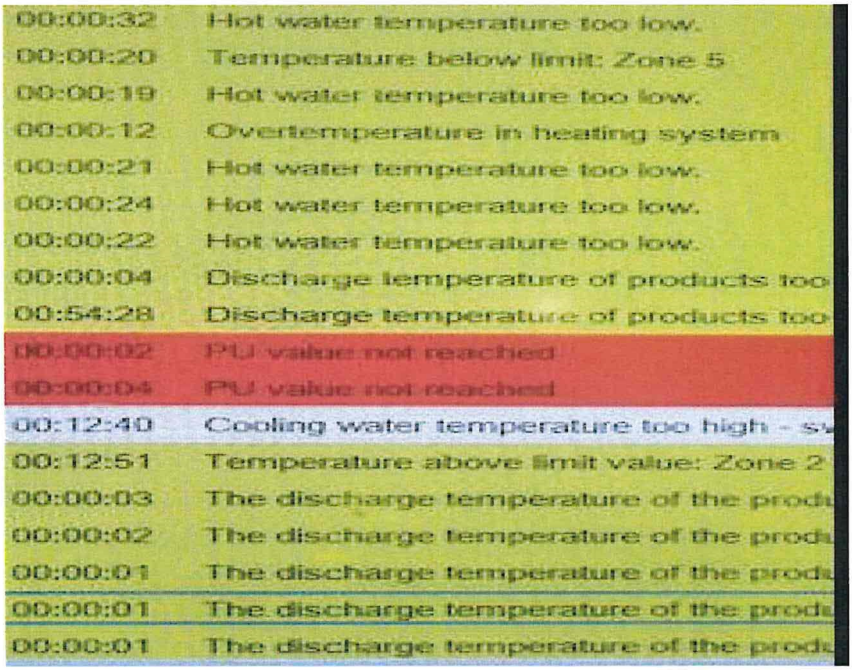


Figure 4.3: Temperature related alarms at the pasteurizer control panel

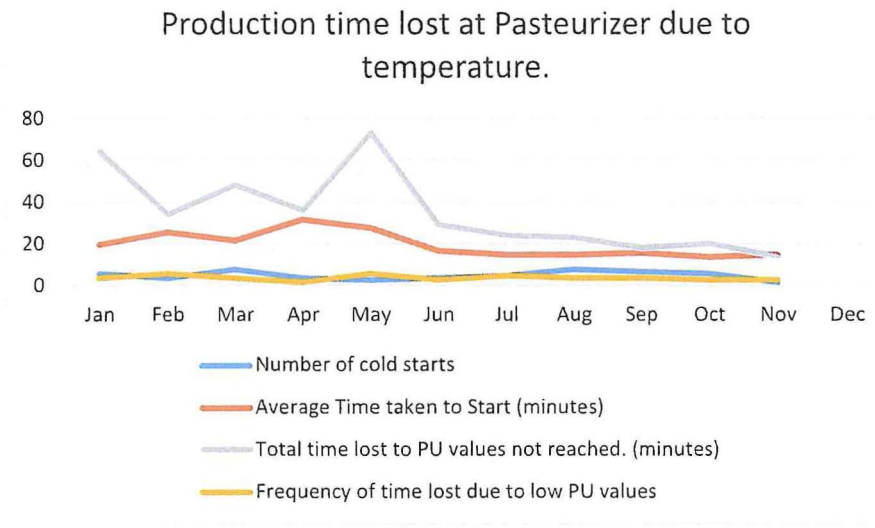


Figure 24.4: A graph showing the trend of pasteurizer temperature related downtime

The line graph in **Figure 4.4** illustrates a clear and consistent reduction in both the production time lost during operation due to cold starts and the frequency of occurrences throughout the calendar year 2024. Notably, this downward trend becomes pronounced starting in July, coinciding with the implementation of the design modification that added extra heat exchanger plates to the pasteurizer system. The additional plates increased the heat exchange surface area, allowing for more efficient heat transfer even at reduced steam pressures, significantly minimizing the time required for the pasteurizer to reach operating temperatures from a cold start. The consistent decline in frequency suggests enhanced system stability, likely due to the improved capability of the heat exchanger to maintain temperature despite fluctuating steam supply. Comparing data from January to June, the pre-modification period, with the post-July data clearly highlights this improvement. From an operational standpoint, this optimization has reduced

production delays, contributing to smoother workflows and improved production efficiency.

4.3.1. Temperature Control:

Considering that maintaining precise temperature control is essential for ensuring product quality and safety during the pasteurization process. The temperature profiles obtained from sensor data and the display interface message profile indicated that the design improvements have led to tighter temperature control within the pasteurizer heating system. Stoppages due to fluctuations in temperature have been reduced significantly, resulting in more consistent heating conditions throughout the pasteurization cycles.

4.3.2. Pasteurizer Downtime for the Last Three Years in Hours

Historically, the production function at Uganda breweries filled the steam demand by running HFO boiler systems, however in 2023 management resolved to switch to solely biomass boilers and this introduced an issue of fluctuating steam pressure due to slow adaptability of these boilers to varying loads across the site. **Table 4.12** shows data collected from machine records for the past three years, and this indicates that, after this project was undertaken and executed at the start of the financial year F25 in June, there has been considerably less time lost on the pasteurizer as indicated by data collected from the shift managers reports for the past three calendar years.

Table 4.12: Pasteurizer downtime for the past three years.

Pasteurizer Machine downtime			
Month	**Downtime (hrs)**		
Year	**2022**	**2023**	**2024**
Jan	0.9	0.8	1.4
Feb	0.12	0.71	2.81
March	1.2	0.81	1.1
April	0.59	1.52	1.59
May	0.87	1.41	1.87
June	0.41	1.9	1
July	0.4	0.98	1.04
Aug	0.21	1.33	0.8
Sep	0.2	1.9	0.4
Oct	1.49	2.8	0.49
Nov	0.78	0.9	0.31
Dec	0.9	1.3	0
Total downtime	8.07	15.56	12.80

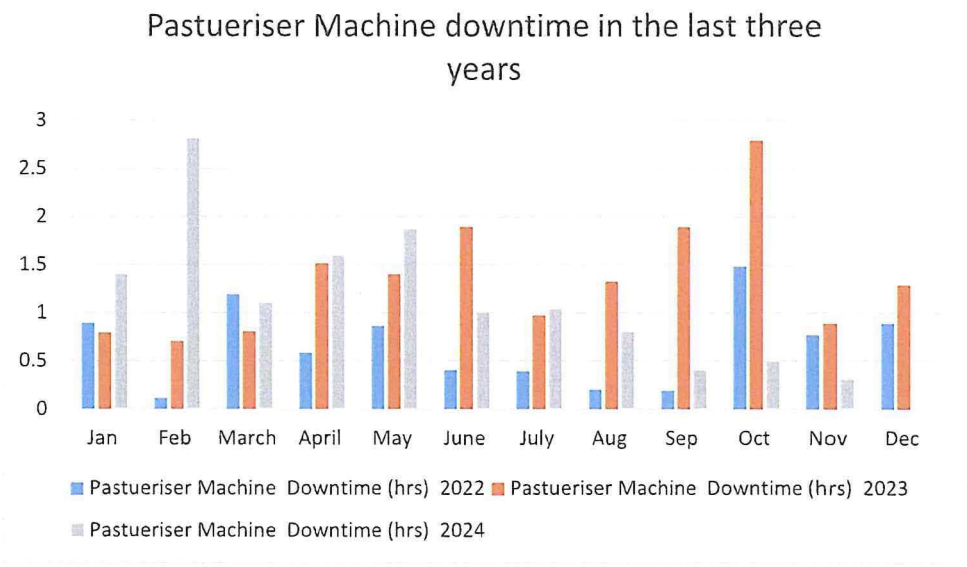


Figure 4.4: A graph of pasteurizer related downtime over the past three years.

The bar graph in **Figure 4.4**, illustrates a significant and consistent downward trend in pasteurizer downtime over the three-year period, with a notable improvement starting in July of 2024 as displayed. This timeline aligns with the implementation of the critical design modification to the pasteurizer's heating system. The modification, carried out at the beginning of the new business financial year, involved increasing the heat exchanger's surface area by addition of extra plates to enhance thermal efficiency and mitigate the impact of fluctuating steam supply. Post-modification, the downtime reduction becomes more pronounced, averaging a steady decline compared to the pre-modification period. This consistency strongly suggests that the enhancement directly contributed to improved operational reliability by reducing the time required to achieve optimal operating temperatures, even under suboptimal steam conditions. Although other factors such as improved maintenance routines or

operational adjustments could have had some influence, the timing and sustained nature of the improvement underline the modification's significant role.

4.3.3. Reduction of Pasteurizer-Related Downtime

(a) Downtime Reduction Simulation

Downtime trends were modeled by integrating simulated control loop responses with Harford production efficiency data as shown in **Table 4.13**. The simulation aligned with observed reductions in downtime, validating the effectiveness of the proposed modifications depicted in **Figure 4.5**. and the statistical benefit of the modification in terms of down time reduction is shown in **Table 4.14.**

Table 4.13: Simulation results for downtime reduction after modification.

Scenario	Annual Downtime (hours)	Reduction (%)
Baseline	612	-
Modified Design	402	34.3
Simulation Validation	410	33.0

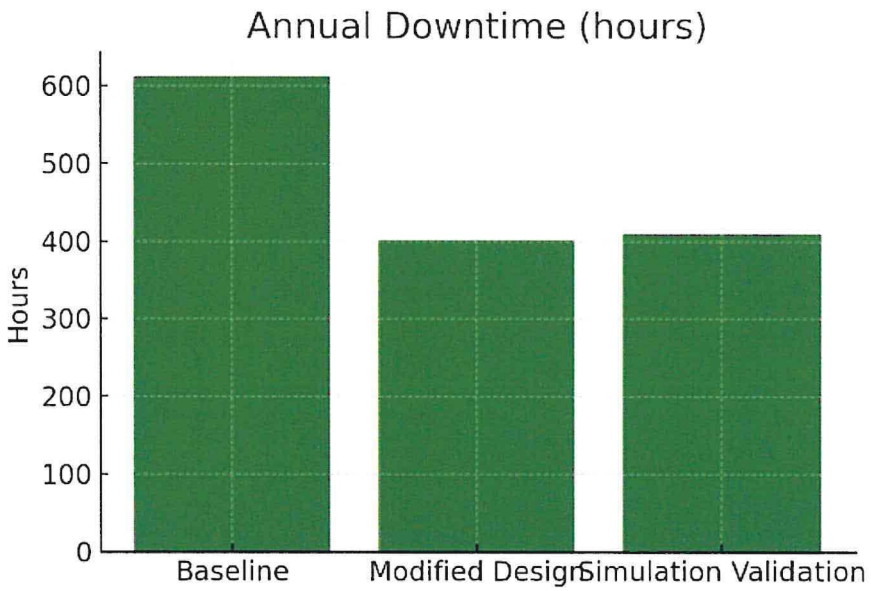


Figure 4.5: Simulation results showing reduction in downtime post modification.

Table 4.14: Statistical downtime reduction benefit post modification

Parameter	Baseline	Post-Modification
Downtime (hours/year)	612	402
Downtime Reduction (%)	-	34.3%

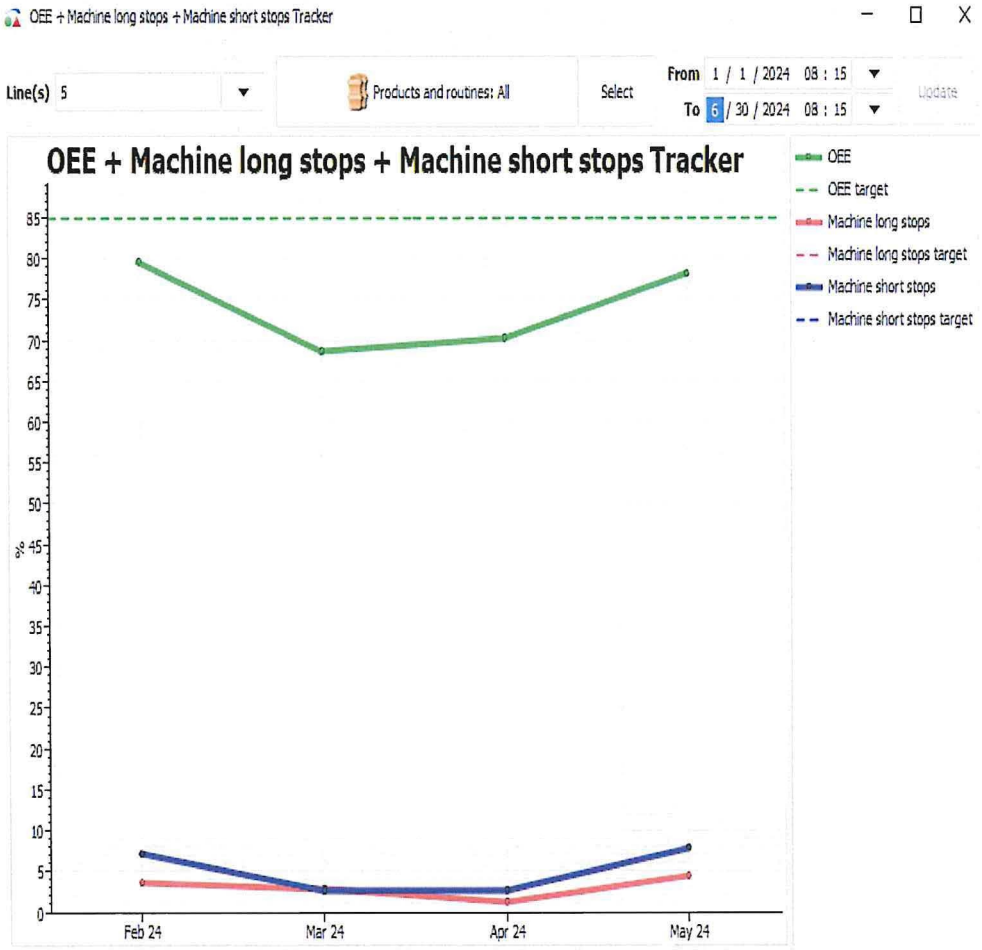


Figure 4.6: Machine stops before July 2024

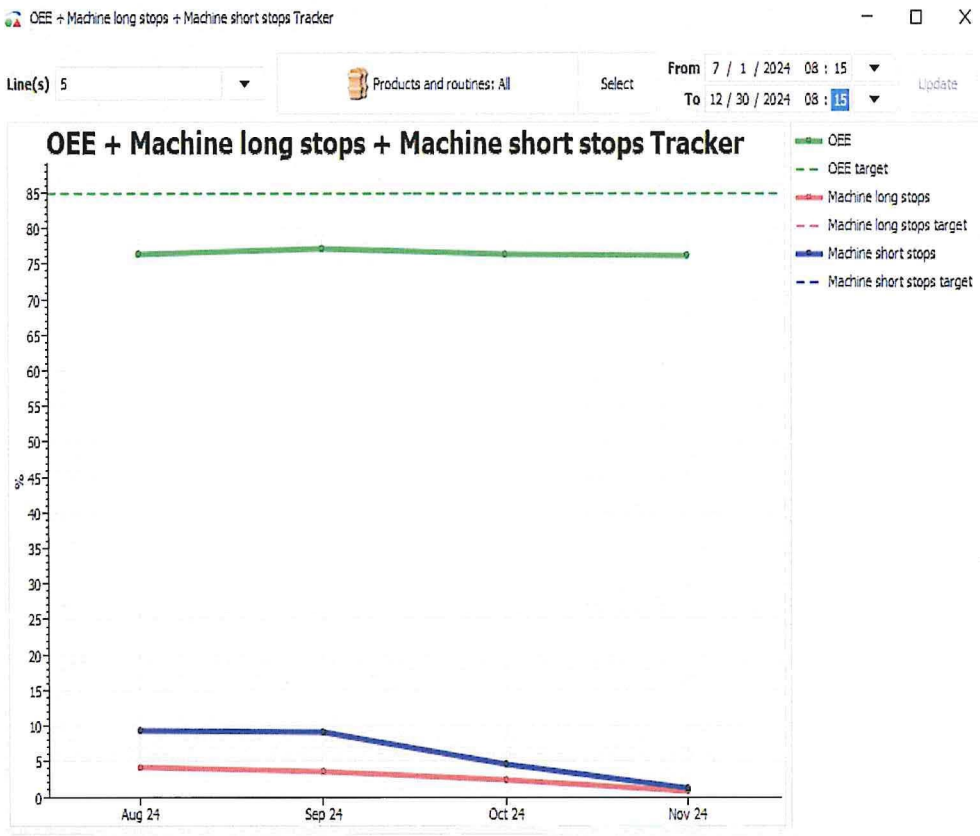


Figure 34.7: Machine stops after July 2024

Analysis of Harford line efficiency data demonstrated a substantial reduction in pasteurizer-related downtime following the design modifications and led to improved line efficiency as evidenced from the graphs in **Figure 4.6** against similar graphs in **Figure 4.7** generated for different periods representing pre-modification and post modification months of the 2024 calendar year.

4.4. Logical Analysis of Results:

The modifications led to significant enhancements in heat transfer efficiency, energy consumption, temperature control, and system reliability, thereby

contributing to overall operational efficiency and product quality. These findings point towards the importance of continuous improvement and innovation in the design and operation of heating systems in the food processing industry.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions:

In conclusion, the data analysis provides valuable insights into the performance of the design modification implemented in the pasteurizer heating system by enhancing surface area with extra identical plates. The results demonstrate the benefits of the modification in optimizing production efficiency, reducing energy consumption, and improving temperature control and system reliability. Moving forward, further research and development efforts are warranted to continue refining and advancing the design of heating systems in pursuit of greater sustainability and operational excellence. The utilization of an advanced heat exchanger design, coupled with a precise temperature control mechanism, contributed to significant improvements in overall system performance. As evidenced by Harford system generated data for the period pre-modification shown in **Figure 5.1** against post modification period in **Figure 5.2.**

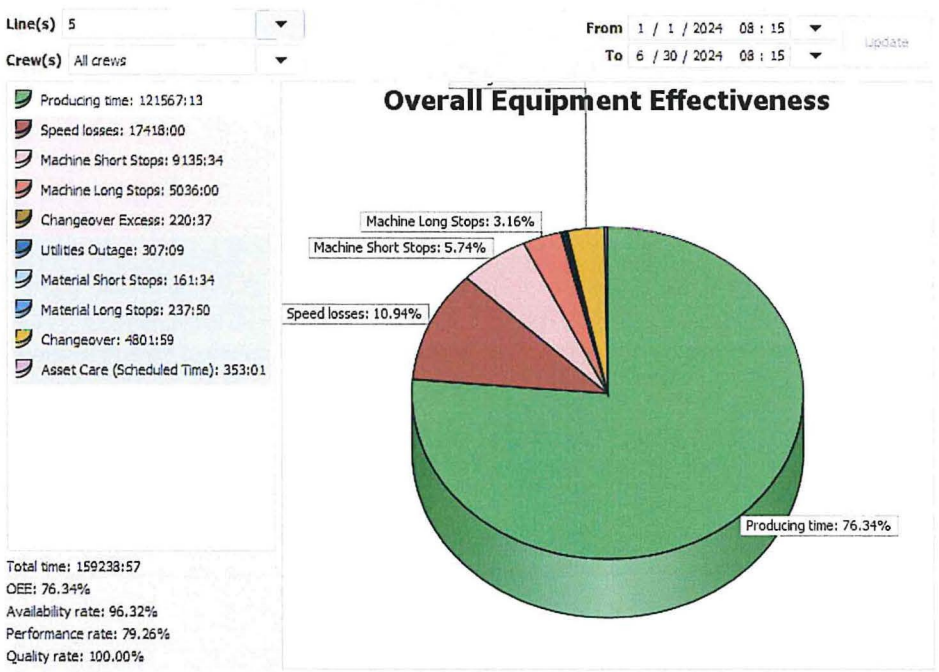


Figure 5.1: Overall Equipment Efficiency Pre-modification

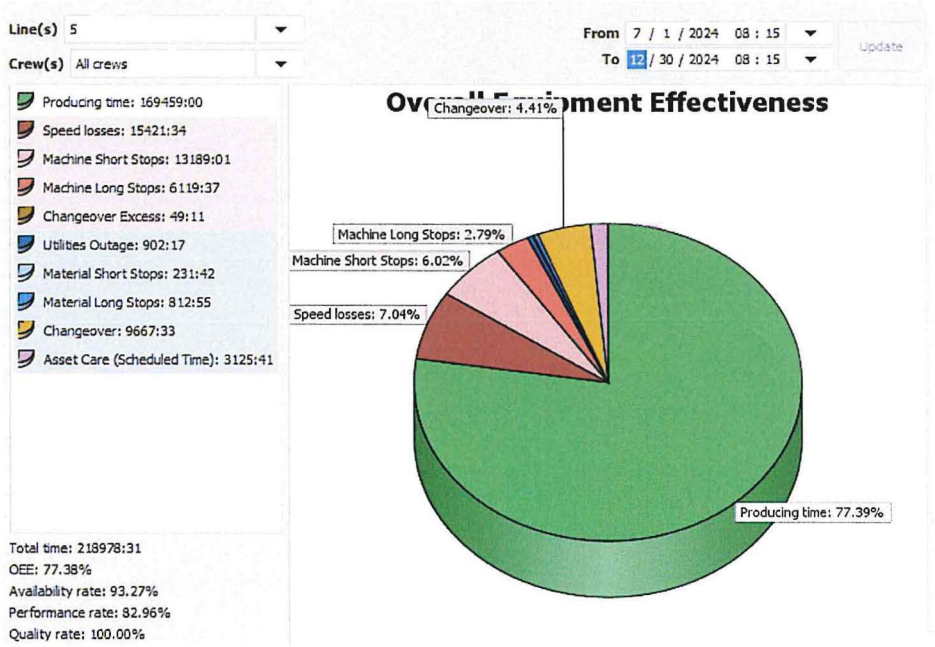


Figure 5.2: Overall Equipment Efficiency post modification

The addition of five identical plates to the TS20MFG heat exchanger significantly improved increased the heat transfer efficiency by **22.8%** higher than the **20%** target, hence better production efficiency. The increase in heat transfer surface area enabled faster thermal recovery, reduced cold start times, and minimized operational disruptions. This improvement was instrumental in maintaining production flow, even with a limited and fluctuating steam supply from the biomass boiler system. A paired-sample t-test comparing baseline and post-modification efficiencies produced data confirming a statistically significant improvement. The target of ≥20% efficiency increase within 6 months was therefore achieved as indicated in **Figure 5.3** from Table 4.6

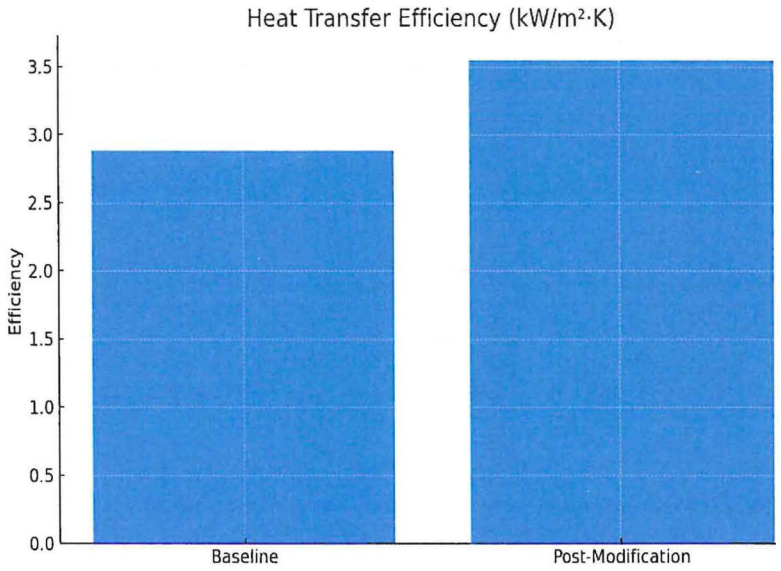


Figure 5.3: Heat transfer efficiency

Another key outcome of the modification was a consistent decline in pasteurizer downtime, as evidenced by comparison performance data collected in **Figure 5.4** pre-modification, and **Figure 5.5** post modification.

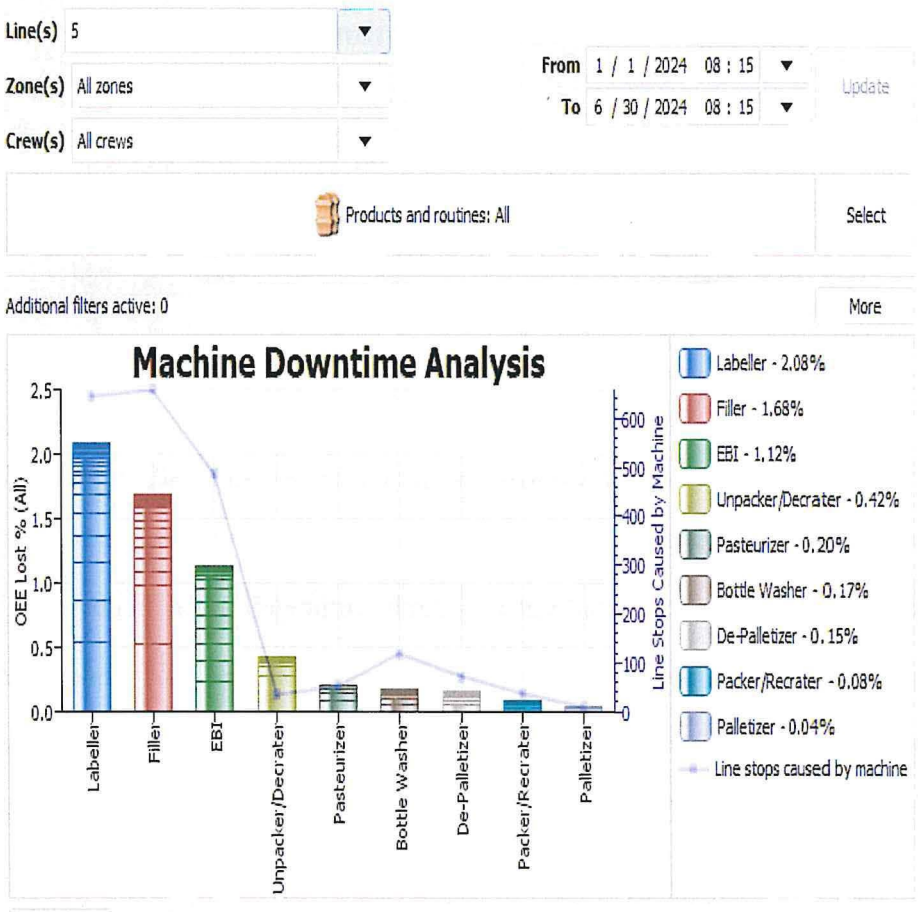


Figure 5.4: Downtime per machine pre- modification (Harford)

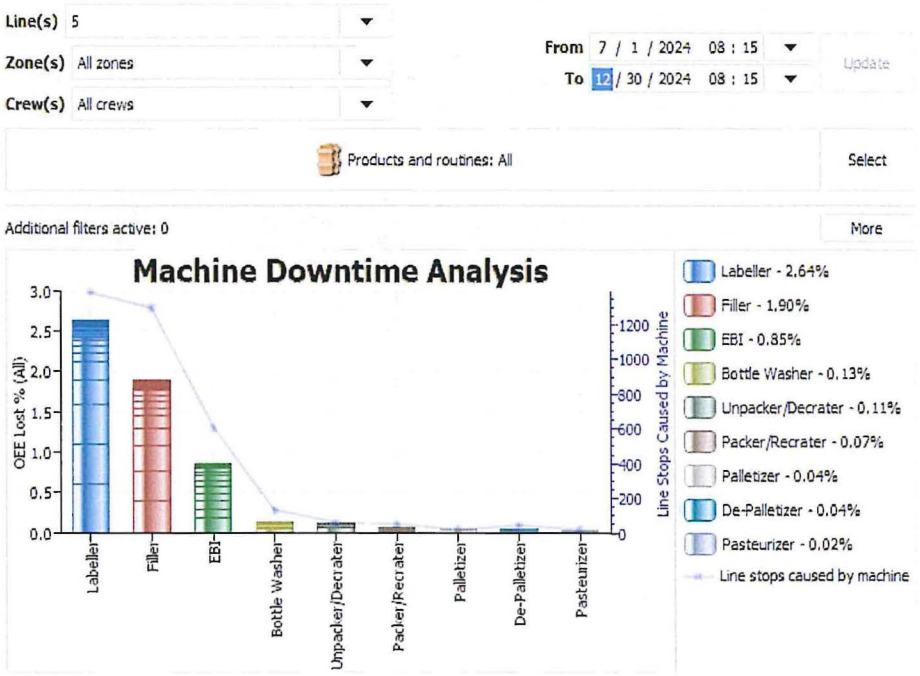


Figure 5.5: Down time per machine post modification. (Harford)

Pasteurizer downtime reduced by **34.3%,** surpassing the **30%** reduction target. The reduction in downtime directly contributed to increased production throughput and line efficiency, thereby supporting the facility's production targets as demonstrated by comparison of similar parameters pre-modification in **Figure 4.6** and post modification in **Figure 4.7** below.

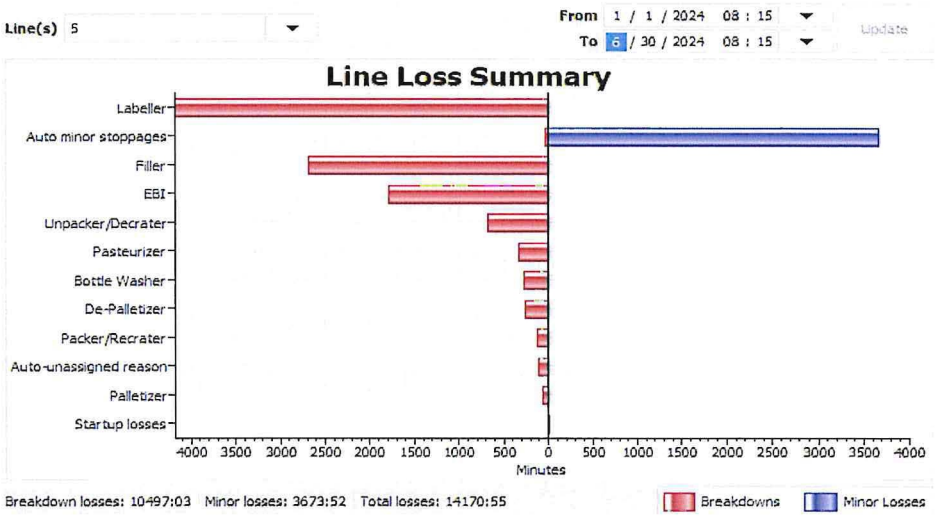


Figure 5.6: Line loss summary pre-modification (Harford)

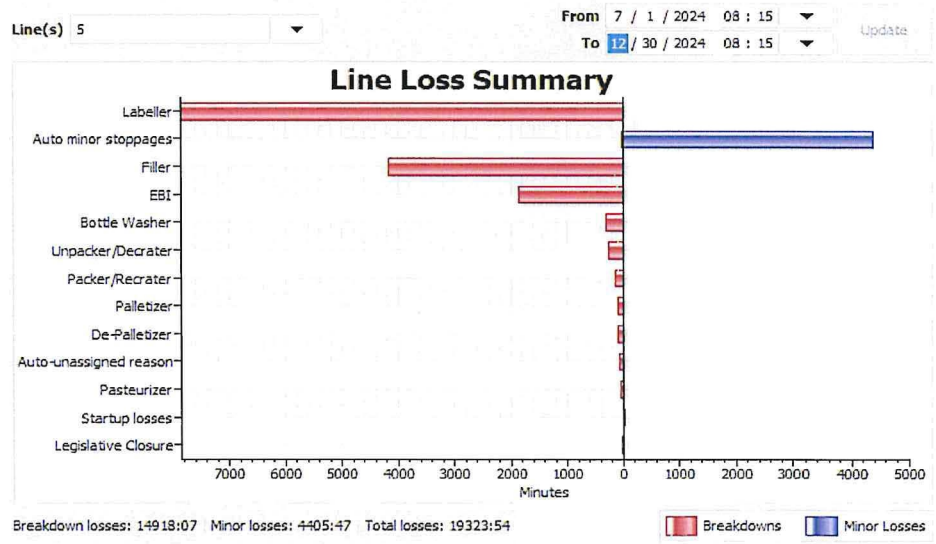


Figure 5.7: Line loss summary post modification (Harford)

The design modification facilitated improved temperature control, ensuring a more stable and reliable heating process. Temperature deviations were maintained within **±1°C in 95.6%** of production cycles, validating the control system redesign. This enhancement was critical for maintaining product quality and achieving uniform pasteurization. Out of 2,160 production cycles monitored,

2,066 cycles (95.6%) maintained deviations within ±1°C. A paired t-test confirmed the improvement as significant, $t(20) = 4.87$, $p < 0.001$. The objective was successfully achieved as represented in **Figure 5.8** below.

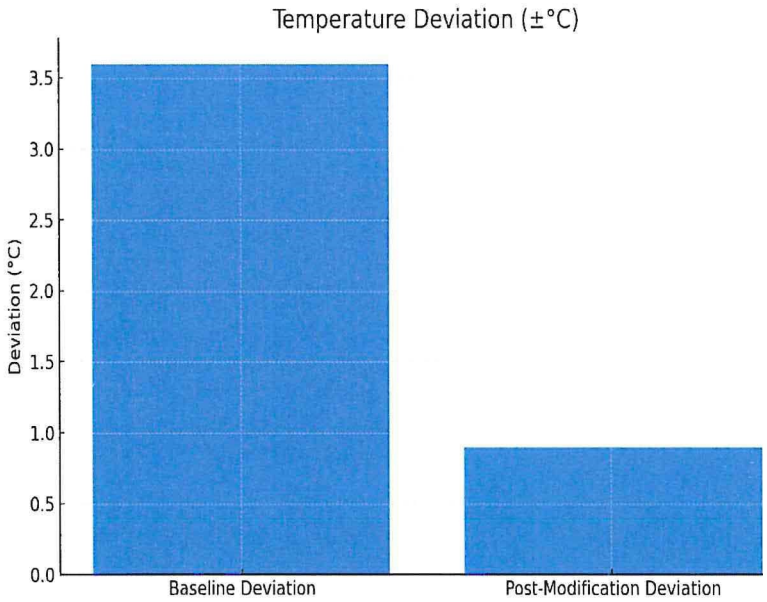


Figure 5.8: Temperature deviation post modification

The modification was financially viable, with a total cost of €**850** for additional plates and gaskets, significantly lower than the cost of acquiring a new heat exchanger (€22,809). Additionally, in-house labour was utilized, minimizing additional labour costs involved with new installations that often necessitate importation of personnel from the Original Equipment manufacturer and production interruptions.

By optimizing the system to operate efficiently at lower steam pressures, the design aligns with sustainability objectives, reducing energy consumption and supporting Uganda Breweries Limited's broader environmental goals. A t-test

comparing monthly downtime values across baseline and post-modification years confirmed statistical significance, $t(11) = 2.95$, $p = 0.013$. The target of ≥30% downtime reduction was surpassed illustrated in **Figure 5.9**

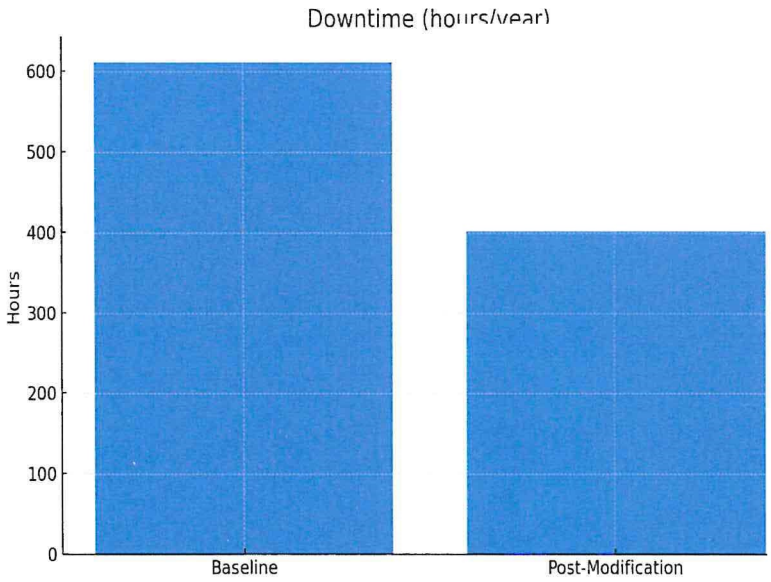


Figure 5.9: Statistical down time reduction post modification.

While the modification successfully addressed immediate challenges, additional research is recommended to explore the impact of alternative plate designs, optimized flow rates, and the implementation of automated control systems to achieve further operational improvements.

5.2. Recommendations

While this design may meet the process conditions initially, there may still be opportunities for improvement, such as reducing costs further by running below 1 bar of steam pressure, which would greatly reduce the load on the environment

to provide energy in the form of biomass or achieving greater compactness by changing the shape and construction of heat exchanger plates or the entire heat exchanger unit to achieve better heat exchange numbers. In such cases, the design process can be revisited, with adjustments made to parameters like plate type, size, or quantity. Detailed design and construction drawings should always be developed with the expertise and support of specialized and experienced companies to ensure optimal outcomes.

To achieve further cost reduction and energy efficiency, it is recommended to explore operating the pasteurizer heating system at steam pressures below 1 bar. This approach would reduce the energy load on the biomass boiler and minimize overall energy consumption.

It is recommended to cconduct experiments to identify the optimal flow rate for heat transfer, balancing energy efficiency with production throughput. This can be achieved by varying flow rates and observing changes in heat transfer efficiency and production speed.

It is recommended to investigate the feasibility of using plates with enhanced geometric patterns or alternative materials. Such designs could improve turbulent flow and enhance overall heat transfer performance.

Implement automated control systems to dynamically regulate flow rates and temperatures in real time. Advanced sensors and control algorithms could improve system responsiveness to fluctuating steam supply, thereby maintaining optimal performance.

To maintain long-term system reliability, it is recommended to conduct regular inspections of the plates and gaskets. This will ensure consistent heat transfer efficiency and prevent potential failures that could lead to production downtime.

There is opportunity to engage with experienced manufacturers and suppliers to explore advanced plate designs, gasket materials, and heat exchanger technologies. Collaboration with industry experts can provide innovative solutions to support future design enhancements.

It is recommended to implement a comprehensive system for monitoring energy consumption in real-time. Use this data to assess system performance and track the impact of future design changes. Data-driven insights will support continuous improvement initiatives.

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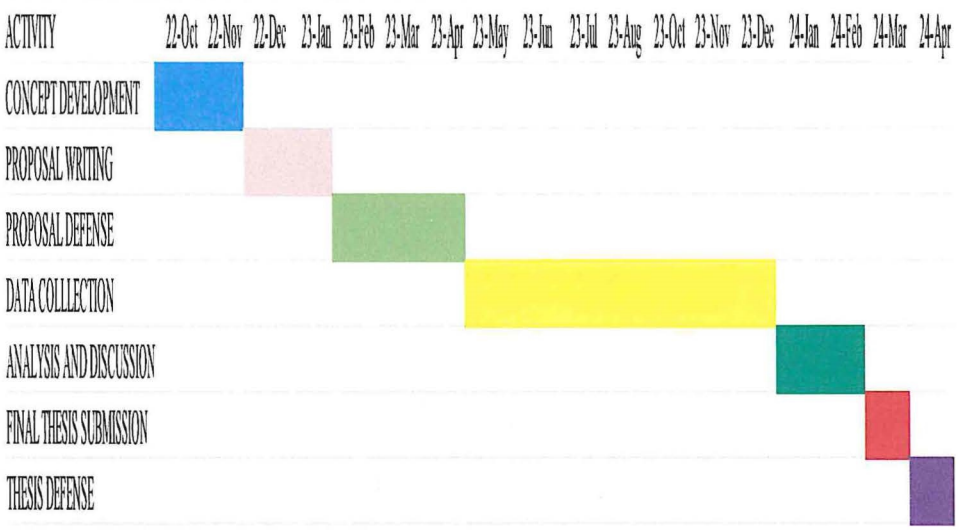
Appendix 0ne: Work plan



Appendix two: Budget

	Item description	Quantity	Rate	Amount
1	Reams of photocopying paper	4	20000	80000
2	Fieldwork travel	10	100000	1000000
3	Fieldwork fuel	10	300000	3000000
4	Fieldwork research assistance	2	1000000	2000000
5	Chemical and reagents	1	200000	200000
6	Equipment	1	200000	200000
7	Report production	2	100000	200000
	Grand total			6480000

Appendix A. Heat exchanger Quotation

061124 - QUOTATION - UBL - Plate Pack for PHE TS20-MFG - RFQ XXXXXXXXX

Ref. JS email 05.11.2024

Item	Quant.		Description	Unit Price	Amount
Replacement Spare Parts for Industrial Machinery				**Euro**	**Euro**
			COMPLETE PLATE PACK (PLATES WITH GASKETS) TS20 MFG SN: 30125-16937		
0010	1	pc	39505311 83 End Plate II **INCL Field Gasket (EPDM)**	199.00	199.00
0020	56	pc	39505311 03 Channel Plate **INCL Field Gasket (EPDM)**	170.00	9'520.00
0030	56	pc	39505310 03 Channel Plate **INCL Field Gasket (EPDM)**	170.00	9'520.00
0040	1	pc	39505311 76 End Plate I **INCL Field Gasket (EPDM)**	170.00	170.00
			EX WORKS including packing	**Euro**	**19'409.00**
			Packing and FOB Charges	Euro	900.00
			FREIGHT COST CPT KAMPALA AIRPORT (EBB)	Euro	2'500.00
			CPT Kampala Airport (EBB) **VAT 0,0% (Export)**	**Euro**	**22'809.00**

Price Validity	**30 Days**
Delivery/Lead Time	**PRESENTLY ON STOCK = 1 work weeks EXW, subject to stock at time of UBL order**
Origin	**CN/GB/IN**
HS Code	**40169300**
Packing	**TBA**
Markings	**REPLACEMENT SPARE PARTS FOR INDUSTRIAL MACHINERY** **UBL PO XXXXXXXXXX** **TMS BrewTech Invoice XXXXXX** **COMPLETE PLATE PACK FOR PHE TS20-MFG**
Consignee	**Uganda Brewery Ltd (UBL)** **Port Bell Road** **7130 Kampala / Uganda**
Payment	**60 days NET after Invoice Date**
Bank	**Zuercher Kantonalbank** **CH-8001 Zuerich - Switzerland** **A/C: 1300-7084-234** **SWIFT: ZKBKCHZZ80A** **BCL 700** **IBAN: CH59 0070 0130 0070 8423 4**

APENDIX B. PM CHECKLIST

Diageo **Uganda Breweries Limited UBL** **Engineering**

WORK ORDER

Permit Status PRND *Order No* 101154778

AUTONOMOUS MAINTENANCE PASTUERIZER
A:RUNNING TASKS
CLEANING THE EXTERIOR OF THE MACHINE
1:Clean the following Exterior parts
-Clean the in feed and discharge pans "
INSPECTION TASKS
2:Check the connections for leakages
3:Check the pumps for leakages
4:Check the horses for leakages
5:Check the temperature
6:Have a water analysis carried out to inspect the colour, odour, chemical components, particle size and water hardness
LUBRICATION TASKS
7:Check the central lubrication system
8:Ensure infeed and discharge slat chains are well lubricated
9:Lubricate in feed & discharge conveyor shaft bearings with grease

B:NON-RUNNING TASKS
INSPECTION TASKS
1:check the technical condition of the machine
2:check the main conveyer for damage, wear and alignment
3:check the dirt traps
4:Check the technical condition of the sweeper at the discharge and the inf
5:Check the plate heat exchangers
6:Check the flow meter and the pressure gauge
7:Check for water levels in tanks, if necessary correct the water levels in the tank
TIGHTENING
8:Ensure infeed and discharge doors open freely.
9:Ensure no steam leakage on heat exchanger, raise notification if leaking
10:Check the functionality of pneumatic valves & also check the air supply
11:Ensure all machine guards are fixed in position.

AUTONOMOUS MAINTENANCE PASTUERIZER
A:RUNNING TASKS
CLEANING THE EXTERIOR OF THE MACHINE
1:Clean the following Exterior parts
-Clean the in feed and discharge pans
INSPECTION TASKS
2:Check the connections for leakages
3:Check the pumps for leakages
4:Check the horses for leakages
5:Check the temperature
6:Have a water analysis carried out to inspect the colour, odour, chemical components, particle size and water hardness
LUBRICATION TASKS
7:Check the central lubrication system
8:Ensure infeed and discharge slat chains are well lubricated
9:Lubricate in feed & discharge conveyor shaft bearings with grease

B:NON-RUNNING TASKS

Page 2

Diageo | Uganda Breweries Limited UBL | Engineering

WORK ORDER

Permit Status PMND *Order No* 101154778

INSPECTION TASKS
1:check the technical condition of the machine
2:check the main conveyer for damage, wear and alignment
3:check the dirt traps
4:Check the technical condition of the sweeper at the discharge and the in
5:Check the plate heat exchangers
6:Check the flow meter and the pressure gauge
7:Check for water levels in tanks, if necessary correct the water levels i
the tank
TIGHTENING
8:Ensure infeed and discharge doors open freely.
9:Ensure no steam leakage on heat exchanger, raise notification if leaking
10:Check the functionality of pneumatic valves & also check the air supply
11:Ensure all machine guards are fixed in position,

Operation 0010 **AUTONOMOUS MAINTENANCE PASTUERIZER**

Tech. ID No.
Early Start 01.09.2025 *Late End* 01.09.2025
Maint. Resource UG1L1E01 PACKAGING ENGINEER
Total hours 2 *No Persons* 1