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Optimisation of brewing processes to reduce wastewater generation and improve wastewater PH and PV: a case study of Delta Beverages (lagers), Manchester brewery, Harare, Zimbabwe.

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DECLARATION

To be compiled by the student

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I, Takudzwa Karimunhenga, hereby declare that all the information presented in this project is my original work and has not been submitted previously. I also assert that the information was obtained and presented per academic standards and ethical conduct. Any information sourced from other authors is properly cited in the project.

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This dissertation is suitable for submission and has been checked for conformity with the University guidelines

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DEDICATION

I dedicate this research project to Delta Beverages (Lagers), whose collaboration and support have been instrumental in shaping this study and advancing understanding of wastewater generation, pH, and PV management.

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ABSTRACT

A cross-sectional study was conducted at Delta Beverages Lagers to optimise brewing processes by determining strategies for controlling wastewater generation, pH and PV. The study area was Delta Lagers located in Southerton, Manchester Brewery, Harare. Data was collected through interviews, observations, document reviews, questionnaires and lab analysis. A sample size of 30 was selected from a target population of SHE practitioners, Utilities workers, Brewing Management and process operators. Interviews were conducted through convenient sampling to identify factors contributing to wastewater generation, pH and PV, and strategies to manage them. Observations were performed to identify factors that affect wastewater generation, pH and PV. A questionnaire was generated through responses from interviews and information from the literature reviewed. Documents were reviewed to identify critical areas to focus on based on levels of wastewater quantity, pH and PV. Results indicated high wastewater generation in most areas, including filtration, fermentation and packaging. The wastewater results for the processes exceeded the average, with an average of 1270% against what most breweries typically discharge per barrel of beer produced. Samples of wastewater from fermentation, filtration, packaging, composite brewing, and raw wastewater were taken to test for temperature, pH and PV. The lab results were analysed using descriptive statistics, means, and standard error of mean and results showed pH and PV exceeding established guidelines. The study also analysed the relationship between wastewater quantity and quality (pH, PV and temperature) and found no significant association between the parameters, suggesting that other factors significantly affect wastewater quality. To identify strategies for controlling wastewater generation, pH and PV, responses from questionnaires were analysed through descriptive statistics. From the results, to control wastewater generation, pH and PV, participants believed that the brewing processes can be optimised through a closed circuit system, reduction of cleaning frequency, replacement of packaging machinery with new machines, replacing caustic soda with surfactant based cleaners such as CIP surf, brewing machine maintenance twice a week, replacing Plate and Frame with modernised BMF and weekly review of the trub program. However, further research is required to identify all factors affecting wastewater generation, pH, and PV.

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LIST OF ACRONYMS AND ABBREVIATIONS

BMF	Beer Membrane Filtration
SHE	Safety, Health and Environment
pH	Potential of Hydrogen
PV	Permanganate Value
SPSS	Statistical Package for Social Sciences
ISO	International Organisation for Standardisation
SI	Statutory Instrument
Bbl	Barrel of beer
EPA	Environmental Protection Agency
EMA	Environmental Management Agency

DEFINITION OF KEY TERMS

Process optimisation- The implementation of structured methods and strategies aimed to enhance a specific process regarding its efficiency, effectiveness, and quality. The goal is to achieve maximum performance, productivity, and quality while minimising costs.

Wastewater- refers to water that has been contaminated by substances that dissolve or suspend in water during industrial processes.

Potential of Hydrogen (pH)-pH is defined as a measure of the concentration of hydrogen ions in a substance, indicating how acidic or basic a solution is.

Permanganate Value (PV) -refers to the concentration of substances in a wastewater stream that can be oxidized by potassium permanganate under acidic conditions. Potassium permanganate is a reagent used in water treatment plants to eliminate foul odours and remove contaminants.

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Industrialisation has led to the growth of various industries in developing countries, contributing to increased output and economic development. According to Alam et al., (2016) and Gorfie et al., (2022), this growth has also resulted in the release of large quantities of industrial wastewater into the environment, often without adequate treatment, which poses a significant environmental concern. The brewing industry is a vital part of the global food sector. In 2022, it achieved remarkable sales, with 279.4 billion litres of beer sold worldwide (Statista, n. d.), ranking just behind tea, fizzy drinks, milk, and coffee. Adults aged 15 and older consume about 9.6 litres of beer yearly (Stockwell et al., 2009). This high output and consumption create a substantial demand for two essential resources: water and energy (Märker et al., 2022; Tan et al., 2022).

The brewing process involves the combination of malt, hops, sugar extracts, and water, followed by fermentation with yeast (dos Santos et al., 2023; Oke et al., 2023; Olajire, 2020). This process, typically implemented using various batch-type methods, requires a significant amount of water for brewing and entails extensive washing, sanitising, and sterilising of equipment after each batch. Consequently, considerable volumes of water are discharged as wastewater (Nota et al., 2020). Key areas within a standard brewery that contribute to high water consumption and wastewater output include the brew-house, cellars, packaging, general product water usage, vessel washing, general cleaning, and cleaning in place. The importance of monitoring water intake and wastewater generation in these areas cannot be overstated (Kesari et al., 2021). A brewery's incoming water usage can range from 4 to 16 barrels of water per barrel of beer produced. The wastewater generated is typically 1.3 to 2 barrels less than the water used per barrel of beer (UNEP, 1996). There is a strong correlation between beer production and wastewater generation; it has been noted that the wastewater load is directly related to the water load, as a substantial portion of the water ultimately becomes wastewater rather than being utilised in the beer-making process (Comber et al., 2022).

Brewery wastewater contains various physical, chemical, and biological contaminants that can pollute water and soil, posing risks to living organisms. According to Gorfie et al (2022), using contaminated water for irrigation can lead to the accumulation of heavy metal ions and other harmful substances in crops. This can result in phytotoxicity, reduced crop yields, and health issues for consumers (Gorfie et al., 2022). The continuous discharge of highly polluted wastewater threatens agricultural productivity and public health. For instance, excessive amounts of total suspended solids (TSS) in effluent can cause water turbidity, which reduces sunlight penetration and interferes with photosynthesis (Dey and Vijay, 2021). These discharges can degrade soil quality by increasing levels of chemical oxygen demand (COD), biological oxygen demand (BOD), nitrogen, and phosphorus (Brewers Association,2011). Brewery wastewater poses a significant environmental challenge due to its capacity to alter levels of total solids, total nitrogen, total phosphorus, chemical and biological oxygen demands, and the presence of pathogens (Alayu et al., 2023). Suppose parameters such as pH and permanganate value (PV) are not properly managed. In that case, the environment can suffer significantly, leading to issues such as aquatic life toxicity, ecosystem imbalance, and degradation of water quality. Delta Beverages is one of the companies in Zimbabwe that produces large amounts of low-quality wastewater.

At Delta Beverages, Lagers, there is a high generation of wastewater indicated by a daily average of $1367m^3$ which approximates to $17.8m^3$ of wastewater generated per barrel of beer produced against an average of $1m^3$ of wastewater per barrel of beer for most breweries. The significant deviation indicates high water consumption rates, which is a serious environmental concern that can result in significant impacts such as water scarcity and risks to public health. High wastewater generation translates to increased costs for the company according to Harare City laws SI 153 of 2022. Large volumes of wastewater require more resources to treat, which compounds the financial burden, especially following recent expansion projects to boost production volume. A high rate of water consumption results in elevated water usage charges from the municipality, further adding to the company's expenses. To address the issue of high wastewater generation, the company has proposed the installation of tanks for water reuse to reduce wastewater generation, but this plan has yet to be implemented due to financial constraints. Delta Lagers Brewery can only reuse wastewater that has low contaminant levels, as there is currently no water treatment plant available to process it effectively. This limitation hampers their ability to properly reuse, manage, and control wastewater. Consequently, there is a need for thorough research to identify strategies for reducing the generation and improving wastewater pH and PV.

Wastewater pH and PV are another concern for the company, as wastewater discharged into the environment exhibits high levels of these parameters. Delta Beverages is generating wastewater of poor quality, with a daily average pH value of 11.9 exceeding EMA standards, which range from 6-9 (SI 6,2007). The pH can fluctuate from as low as 6.5 to as high as 11.9, compared to the company's target range of 6.90-9.00 for lower and higher pH levels, respectively. PV has posed a challenge in the wastewater generated by Delta Beverages Lagers, with a weekly average PV value of 110 ppm. Daily wastewater can have PV values as high as 109 ppm, surpassing the company target of 80 ppm. The company struggles to control these parameters due to constructed catch pits that are ineffective in treating the wastewater, leading to violations of established EMA standards and serious penalties. If these parameters are not controlled, this can lead to environmental pollution, posing a significant risk to the ecosystem and impacting the company’s reputation. The company proposed constructing a wastewater treatment plant to address these challenges, but this has not been established due to financial limitations. This challenge necessitates research to determine the control points for pH and PV within the brewing processes to improve the wastewater quality.

This research will assess how the brewing processes can be optimised to operate sustainably and in an environmentally friendly manner. Most existing research has concentrated on treating wastewater after its discharge from brewing processes rather than on managing wastewater quality during brewing processes. Many studies have focused on water reuse and recycling, neglecting the factors that contribute to wastewater generation. A comprehensive study on brewing process optimisation aimed at reducing wastewater generation and improving wastewater PV and pH is required to address this knowledge gap. The results of this research will provide valuable insights for environmentalists and brewers, encouraging a more sustainable future for the brewing industry.

1.2 STATEMENT OF THE PROBLEM

Delta Beverages, Lagers, is generating high volumes of wastewater, indicated by a daily average of 1367m^3 which translates to 17.8m^3 per barrel of beer, against 1m^3 per barrel of beer for most breweries, despite the control measures in place. Recent expansion projects to boost production have accelerated wastewater generation. The wastewater exhibits a high pH and PV that exceed established international and national standards. While catch pits are available to treat and control the wastewater parameters, they are not effective enough to bring these parameters down to acceptable levels, resulting in the discharge of poor-quality wastewater that violates environmental standards and limits. Some systems that have been implemented to control wastewater PV and pH during the brewing processes, such as the trub program and yeast drying, often fail due to a lack of maintenance and energy costs, respectively. High-wastewater generation and poor-quality wastewater have negative consequences for both the environment and the company. Most studies have concentrated on managing wastewater after it has been discharged from brewing operations, with limited attention paid to improving brewing processes to minimise wastewater generation and improve wastewater PV and pH. This research will focus on reducing wastewater generation and improving wastewater PV and pH at source. This research aims to determine ways to optimise the brewing processes, thereby minimising environmental harm and fostering sustainable production.

1.3 AIM OF THE STUDY

- To reduce wastewater generation and improve wastewater pH and PV at Delta Beverages Lagers

1.4 OBJECTIVES OF THE STUDY

- To determine strategies for controlling wastewater generation at Delta Beverages, Lagers
- To determine strategies for controlling PV and pH at Delta Beverages, Lagers

1.5 RESEARCH QUESTIONS

- What are the strategies for controlling wastewater generation at Delta Beverages, Lagers?
- What are the strategies for controlling PV and pH at Delta Beverages, Lagers?

1.6 SIGNIFICANCE OF STUDY

Despite having mechanisms in place to reduce the amount of wastewater generated, Delta Beverages still produces a significant volume of wastewater. This is evidenced by a daily average of 17.8 m^3 of wastewater generated per barrel of beer, which exceeds by 1 680% what most breweries produce. The wastewater produced is of low quality, as indicated by high levels of PV and pH that do not meet established guidelines. This research will assist the company in determining strategies that can be employed to reduce wastewater generation and improve wastewater PV and pH. This study will determine how wastewater generation, PV and pH can be controlled at source. Despite the ineffective catch pits currently in place, identifying these strategies will enable the company to meet regulatory standards for wastewater discharge and avoid fines and penalties. By improving the PV and pH of wastewater and reducing its generation, the company can also decrease costs associated with wastewater treatment and water usage. The results of this research are crucial in achieving Sustainable Development Goals such as Clean Water and Sanitation, Responsible Consumption and Production, Life

Below Water, Good Health and Well Being (United Nations,16.09.2024). By determining strategies for reducing wastewater generation and improving wastewater PV and pH, the company can demonstrate its commitment to environmental sustainability, which enhances its reputation and expands the international market and increases profits. The research findings are valuable in generalising results for use in other breweries to control wastewater generation, PV and pH, ultimately contributing to achieving sustainable development.

CHAPTER TWO

2.0LITERATURE REVIEW

2.1THEORETICAL FRAMEWORK

2.1.1The Cleaner Production Theory

Cleaner production (CP) has emerged as a novel approach to address the significant environmental challenges caused by industrialisation. Research has shown that relying solely on end-of-pipe solutions to solve environmental problems has been ineffective (Scheverin et al., 2020; Jiang et al., 2022). Consequently, cleaner production was developed as a strategy for overall pollution reduction, initially introduced in the chemical industry (Eder, 2003). Over the years, its popularity has grown, and it has been applied across various sectors, including agriculture and manufacturing. In practice, CP is recognised for its essential role in resource conservation, enhancing efficiency, and reducing pollutant emissions (Scheverin et al., 2020). Cleaner production contributes to achieving sustainable development goals (Cardoso et al., 2019) and is a crucial means of attaining sustainability. Many researchers describe it as a plan for pollution prevention, clean technology implementation, energy savings, and emission reductions (Gunarathne and Sankalpani, 2021). Given that industrial advancements vary across countries, the United Nations Environment Programme (UNEP) sought to establish a standard definition of CP in 1996. This definition characterises CP as a systematic, sustainable, and innovative mind set integral to environmental protection strategies across all aspects of management, production, and services, aimed at minimising environmental harm resulting from economic activities (Shi and Xiang, 2002). Cleaner production embodies a way of thinking that promotes integrity, sustainability, and innovation. This concept underpins environmental protection initiatives throughout all components of production, management, and service (Scheverin et al., 2020; Jiang et al., 2022). The UNEP's Fifth High-Level Seminar on Environmental Sustainability further expanded the concept of cleaner production by incorporating industrial ecology into its framework (Shi and Xiang, 2002).

In management, cleaner production is defined as the integration of environmental factors into regular operations. To reduce pollution, the production process primarily focuses on using eco-friendly, energy-efficient, and non-toxic materials (Hoof and Lyon, 2013). In terms of product design, the need to mitigate environmental impacts after a product is abandoned helps alleviate the potential for severe environmental consequences (Wang et al., 2021). Essentially, cleaner production encompasses production methods that minimise the negative environmental impacts associated with human economic activities, leading to more efficient resource utilisation (Wang et al., 2021; Jiang et al., 2020). Cleaner production can be achieved by implementing specific measures, such as upgrading technology and management systems, streamlining manufacturing processes, and reducing pollutant emissions from products or services (Scheverin et al., 2020). As a universal, scientific, and environmentally friendly strategy, cleaner production has become a crucial tool for achieving sustainable development. Key components of cleaner production include green production, low-carbon production, lean production, and circular production (Wang et al., 2021). However, numerous barriers exist to the adoption of cleaner production practices. For instance, Leite et al. (2019) found that cultural and technological constraints hinder the adoption of cleaner production methods among small businesses. The size of an organisation can significantly influence the adoption and implementation of cleaner production (Neto et al., 2020). These challenges need to be addressed to achieve better implementation outcomes.

Three key elements highlight the importance of Clean Production (CP). First, CP emphasises preventing and controlling pollutants at their source. It takes into account all phases of product manufacturing, not just the production process. Rather than relying on conventional end-of-pipe treatment methods, CP aims to reduce pollutants directly at their source and improve resource efficiency (Wang et al., 2021). Secondly, the objective of CP is to change the trajectory of economic growth. It differs from the traditional extensive development model by promoting a more intensive production strategy (Scheverin et al., 2020; Jiang et al., 2021). Thirdly, CP has the potential to contribute to sustainable development. Implementing clean production methods is crucial for enhancing production and management standards, maximising benefits, and protecting the environment (Nasrin et al., 2015).

In 1989, the United Nations Environment Programme (UNEP) introduced the term "cleaner production." Following this, the UNEP developed the "Cleaner Production Plan”.

Since the inception of the cleaner production concept, scholars have conducted extensive and ongoing research into clean production processes. In 1990, the U.S. Congress passed the Pollution Prevention Act, which shifted focus from long-term "end-of-pipe" pollution control programs to a proactive pollution prevention policy. In 2019, the UNEP recommended the adoption of cleaner production as a development strategy and encouraged the integration of its principles throughout all phases of administration and manufacturing, including efforts to reduce environmental pollution. In 2002, China implemented its Cleaner Production Promotion Law. This legislation aims to protect the environment by promoting the efficient use of resources while minimising or preventing the generation of pollutants. Various studies on cleaner production have examined aspects such as legal frameworks, standards, development processes, technology, and management (Shi and Xiang, 2002). Despite this body of research, there are currently no empirical studies exploring the formation and evolution of cleaner production. Therefore, further investigation into this area is necessary to enhance understanding and guide future research, as well as to improve the distribution of publications on the subject (Shi and Xiang, 2002).

2.2 EMPIRICAL LITERATURE REVIEW

2.2.1 To test the possibilities and effectiveness of the designed water treatment system for use in a microbrewery after the production process and installation cleaning

According to Zaborowski et al. (2024), research was conducted in North Central Poland to assess the feasibility and effectiveness of a newly designed water treatment system for use in a microbrewery. This closed-circuit system consists of a rinse water flocculation tank, a circulating pump with a pre-filter, an ultrafiltration system, an additional disinfection system, and an expansion unit. The study aimed to evaluate water quality following the production process and cleaning of the installation. The investigation analysed both the rinse water obtained from the brewery and that treated through the water treatment system. Results showed significant changes in most water parameters compared to the rinse water from the brewery. The pH level of the purified water decreased from 7.71 to 7.31, primarily due to a reduction in alkaline ions during the purification process. The treatment did not affect the water hardness, but the conductivity of the purified water was reduced by 25.6%, indicating a decrease in the overall concentration of dissolved chemicals. The purified water exhibited a 61% lower bromide concentration than the rinse water, which is attributed to the reduction of disinfection residues by the cleaning system. Ammonium levels decreased from 0.19 to 0.063 milligrams per litre (mg/dm^3), marking a reduction of 66.8%. Nitrate levels were also reduced from 3.16 mg/dm^3 to 1.23 mg/dm^3, a decrease of over 61.07%. However, the concentration of chloride in the filtered water more than doubled, increasing from 41.7 mg/dm^3 to 93.6 mg/dm^3. Overall turbidity improved, falling below the minimum acceptable level. The researchers concluded that the technology demonstrated in the study is a viable solution for small-scale breweries. The purified rinse water displayed significantly altered chemical characteristics that comply with drinking water regulations. Some modified parameters, such as reduced turbidity and increased chloride levels, positively influence the technological use of water in breweries. The compact design of the described solution, combined with the use of inexpensive and widely available components, makes it suitable for even the smallest breweries. This approach not only offers financial benefits through potentially lower water consumption but also aligns with the principles of sustainable development.

2.2.2To assess the current water and waste management practices, analyse their impact on sustainable production and provide recommendations for more sustainable water and waste management practices in the brewery

According to Pehlivani et al. (2023), research was conducted at the Birra Peja Brewery in Peja, Kosovo, to evaluate the current water and waste management practices. The study aimed to assess their impact on sustainable production and provide recommendations for more sustainable practices within the brewery. The findings highlighted the importance of evaluating water usage and waste management at Brewery Birra Peja for long-term production sustainability. The research identified several opportunities for improving water management and waste reduction, demonstrating that the implementation of sustainable practices can greatly benefit the environment, the community, and the company's finances. The evaluation emphasised the need for water conservation measures, including optimising water use in the manufacturing process, reusing wastewater, and adopting effective cleaning techniques. The study offered valuable insights and recommendations not only for Brewery Birra Peja but also for other breweries seeking to implement sustainable practices. Furthermore, the case of Birra Peja underscored the importance of stakeholder involvement and collaboration in achieving sustainable production. Engaging closely with local authorities, suppliers, and customers is essential. Overall, the evaluation stressed the necessity of conducting regular water and waste assessments in breweries to pinpoint areas for improvement and promote sustainable practices. The study's findings indicated that adopting more effective cleaning techniques and enhanced waste management practices could significantly reduce water usage and waste for Brewery Birra Peja while also minimising its environmental footprint. Some potential approaches include (1) investing in water-efficient manufacturing processes and equipment. Birra Peja should invest in new water-saving equipment and processes, such as water-efficient cooling systems, high-pressure cleaning systems, and more efficient bottling and packaging systems. (2) Reusing water in the production cycle: To reduce water waste, the brewery might install a closed-loop water system that recirculates water throughout the manufacturing process. This could include treating and reuse of waste water produced during the brewing process (EC, 2019).

2.2.3 To assess discharged effluent parameters, sustainable management practices, and potential wastewater reuse options within the context of urban sustainability

According to Swaray (2024), a study was conducted on the beer production industry in Montserrado, Liberia. The study aimed to evaluate the characteristics of discharged effluent, sustainable management techniques, and potential wastewater reuse solutions within the context of urban sustainability. The findings revealed that Liberian authorities face significant challenges in protecting the environment, supporting economic growth, and maintaining public health due to an increasing population and insufficient wastewater treatment infrastructure. The study discovered that the high concentration of BOD was caused by yeast metabolising carbohydrates to produce alcohol and CO2 during fermentation. The residual yeast and other fermentation by-products that remain after the beer has been processed contribute to the organic load in the wastewater. The study examined the COD concentrations, and all of them remained within Liberia's allowed discharge guidelines of 100mg/L. Cleaning and sanitising chemicals used in brewing equipment can dissolve into wastewater, increasing TDS levels, and the concentrations were found to be higher than both national and international guidelines.

In conclusion, the study analysed the characteristics of discharged effluent, sustainable management techniques, and opportunities for wastewater reuse in Montserrado's brewing sector. It identified a concerning increase in pollution levels in the industrial sector, indicating the need for urgent action. However, implementing a singular set of rigid national standards without a well-defined development strategy risks hindering the overall growth of the sector due to the high investments required. This, in turn, could exacerbate pollution and public health issues in underserved areas. Establishing a uniform set of national guidelines for industrial wastewater discharge is unlikely to effectively mitigate pollution and water insecurity threats across most Liberian counties. To address Liberia's industrial challenges, it is essential to first develop a comprehensive set of diverse industrial standards throughout the country, as evidenced by practices in other regions worldwide. Following this, a robust framework for management and compliance should be built to enable the adoption of more sophisticated norms in the future. The discharge standards established in 2002 may not provide a feasible and effective foundation for national-level discharge regulations compared to the proposed standards. The research offered insights into wastewater reuse options for brewery wastewater by examining various treatment technologies that allow for water reuse and highlighting key research into the characterisation of the studied brewery effluent data. Brewery wastewater can be repurposed through several treatment and recycling processes, including onsite treatment, irrigation, resource recovery, and cooling systems. However, these methods require careful management to address risks such as health and environmental degradation, regulatory compliance, infrastructure investment, public perception, and operational challenges. The findings indicated that the current effluent control practices in Liberia are significantly less advanced, resulting in ongoing challenges for the brewery industry. This highlights a policy and infrastructural gap in Liberia that needs to be addressed to improve sustainability practices. Adopting sustainable water reuse technologies not only ensures compliance with stricter environmental standards but also enhances the overall operational effectiveness of breweries, potentially yielding financial benefits within three to five years. Nonetheless, maintaining and operating these systems can be complex and necessitate skilled personnel, leading to operational challenges and financial repercussions. Since many local communities rely on subsistence farming, there may be public concerns regarding the safety and purity of reused wastewater, which could result in opposition to these wastewater reuse initiatives. In conclusion, the main benefit of implementing effective effluent treatment is the ability to significantly reduce its ecological impact and conserve water resources.

2.2.4 To evaluate the use of Moringa oleiferra (MO) powder and synthesised 1.0 and 2.0 g TiO2NPs as green synthesised nanoparticles for the remediation of brewery wastewater using standard methods

According to Owolabi et al. (2023), a study was conducted at International Breweries Plc in South-western Nigeria to evaluate the efficacy of Moringa oleifera (MO) powder combined with synthesised titanium dioxide nanoparticles (TiO2NPs) at concentrations of 1.0 g and 2.0 g. The goal was to assess their effectiveness as green nanoparticles for treating brewery wastewater using conventional methods. Analysis of raw brewery wastewater from the facility indicated significant pollution, with all measured physicochemical and biological parameters exceeding the limits set by FEPA and IESIPIE. However, wastewater treatment using the green synthesised TiO2NPs led to a notable reduction in these parameters. Fourier-transform infrared spectroscopy (FTIR) studies identified several functional groups, including Ti-O, C-C, C-H, and O-H, in the nanoparticles; these groups were determined to play a key role in the removal of pollutants from the wastewater. Scanning electron microscopy (SErM) results showed that the nanoparticles were highly crystalline and possessed active sites suitable for adsorbing contaminants. Overall, the synthesised nanoparticles proved to be effective in removing harmful substances from the brewery wastewater, thereby protecting human health and aiding in the restoration of the ecosystem.

2.2.5 To assess reuse options of brewery effluent for agriculture.

According to Salian et al. (2017), research was conducted at the Brewery Factory in Sangareddy, Telangana, India. The study aimed to evaluate potential reuse options for brewery wastewater in agriculture. The findings revealed that the pH of brewery wastewater collected at various stages of the treatment plant was nearly identical to that of tap water, although the effluent from the effluent treatment plant (ETP) had a slightly higher pH of 7.83. The pH level in brewery effluent is primarily influenced by the quantity and type of chemicals used in the cleaning unit, including phosphoric acid, nitric acid, and caustic soda. The highest electrical conductivity (EC) was reported from the reverse osmosis (RO) reject outlet, measuring 12.07 S/m, followed by the Upflow Anaerobic Sludge Blanket Reactor (UASBR) and ETP outlets, which measured 4.37 and 4.04 S/m, respectively. The lowest EC value was found in tap water, which measured 0.62 S/m. In terms of total dissolved solids (TDS), the highest concentration was observed in the RO reject outflow at 7578 mg/l, while the lowest concentration was in tap water at 445 mg/l. Tap water also had the lowest total suspended solids (TSS) value at 5.06 mg/l, while the UASBR output effluent recorded the highest TSS at 46.5 mg/l. High salinity in water can be attributed to the presence of carbonates, chlorides, sulphates, and nitrates of calcium, magnesium, and sodium (Pandey and Sharma, 2002). The largest concentration of plant nutrients, particularly nitrates, was found in the ETP outlet effluent (20.46 mg/l) and RO reject output (16.29 mg/l), whereas tap water exhibited the lowest concentration at 1.82 mg/l. The UASBR outlet effluent showed the highest level of ammonia nitrogen (NH4-N) at 66.82 mg/l among all water types, with the RO reject outlet and tap water demonstrating the lowest values at 10.06 and 2.67 mg/l, respectively. The nitrogen concentration in the brewery effluent is influenced by the handling of raw materials and the quantity of spent yeast (Parawira et al., 2005). Tap water contained a low phosphate concentration of 0.02 mg/l, while the UASBR outflow had the highest concentration at 1.57 mg/l. The RO reject outlet recorded the highest levels of potassium, chlorides, chemical oxygen demand (COD), fluorides, sodium, total hardness, and alkalinity (119.05, 430, 365.33, 2.13, 1126.77, 685, and 1138 mg/l CaCO3), whereas tap water showed the lowest values (14.87, 53.88, 49, 1.27, 12, 134.66, and 128 mg/l CaCO3). The RO reject outlet also had the highest concentrations of calcium and magnesium at 93.64 and 67.77 mg/l, respectively, while the ETP outlet effluent contained the lowest amounts at 39.50 and 26.57 mg/l. Heavy metals, such as boron and iron, were found at higher concentrations in the RO reject outlet effluent (0.16 and 1.56 mg/l, respectively), while other heavy metals were below detectable levels in all water sources. The percentage of seed germination decreased steadily as the concentration of effluent increased in all three crops. In chickpeas, seed germination was 97% for both the UASBR50 and ETP50 treatments, while the RO10 treatment showed a germination rate identical to the control (tap water) at 93%. However, the RO25 treatment exhibited an inhibitory effect on germination, resulting in a lower germination rate of 60%. The UASBR100 and ETP100 also demonstrated a positive effect, with 83% seed germination. In maize, both the ETP50 and control treatments resulted in 100% seed germination, whereas UASBR50 produced a 90% germination rate. The UASBR100 and ETP100 treatments also showed favourable effects, with germination rates of 83% and 87%, respectively. Conversely, both dilutions of the RO reject resulted in very low germination percentages, with 47% for RO10 and only 17% for RO25. In pigeon peas, a seed germination rate of 97% was observed for the control and UASBR50 treatments, with 90% for ETP50. The RO reject outlet at 10% dilution showed 87% germination, followed by 83% for the UASBR100 and ETP100 treatments. However, higher salt content negatively affected seed germination in pigeon peas, with only 53% germination observed in the RO25 treatment. Barazani and Golan-Goldhirsh (2009) reported that increased salt concentrations inhibited the germination of Salsola inermis, as did Khan et al. (2017) for rice. According to Rusan et al. (2015), the osmotic pressure and ion toxicity of salts in brewery wastewater (specifically RO reject) may adversely affect seed germination when applied to barley alongside olive mill wastewater. Higher salt concentrations create osmotic pressure, which primarily hinders water uptake by seedlings, thereby inhibiting or reducing seed germination (Naeem et al. 2015). Among the three crops studied, maize was most affected by the RO reject effluent, showing the lowest germination rates compared to the others. In contrast, the diluted effluents from the UASBR and ETP exhibited a promoting effect on seed germination, attributed to their higher nutritional content than that of tap water. Wastewater contains essential organic compounds that can enhance crop growth (Pathak et al. 1999; Ramana et al. 2002; Nagajyothi et al. 2009). However, at higher concentrations of these effluents (UASBR100 and ETP100), the percentage of germination decreased, indicating that excessive effluent concentrations may have harmful effects (Nagda et al. 2006; Khan et al. 2011). Research by various authors has shown that the toxicity level of effluents depends on the nature and concentration of the chemicals present, meaning that the inhibition or reduction of seed germination cannot be attributed to a single component. This study found that the concentration of treated brewery effluent collected from different treatment phases did not inhibit the seed germination of the three crops, except for the RO25 concentration. While undiluted UASBR and ETP effluents positively influenced germination, the diluted UASBR50 and ETP50 significantly enhanced the growth of seedlings across all three crops. Therefore, it is recommended to dilute brewery effluent before using it for irrigation purposes.

2.2.6 To identify possible factors affecting contaminant concentrations in effluent

A study conducted by Kinnunen et al. (2023) in Finland and Sweden examined potential factors influencing pollutant concentrations in effluent, with a particular focus on weather-related parameters. The research found a correlation between changes in effluent water temperature and air temperature for both the PP (Presumably Pre-treatment) and SBS (Sequential Batch System) categories. This association was strong and positive, with Pearson's correlation coefficient (r) values of 0.69 for PP and 0.80 for SBS. This finding confirmed the expectation that the temperature of wastewater in on-site wastewater treatment systems (OWTS) units varies throughout the year in response to air temperature. However, some of the datasets containing water temperature observations did not include data from days when air temperatures dropped below -5°C. These low subfreezing temperatures reduce biological activity and hinder biological processes related to Biological Oxygen Demand (BOD), NH4-N oxidation, and phosphorus removal mechanisms, such as precipitation (Luostarinen et al., 2007; Kauppinen et al., 2014; Vidal et al., 2018). The study explored the impact of unit age and load on pollutant concentrations. The SBS dataset included older units compared to the PP dataset, and there was a slightly stronger correlation between unit age and total phosphorus (Tot-P) concentration in the effluent for SBS than for PP. This was evident in both rank correlation and linear correlation analyses. However, no significant correlation was found between unit age and BOD, Tot-P, or total nitrogen (Tot-N), despite the small p-values suggesting that the observed rank correlations were indeed greater than zero.

The impact of system-specific processes on effluent water quality was evaluated. Lower effluent BOD values were observed in AG-SBS systems, followed by SG-PP and AG-PP. The higher concentration values found in AG-PP effluents indicate issues with continuous operation, making it difficult to adapt to changes in flow conditions. These changes can include solids flushing or challenges in maintaining biological activity with varying organic loads, especially without sludge recirculation (Moelants et al., 2008; Dubois and Boutin, 2018). In contrast, SBS units operate continuously, and the lower effluent BOD7 concentrations measured can be attributed to more stable flow conditions and the retention of particulate organics during filtration (Dubois and Boutin, 2018). Additionally, SBS systems typically have a longer water retention period, allowing for both aerobic and anaerobic breakdown of organic molecules (Jenssen et al., 2010; Wilson et al., 2011).

There were some changes in the median total nitrogen (Tot-N) concentrations observed in the effluents from the AG-PP, AG-SBS, and SG-PP systems. Still, these changes were not statistically significant (p-values > 0.36). As previously mentioned, the AG-PP units in this study utilised rotating biological contactors, which are capable of removing Tot-N through nitrification and denitrification processes (Tawfik et al., 2006). The AG-SBS system supports both nitrification and denitrification processes (Vilpas and Santala, 2007; Laaksonen et al., 2017). However, in the SG-PP system, denitrification is largely overlooked, as it does not employ sludge recirculation (Vilpas and Santala, 2007; Dubois and Boutin, 2018; Olivier et al., 2019). Although most SG-PP units in this study (approximately 70%) have some form of recirculation, concerns have been raised regarding the effectiveness of soil filters, which are based on natural soil types, in removing phosphorus (P) (Eveborn et al., 2014; Vidal et al., 2018). Biological treatment processes alone are ineffective for P removal (Yang et al., 2021). The results of the study supported this conclusion, as both floating plants (FP) (median 0.69 mg/L) and constructed wetlands (CP) (median 1.54 mg/L) exhibited better effluent quality compared to soil filters (SF) (median 4.00 mg/L), with over 40% of these units failing to meet the more stringent projected Swedish regulatory requirements. The differences in effluent total phosphorus (Tot-P) concentrations between SF and CP units and between SF and FP units were statistically significant. The addition of coagulants reduces alkalinity and lowers pH, while phosphorus-sorbing filter media can be alkaline, causing the dissociation of alkaline substances to raise the pH in water (Vidal et al., 2018; Cainglet et al., 2020).

In conclusion, the findings indicated the following: (1) The variability in effluent water quality was not explained through meteorological factors (air temperature, precipitation, and snowmelt) in either soil-based systems (SBS) or package plants (PP) within the analysed dataset. (2) Traditional sand filters are recommended when the focus is on removing BOD (biochemical oxygen demand) and nitrogen. However, they have proven to be inadequate for phosphorus removal, and it is necessary to implement a tailored strategy to enhance phosphorus removal. Chemical precipitation and phosphorus filters exhibit similar effectiveness in removing phosphorus.

2.2.7 To determine factors affecting wastewater characteristics in the beverage industry and to identify methods for treating and reducing wastewater.

According to Rinne (2024), research was conducted at Hartwall Beverage Manufacturing in Finland. The study aimed to investigate the factors influencing wastewater characteristics in the beverage industry as well as techniques for treating and reducing wastewater. Four separate wastewater streams from the factory were analysed for their composition, flow rate, and potential treatment solutions. These streams were sourced from the PT-cellar drain, the balance tank, and two drains involved in wort production. Before sampling, it was observed that the balance tank generated the most wastewater, while the PT-cellar outflow primarily consisted of detergent and product residues. The wort production process produced wastewater with suspended particles and organic matter. Due to the small volume and unpredictable composition of the PT-cellar drain, treating it as a separate stream was deemed unprofitable. In contrast, the wastewater from the balance tank was considered the easiest to process since it was already collected in a separate tank. One possible treatment option is membrane filtration. Depending on the type of filter used, the treated water could potentially be reused for cleaning in place (CIP) washing or in heating and cooling systems. However, further investigation into the financial viability of this option is necessary, as membrane filtration requires pre-treatment before implementation. The wastewater generated during wort production was also relatively small in volume, but the concentration of various substances was significantly high. Therefore, it may be economical to treat it as a separate stream. A feasible treatment approach is to collect the wastewater from the wort production process and route it to the existing biogas plant along with the mash. The primary investment needed would be in the collection system. Anaerobic reactors were considered for total wastewater treatment based on the COD: N:P and BOD/COD ratios, both of which indicate that the wastewater is suitable for anaerobic treatment. The Upflow Anaerobic Sludge Blanket (UASB) reactor was selected for its proven efficiency in treating wastewater from the beverage industry and its established technology. While the UASB reactor could reduce industrial wastewater fees, it would require the largest investment. Before initiating treatment of the entire wastewater using a UASB reactor, it is crucial to identify the main causes of concentration changes, as these can influence the reactor's performance. To gain a deeper understanding of the factors affecting overall wastewater composition, simultaneous measurements should be taken of both total wastewater and individual wastewater streams. Analysis of the wastewater streams did not reveal any clear reasons for the discrepancies in wastewater quality. The likely cause is a reduction in water usage, which concentrates the wastewater. It was found that the amount of effluent generated per litre of the finished product had dropped by approximately 10%. The analysed wastewater streams accounted for about 11% of the total wastewater produced. Further research is needed to obtain a more comprehensive understanding of the origins of wastewater loads and flows. It should be explored whether it’s feasible to pool and simultaneously treat certain wastewater streams, as this could enhance the profitability of treatment. For example, in beer manufacturing, it may be worth investigating if other wastewater streams can be combined with those generated during wort production. Possible streams for blending with the balance tank wastewater could include wastewater from various rinsing processes.

2.2.8 To identify opportunities for increased sustainability and efficiency in brewing processes and to assess innovative wastewater management in the brewing sector.

According to Ifeanyi-Nze et al. (2024), a study was conducted at Nigerian Breweries PLC in Lagos, Nigeria. The study aimed to identify opportunities for enhancing sustainability and efficiency in brewing processes and to evaluate innovative wastewater treatment methods in the brewing sector. The researchers found that Brewer's Spent Grain (BSG), a high-volume waste product from brewing, possesses interesting properties for composite manufacturing using polymer matrices. In addition to serving as an inert filler, BSG acts as a functional filler, offering antioxidant properties derived from phenolic compounds and free radical scavengers. Its lignocellulosic characteristics were utilised to develop cellulose acetate membranes for filtering and treating brewery wastewater. The study successfully achieved its objectives. Positive results were observed in the brewery effluent treatment process, as demonstrated by thorough analyses of key parameters such as Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), and pH levels. These analyses collectively confirmed the effectiveness of the treatment technique. The cellulose acetate membrane created from BSG proved effective in treating brewery effluent, leading to significant reductions in pollutant levels with each treatment round. This finding highlights the membrane's capability to remove contaminants from wastewater efficiently. It was also noted that increasing the number of treatment runs resulted in greater pollutant reduction from the brewery effluent, showing a positive correlation between treatment frequency and the effectiveness of wastewater treatment. The results of the BOD analysis were particularly encouraging. Starting with a raw wastewater sample from Nigerian Breweries PLC in Lagos, which measured 16.65 mg/l, subsequent treatment runs achieved values of 13.70 mg/l, 11.16 mg/l, 8.37 mg/l, 5.58 mg/l, and 3.14 mg/l. This comprehensive BOD analysis, including the five-day BOD data (BOD5), provided a thorough assessment that showcased the effectiveness of the treatment process. These results indicate a strong biochemical breakdown and demonstrate the treatment method's efficiency in significantly reducing pollutant levels. In conclusion, this study showed that cellulose acetate membranes derived from BSG could effectively treat brewery wastewater while minimising environmental impact. The findings emphasise the potential of this approach in developing sustainable wastewater management practices within the brewing industry, offering economic and environmental benefits.

2.2.9 To assess methods for treating brewery wastewater based implications using the state-of-the-art biological treatment technologies leading to water reuse and/or energy production

Werkneh et al. (2019) conducted a study at the Unicer brewery in South Africa to evaluate techniques for treating brewery wastewater using advanced biological treatment technologies that may lead to water reuse and energy production. The study found that the beer industry consumes vast amounts of water and generates significant quantities of wastewater. Consequently, managing water requirements, energy consumption, and wastewater in breweries remains critical, particularly as waste management regulations become increasingly stringent. Energy demand and water usage serve not only as economic indicators but also as measures of process performance. The paper examined both existing and emerging biological methods for treating brewery wastewater and assessed their implications for water reuse and energy production. Various technologies have been identified for the treatment of brewery wastewater for reuse and recovery purposes, with laboratory-scale studies indicating higher efficiency. Membrane bioreactors and fluidised bed bioreactors are effective in promoting potential water reuse, while anaerobic bioreactors, such as Upflow Anaerobic Sludge Blanket (UASB) and All-in-One Sequential Batch Reactor (ASBR), show promise for producing biomass-based energy sources like biodiesel, biogas, and bio-hydrogen from brewery wastewater. However, wastewater reuse efforts face challenges, including a lack of environmental and health regulatory frameworks, the high costs associated with the necessary technologies, and public perception issues. Therefore, it will be vital to address these challenges in the future to ensure environmental sustainability through effective wastewater treatment and green energy generation in the brewery sector.

2.3.0 To assess wastewater treatment in the brewery industry.

A study conducted in South Africa by Kebede (2018) evaluated wastewater treatment in the brewing industry. Breweries are known for employing cost-effective strategies to produce high-quality products. The research focused on a combination of anaerobic and aerobic technologies. This two-stage method effectively removes organic contaminants and suspended solids, and under the right conditions, it can also eliminate nutrients. Anaerobic treatment is a commonly used technique for processing brewery effluent. The combined anaerobic/aerobic treatment of brewery wastewater offers significant advantages over complete aerobic treatment, particularly in terms of energy efficiency, reduced sludge generation, and lower space requirements. Brewery industries, which often consist of small and medium-sized businesses, have a substantial social and economic impact. Therefore, their commitment to sustainability necessitates implementing high-performance wastewater treatment systems that utilise established procedures and technologies. To comply with stringent requirements related to odour control, space limitations, and minimal sludge production, considerable focus has been placed on anaerobic-aerobic reactors.

When levels of industrial wastewater exceed optimal limits, they can cause major issues for living organisms in food crops, farmland, waterways, and minerals. As wastewater poses health risks and impacts ecosystems, further research from various perspectives on industrial wastewater treatment is essential. This research aimed to enhance understanding of effective treatment methods to promote organismal health. Ana treatment is more cost-effective than aerobic methods, making it the preferred choice. The rising costs of water are just one of the challenges faced by firms that rely on traditional production processes. Advanced technologies can manage wastewater that can be recycled either within the same process or in different applications, suggesting that brewery wastewater can be reused rather than discharged into the environment, thereby preventing pollution.

2.3.1To evaluate the physicochemical and bacteriological properties of the wastewater to determine its suitability for irrigation

According to Adugna et al. (2024), a study was conducted at Harar Brewery in Harar City, Ethiopia, to assess the physicochemical and bacteriological properties of wastewater and determine its suitability for irrigation. Beverage companies like Harar Brewery consume significant amounts of water in their production processes, leading to large volumes of wastewater being discharged into the environment, primarily for land application. The physicochemical and bacteriological properties of this wastewater often exceed acceptable limits, negatively impacting soil quality and indicating environmental pollution. The study aimed to characterise the physicochemical and bacteriological properties of Harar Brewery effluent and assess its suitability for irrigation. Samples were carefully collected and analysed according to standard laboratory procedures, with results compared to national and international standards. The study focused on the concentrations of various physicochemical and bacteriological characteristics in the brewery wastewater. Research findings revealed that nearly all physicochemical parameters were within the acceptable range. Pearson correlation analysis showed high and moderate positive and negative correlations between several parameters, indicating interdependencies. Although the bacteriological properties, particularly total coliform (TC) and E. coli levels, were positive, they remained within tolerable limits. Consequently, the bacteriological quality of the brewery effluent does not pose a concern for irrigation applications. However, concentrations of electrical conductivity (EC), total suspended solids (TSS), total solids (TS), biological oxygen demand (BOD), and chemical oxygen demand (COD) did not meet the standards for brewery wastewater. The elevated EC levels surpassed the Environmental Protection Agency (EPA) regulatory limit, indicating the presence of dissolved salts and minerals that can lead to soil salinity and reduced crop productivity when used for irrigation. Similarly, high levels of TSS and TS can cause soil clogginess and hinder water infiltration, limiting plant growth. Additionally, elevated COD levels suggest the presence of organic matter, which can deplete dissolved oxygen in soil and water bodies, resulting in environmental degradation. Therefore, additional treatment and management procedures are essential to ensure that this wastewater can be used safely for irrigation. Such measures may involve physical, chemical, and biological processes to reduce pollutants in the wastewater. Management strategies might also include proper storage, distribution, and application procedures to minimise environmental impact. In conclusion, while the physicochemical and bacteriological properties of Harar Brewery wastewater met Ethiopian and international standards for most parameters, further treatment and management strategies are necessary to guarantee its safe use for irrigation. Implementing these strategies can help prevent environmental degradation while enhancing agricultural productivity.

Conclusion

The review of existing literature by the investigator primarily focused on the effectiveness of various wastewater treatment technologies, including membrane bioreactors, fluidised bed reactors, UASB (Upflow Anaerobic Sludge Blanket), ASBR (Anaerobic Sequencing Batch Reactor), Moringa oleifera (MO) powder, and synthesised 1.0 and 2.0 g TiO_2 nanoparticles. Some research also examined the efficacy of combined anaerobic and aerobic treatment systems for wastewater. Other studies analysed factors that influence the properties of wastewater. Most research has centred on wastewater reuse, water optimisation, and effective cleaning procedures to reduce water consumption and wastewater generation. However, the investigator identified several gaps in the literature that warrant further investigation. Most studies have concentrated on managing wastewater after it has been discharged from brewing operations, with limited attention paid to improving brewing processes to minimise wastewater generation and improve wastewater PV and pH. This research will focus on how wastewater generation can be reduced and wastewater PV and pH improved at source. One particular study emphasised optimising water usage through efficient processes and equipment. However, there has been no comprehensive examination of all the factors that contribute to wastewater formation. Further research is necessary to identify all the elements that can help reduce wastewater output. Existing studies have not focused adequately on the factors influencing pH and permanganate value, as well as how these factors might be managed. Consequently, this research aims to address this information gap through an in-depth study.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1.0 Introduction

The study employed a mixed-method approach that combines both qualitative and quantitative methodologies. Data will be collected through direct observations, in-depth interviews, document reviews and questionnaires. This chapter will cover the study area, sampling strategy, research design, data collection techniques, data analysis and research ethics.

3.1.1 Study Area

The study was conducted at Delta Beverages Lagers, located at the corner of Manchester Road and Highfields Road, Southerton, Harare. The company was first listed on the Stock Exchange in 1946 as Rhodesian Breweries Limited and later changed its name to Delta Corporation in 1978. Delta Lagers is one of the four strategic business units (SBUs) of Delta Beverages. It produces a variety of lager beers, including Castle, Zambezi, Bohlingers, Lion, and Eagle Lager. Recently, Delta Beverages Lagers also commissioned a canning line for Coca-Cola products. According to the organisation's 2023 Annual Report, Delta Beverages Lagers improved its production volume by 17%, reaching 2.2 million hectolitres of beer per year. However, this increased production has resulted in higher levels of wastewater generation. In response, the organisation has implemented several sustainable wastewater management practices.

Latitude: -17.86982º or 17º52'11" south **Longitude:** 31.0145º or 31º0'52" east

Figure 3. 1 Map of Delta Beverages Lagers

3.1.2Research Design

The study was based on a cross-sectional design, which is a type of observational research that analyses demographic statistics at a specific moment in time. Unlike other forms of observational research, cross-sectional studies do not track individuals over a period. The researcher chose this approach because cross-sectional studies are easy to conduct, cost-effective, and useful for collecting preliminary data that can inform future research planning (Wang et al., 2020).

3.1.3 Data Collection and Analysis

3.1.3.1 Target Population

The target population was SHE practitioners, brewing process operators, brewing top management and utilities team members.

3.1.3.2 Determining sample size

To determine the sample size from the target population, the researcher used the Yamane's formula

$n = \frac{N}{1+N(e)^2}$(Yamane,1967;Akosuaetal.,2021)

Whereby,

n=the sample size

N=The target population size (N=33)

e=the acceptable margin error (industry standard is 5% i.e. 0.05)

Therefore, $n = \frac{33}{1+33(0.05)^2}$

n=30.485=30

30 is the determined sample size for the research

3.1.3.3 Sampling Method

To obtain a sample, the researcher utilised stratified sampling. In a stratified sampling, researchers divide a population into homogeneous subpopulations called strata based on specific characteristics (e.g., race, gender identity, location, etc.). Every member of the population studied should be in exactly one stratum. (Thomas,2020). Researchers then select a random sample from these strata (Gravetter and Forzano, 2012; Sampling et al., 2012). The researcher chose this sampling method because it includes subjects from every subgroup, ensuring that it reflects the diversity of the population. (Thomas,2020). Therefore, the stratified random sampling technique was deemed the most suitable for this research, ensuring sufficient samples were collected from every stratum in the population. The convenience sampling method was utilised for interviews through interviewing the available and accessible members from each stratum. (Gravetter and Forzano,2012; Critically, n.d.). Convenience sampling could be a good fit for research to get opinions from people. (Nikolopoulou,2022)

3.1.3.4 Data Collection Techniques

The researcher utilised various methods, including questionnaires, interviews, document reviews and observations to obtain data for the study questions. Multiple documents were analysed to gather information on wastewater volumes and quality from brewing processes. This was done to identify critical areas to focus on. Document analysis is a systematic approach to studying and evaluating documents, providing context, raising questions, complementing other types of research, tracking changes over time, and verifying other sources (Bowen, 2009). During data collection and analysis, documents can help address research questions. Document analysis can be combined with other widely used research methods, such as interviews (Berner-Rodoreda et al., 2018), observations (Harvey, 2018), and quantitative analyses, depending on the specific goals of the study. Samples of wastewater generated from the brewing processes were collected to confirm the results from document reviews. Grab sampling was used to obtain these samples. Grab samples consist of either a single discrete sample or individual samples collected over some time not to exceed 15 minutes. The grab sample represents of the wastewater conditions at the time of sample collection. (EPA,2013). Three samples per category were taken at an interval of 2 hrs. The pH was measured using a pH meter (ISO 10523,2008), while the permanganate value was assessed using the titration method in the laboratory (ISO 8467,1993). The samples were also analysed for temperature to determine if they are within guidelines.

Interviews were utilised in the study to gather information from the target population regarding the variables that influence the production, pH and PV of wastewater, and strategies for optimising brewing processes. Interviews are one of many qualitative research techniques used to gather data on the participants' subjective experience. The purpose is to get detailed information that sheds light on an individual's perspective about a particular topic, issue or process. (Rutledge and Hogg,2020). The interviews were based on a semi-structured interview guide, with a list of questions to collect new and exploratory data related to the research topic. (DeJonckheere & Vaughn, 2019). Although interviews typically yield richer and more detailed data than surveys, many research questions that can be explored through surveys can also be investigated via interviews. However, it is important to note that conducting interviews often requires more time and resources (Teherani et al., 2015).

During the research, observations were conducted to identify factors influencing the formation, pH and PV of wastewater. The researcher observed the brewing processes to pinpoint the factors that affect wastewater generation, pH and PV. The observation method involves systematically watching directly and recording the behaviour of subjects or phenomena in a specific setting. (Journalism University,09.05.25). Observations are particularly valuable for documenting, exploring, and understanding activities, actions, and interactions as they happen. (Teherani et al., 2015).

A sample from the target population received questionnaires to obtain data about how the brewing processes can be optimised to reduce wastewater generation and improve wastewater pH and PV. A questionnaire is a data-gathering instrument that includes a list of questions designed to elicit information about respondents' experiences or opinions. Questionnaires can be utilised to gather quantitative or qualitative information. (Bhandari,16.05.2025). These questionnaires are useful and standardised, allowing for comparison across groups and locations. However, a questionnaire only captures the data that respondents are willing to provide and the method's limitations, reflecting the structured interaction between the researcher and the participants (Ranganathan and Caduff, 2023). The questionnaire was designed using responses from interviews and the literature reviewed.

3.1.3.5 Questionnaire Response Rate

Below shows the response rate for the questionnaires distributed. Thirty questionnaires were distributed online and thirty responses were received. The response rate was 100%.

Questionnaires distributed	Questionnaire responses	Response Rate
30	30	100%

Table 3.1 shows Questionnaire Response Rate

3.1.3.6 Wastewater generation points

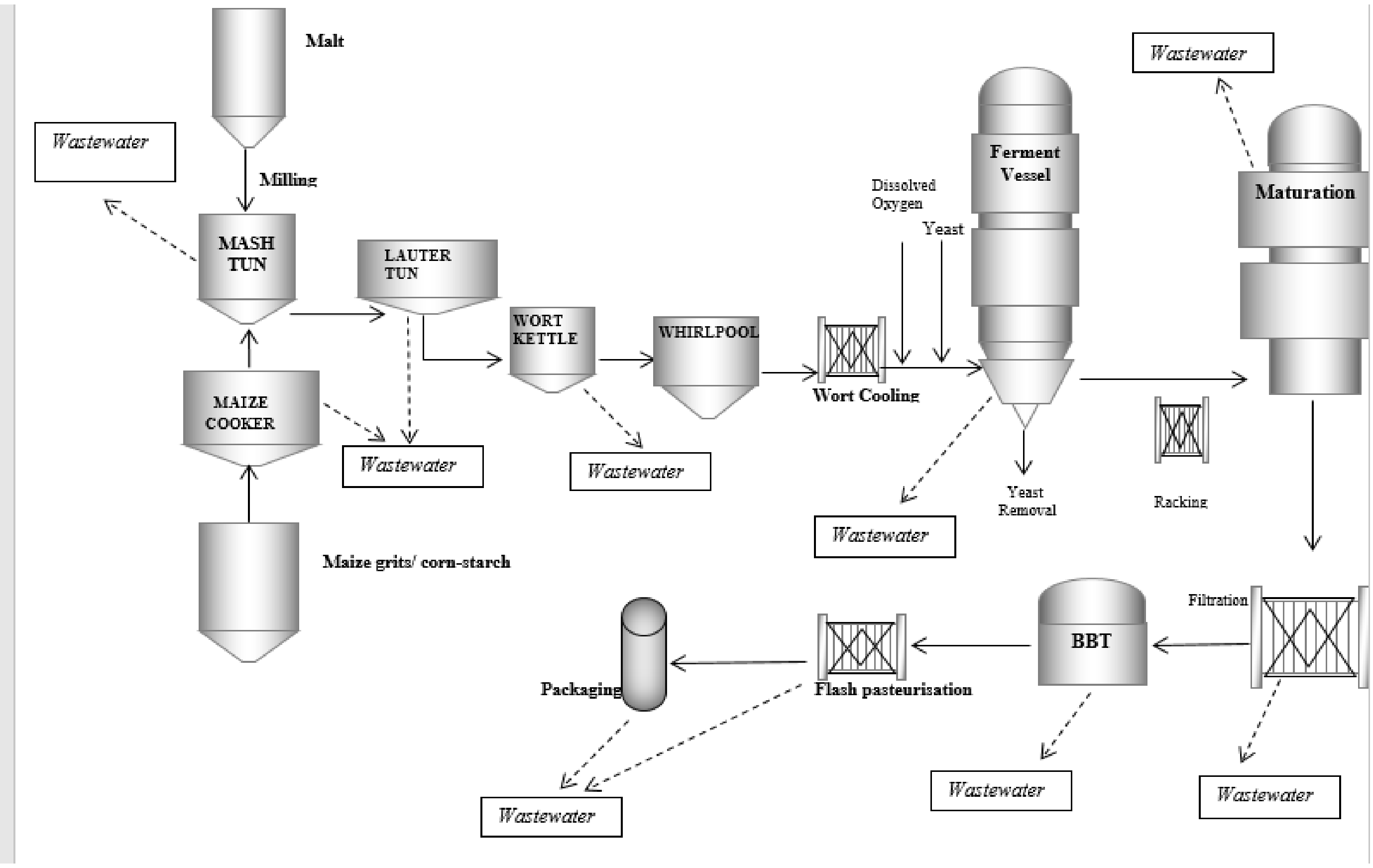

Figure 3. 2 Wastewater generation points

3.1.3.7 Data Analysis

In the study, the investigator utilised SPSS. According to John (14.05.2025), SPSS is user-friendly, determines trends in data, conducts complex statistical analysis and descriptive statistics. With SPSS, the researcher can generate distribution plots, charts and tabulated reports. The software offers reliable and fast answers with few chances of errors. (Williams,14.05.2025). The researcher utilised descriptive statistics. Descriptive statistics are specific methods used to calculate, describe, and summarise collected data in a logical, meaningful, and efficient way (Vetter,2017). Descriptive statistics include measures of central tendency such as mean, mode, median and measures of dispersion such as standard deviation and variance. Descriptive statistics were utilised to analyse laboratory results and questionnaires. In the research, the investigator also utilised chi-square tests. Pearson's chi-square test is a statistical test for categorical variables. It is used to determine whether data deviates significantly from expected values. Pearson's chi-square tests are classified into two types: the chi-square goodness of fit test, which determines whether a categorical variable's frequency distribution differs from what is expected, and the chi-square test of independence, which determines whether two categorical variables are related to one another. (Turney,2022). Chi-square tests were utilised to analyse the relationship between wastewater quantity and quality (pH., PV, and temperature).

3.1.3.8 Validity and Reliability

Validity and reliability refer to the accuracy and consistency of a research tool. Validity measures how well a research tool, such as a questionnaire, assesses the intended topic (Tavakol and Wetzel, 2020). In contrast, reliability evaluates whether a research instrument produces similar results when used consistently under the same conditions (Ranganathan and Caduff, 2023). To ensure the data-collecting tools were valid and reliable, the researcher pretested the questionnaires with individuals not involved in the actual study, excluding their responses from the final analysis. The pre-test included four volunteers from the Harare Brewery Sorghum Plant who knew about brewing.

3.1.4 Ethical Considerations

Ethics are the norms and guidelines that regulate acceptable conduct during the research process, ensuring that researchers engage in a way that safeguards the rights, dignity, and welfare of the individuals involved. (Kalpokas & Hecker,2023). Key ethical considerations in research include data management, responsible use of resources, respect for human rights, treating both human and animal subjects, social responsibility, honesty, integrity, and the publication of study results. Ultimately, the goal of ethics in scientific research is to ensure that the pursuit of knowledge does not compromise societal or individual well-being. It fosters an environment where scientific research can develop responsibly (Resnik, n.d.). The researcher conducted interviews and distributed questionnaires while considering these ethical principles.

Informed Consent

Informed consent is a core ethical guideline and a key practice in research involving human participants. Its purpose is for people to voluntarily participate in studies, fully understand what it includes, and obtain consent before participation. (Thourani,2022) Participants must be properly informed about the research objectives, procedures, potential risks, and benefits. They should also be able to ask questions and voluntarily agree to participate without any coercion (Barrow et al., 2023; McDermott and Hatemi, 2020). This approach respects individual autonomy and decision-making. The researcher upheld this principle by obtaining permission from the organisation involved in the study before conducting the research. The investigator did not pressure participants to participate; instead, they encouraged participation based on the individuals' willingness and provided an option to withdraw from the interview if they felt uncomfortable.

Confidentiality and Privacy

In human-subject research, confidentiality is crucial. Participants' personal information must be secured against disclosure (Barrow et al., 2023; McDermott and Hatemi, 2020). The researcher must maintain secrecy to establish trust between the researcher and the participant. Participants who believe their information will be kept confidential are more likely to provide genuine and thorough responses. (Kalpokas and Hecker, 2023). Confidentiality is vital, as it has a direct impact on the quality and trustworthiness of study results. To uphold the anonymity of the research, the researcher refrained from disclosing the names of the participants.

Non-maleficence and Beneficence

These principles are grounded in the need to avoid harm (non-maleficence) and to maximise potential benefits while minimising possible risks (beneficence) (Barrow et al., 2023; McDermott and Hatemi, 2020). Researchers must ensure that their studies do not put participants at risk and that the benefits outweigh any potential harms. The researcher implemented all necessary measures to keep participants safe, physically and mentally. The investigator encouraged participants to voice any concerns or discomfort they experienced and addressed these issues appropriately.

Summary

The chapter outlines the research design used in the investigation, detailing the study area where the research was conducted. It also describes the techniques and tools employed for data collection to address the study questions. Data was gathered through laboratory analysis, document reviews, questionnaires, interviews, and observations. The chapter discusses the sampling method utilised for the study and the analysis tools used to interpret the collected data. It explains the ethical considerations related to the research.

CHAPTER FOUR

4. DATA PRESENTATION AND ANALYSIS

4.1Introduction

This chapter presents the results and analysis of the data collected for this research. The findings are displayed in tabular and graphical formats. The analysis addressed the research questions and objectives of the study. The analysis aimed to determine the relationship between wastewater quantity and quality and to determine the control points for wastewater generation, pH, and PV levels.

4.1.1Wastewater Quantity

Results from the data collected showed that wastewater is highly generated in most brewing sections which include filtration, fermentation, packaging, Lautering, mashing processes and wort boiling. Filtration generates 206m^3 (2.7m^3/bbl), fermentation 191m^3 (2.5m^3/bbl), packaging 183m^3 (2.4m^3/bbl), Lautering 169m^3 (2.2m^3 /bbl), mashing 152 m^3 (2.0m^3 /bbl) and wort boiling 144m^3 (1.9m^3 /bbl) of wastewater daily.

4.1.2 Wastewater Quality

Process		pH.	pH EMA Guideline	PV(ppm)	PV Delta Lagers Guideline	T (ºC)	Temperature EMA guideline
Composite brewing	Mean ± SE	6.8±0.1	6-9	136±4.67	80	28±1	35
Fermentation	Mean ±SE	6.6±0.1	6-9	136±0.88	80	29±0.33	35
Filtration	Mean ±SE	6.8±0.03	6-9	134±6	80	29±0.33	35
Packaging	Mean ±SE	10.8±0.61	6-9	46±1.73	80	27±0.58	35
Raw wastewater	Mean ±SE	11.1±0.33	6-9	111±0.67	80	28±0.33	35

Table 4.1 Wastewater Quality Results

S.E-Standard Error of Mean, T-Temperature

The table shows the mean and standard error results for pH, PV, and temperature analysed in the laboratory. The means indicate that PV exceeds the guidelines in the filtration and fermentation processes, composite brewing, and raw wastewater. pH is high in packaging and raw wastewater, indicated by values of 10.8±0.61 and 11.1±0.33 respectively, exceeding established pH guidelines. Temperatures are within guidelines in all processes.

4.1.3. Relationship between wastewater quantity and quality

	pH.	PV	Temperature
Pearson Chi-square Value	12.000[a]	12.000[a]	8.000[a]

Table 4.2 shows results for the association between wastewater quantity and quality

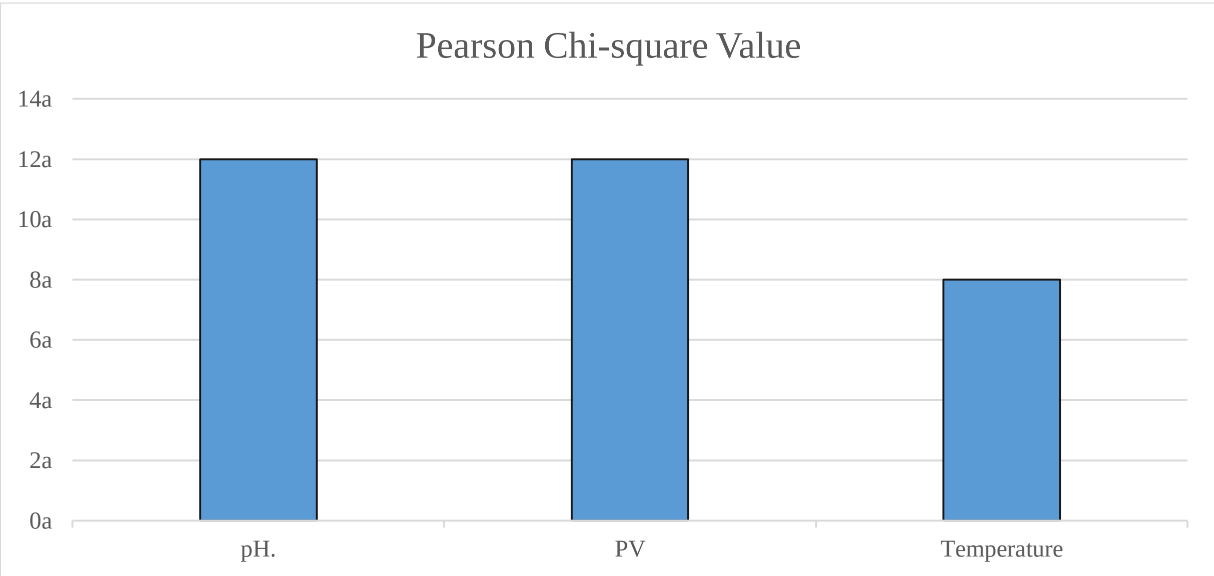

Figure 4.1 shows the relationship between wastewater quantity and quality

The superscripts aa as shown in table and graph denote no significant differences ($p > 0.05$). This indicates that the association between wastewater quantity and the wastewater parameters pH, PV and temperature is insignificant. This implies that changes in wastewater quantity do not have a statistically significant association with changes in wastewater pH, PV and temperature.

4.1.4 Questionnaire Analysis

The results showed that out of 30 participants, 53% agreed or strongly agreed that a closed-circuit system effectively reduces wastewater generation and improves pH and PV. This strategy was supported because a closed-circuit system reclaims wastewater at source, treating it, thereby reducing the volume of wastewater discharged and improving pH and PV.57% of the participants agreed or strongly agreed that reducing cleaning frequency can help decrease wastewater output and improve pH, while 3% disagreed. The strategy was supported because reducing cleaning frequency reduces the amount of water and chemicals used, which reduces wastewater load and improves pH. 60% of participants believed that substituting the plate and frame with a modernised BMF could reduce wastewater output, with 40% expressing a neutral stance. This strategy was supported because modernised BMF requires less water for its operation compared to the Plate and Frame, which requires vast amounts of water. Regarding the replacement of packaging machinery, 93% of participants supported this strategy as effective in reducing wastewater generation, improving pH and PV, while 7% remained neutral. The strategy was highly supported because the ineffective old machinery; for instance, malfunctioning pasteurisers lead to bottle bursting and beer spillage, which increases wastewater volume, pH and PV. 60% of participants suggested that maintaining brewing machines twice a week helps reduce wastewater generation, improves pH and PV and 7% disagreed. The strategy was supported because increasing maintenance frequency ensures that leaks are regularly repaired and that machines operate more efficiently, reducing wastewater output and improving pH and PV.

50% of the participants believed that use of surfactant-based cleaners such as CIP-surf in place of caustic soda is effective in improving wastewater pH, and 7% disagreed. This strategy was supported because CIP surf is neutral compared to caustic soda which is highly alkaline. 63% of the participants suggested that solar drying systems can be introduced as an alternative for drying reclaimed yeast to manage PV and 37% were neutral. This strategy was supported as solar systems are generally cost effective. 73% of the participants agreed-strongly agreed that weekly review of the trub program improves wastewater PV. The strategy was supported because weekly review of the trub program ensures its effectiveness in managing trub which increases PV of wastewater. 40% of the participants believed that suction of malt dust can reduce PV in wastewater,57% were neutral and 3% disagreed. This indicates that most participants were unsure that this strategy is effective in reducing PV.

The closed circuit system can be employed at every point of the brewing processes where wastewater is discharged. This system controls wastewater generation, pH and PV. Reduction of cleaning frequency can be implemented in all areas of brewing where cleaning is practised. The strategy controls both wastewater generation and pH. Replacement of the Plate and Frame with the modernised BMF can be employed in filtration where beer is filtered. At this point, this strategy reduces water usage and wastewater generation. Replacement of packaging machinery with new machinery can be employed in the packaging process and this strategy controls wastewater generation, pH and PV. Brewing machine maintenance twice a week can be practised in all stages of brewing and the strategy manages wastewater generation, pH and PV. Use of surfactant-based cleaners such as CIP can be implemented in all areas of brewing where vessel washing is done. This strategy only controls wastewater pH. Weekly review of the trub program can be implemented in whirl pooling and fermentation processes and this strategy only controls PV.

Over 55% of the participants believed that implementation of the optimising processes can be hindered by financial challenges and resistance to change. Financial challenges can cause the organisation to fail to purchase and install new packaging machinery. The workers can resist changing their practices, which can hinder the implementation of the optimising strategies. Workers may resist using CIP-surf as they are used to caustic soda. Over 50% of the participants suggested that financial challenges can be addressed through financial loans and government incentives. The organisation can take loans from banks and use government incentives, which support environmentally friendly measures, thereby reducing financial costs. To address resistance to change, 80% of the participants suggested that provision of training programs will help employees develop new skills and adapt to changes.

CHAPTER FIVE

5.0Discussion

5.1.0Introduction

This chapter discusses the findings from the research conducted. The discussions in this chapter are based on the data analysis and literature review.

5.1.1 Relationship between wastewater quantity and quality

There is no significant relationship between wastewater quantity and quality (pH, PV, and temperature), which suggests that other factors besides wastewater quantity can affect wastewater quality. Wastewater pH. is affected by the chemicals used in the brewery. For example, at Delta Lagers, caustic soda, which is alkaline, is used in CIP and contributes to the alkalinity of the wastewater. This implies that if there is high wastewater generation with little or no chemicals used, the pH of the wastewater will not be significantly affected. This aligns with a study by Carnevale Miino et al (2025), where they argued that the pH of wastewater is affected by the Clean-in-Place (CIP) sanitisation process due to the chemicals used.

The PV of wastewater can be influenced by other factors, such as dust generated from malt movement rather than the wastewater quantity. Movement of malt can generate dust, which can enter the drains and raise the PV of wastewater. Salian et al. (2017) had similar findings, where they highlighted that the handling of raw materials influences the nitrogen concentration in the brewery effluent. High nitrogen content means high PV of wastewater. Carnevale Miino et al (2025) also highlighted that the total nitrogen of wastewater is affected by the use of processed raw materials.

The wastewater temperature is not significantly associated with its quantity, but with other factors such as the air temperature. If the air temperatures are higher, the wastewater temperature is likely to be higher, and the same applies with lower temperatures. This aligns with a study by Kinnunen (2023), who argued that there is a positive and strong correlation between wastewater temperature and air temperature. This indicates that wastewater temperature is strongly associated with air temperature.

5.1.2 Optimising strategies

Installing a closed-circuit system is effective in reducing wastewater generation, improving pH and PV because the system reclaims the wastewater at source, reusing and recycling it reducing water usage and wastewater generation. By treating the reclaimed wastewater, the system also improves the pH and PV of wastewater. This finding agrees with research by Zaborowski et al. (2024), who indicated that the closed circuit system reduces alkaline ions and the concentration of organic substances in wastewater. Reducing cleaning frequency is effective in reducing wastewater generation and improving its pH because reducing the frequency of cleaning reduces water usage and chemical load which reduce wastewater output and improves its pH. Pehlivani et al. (2023) had the same view in a research they conducted, where they highlighted that adopting effective cleaning practices reduces water usage and wastewater generation. High rates of chemical use affect the pH of wastewater, and low use has a positive impact. This finding aligns with a previous research by Salian et al. (2017), which indicated that the quantity of cleaning chemicals used influences the pH of wastewater; therefore, reducing cleaning frequency reduces the total quantity of chemicals used.

Replacing packaging machinery with new machines is effective in reducing wastewater generation, improving pH and PV because new machines work more efficiently compared to old machinery. This is because old pasteurisers can malfunction, causing bottle bursting and beer spillage, causing wastewater generation and affecting the pH and PV of wastewater. The same issue occurs with old keg fillers that spill vast amounts of beer during operation. This finding aligns with that by Pehlivani et al. (2023), who expressed that wastewater generation can be reduced by investing in new equipment and processes that use less water, such as efficient bottling and packaging systems. Substituting plate and frame with modernised BMF is effective in reducing wastewater generation because the plate and frame requires a vast amount of water for its operation, contributing to wastewater generation, whilst the modernised BMF requires low amounts of water

Brewing machine maintenance twice a week effectively reduces wastewater generation, improves pH and PV because it ensures the machines continue operating efficiently, preventing any beer leaks and spillages. This reduces the volume of wastewater generated and the frequency of cleaning, which reduces the chemical load in wastewater. Use of surfactant-based cleaners in CIP, such as CIP surf in place of caustic soda, is effective in improving the pH of wastewater because caustic soda is a type of chemical that is highly alkaline, and CIP surf is neutral, but serves the same purpose. This finding is supported by Kebede (2018), who highlighted that the use of chemicals such as caustic soda can affect the pH of wastewater, which suggests that other types of chemicals can be used instead.

Weekly review of the trub program effectively improves the PV of wastewater because it ensures that the program is effective, prevents its failure, and decreases organic material in the wastewater. Trub consists of organic material such as yeast and spent grain, which can enter wastewater if not managed effectively. Spent yeast and grain quantity increase the wastewater PV. This finding aligns with that by Kebede (2018), who expressed that the quantity of spent yeast influences the nitrogen content of wastewater. Research conducted by Swaray et al (2024) also found that residual yeast and other fermentation by-products that remain after the beer is processed increase the organic load in the wastewater. Therefore, this implies that proper management of trub reduce the PV of wastewater.

Results indicated that suction of dust generated from malt movement is ineffective in reducing the PV of wastewater. However, this finding disagrees with a research by Salian et al. (2017), who argued that the nitrogen concentration in the brewery effluent is influenced by the handling of raw materials and the quantity of spent yeast. Malt as a raw material in brewing, if not handled properly, can generate dust that can increase the PV of wastewater.

5.1.4 Summary

There is no significant relationship between wastewater quantity and pH, PV and temperature, and this is because of other factors that affect the wastewater parameters. Wastewater generation, pH and PV can be controlled through implementing effective optimisation strategies which include a closed circuit system, reduction of cleaning frequency, replacement of packaging machinery with new machines, replacing caustic soda with surfactant based cleaners such as CIP surf, brewing machine maintenance twice a week, replacing Plate and Frame with modernised BMF and weekly review of the trub program.

CHAPTER SIX

6.0 Conclusions

The study found that wastewater generation is high in various brewery areas, including filtration, fermentation, and packaging, against quantities produced by most breweries and this is due to inefficient processes and practices. Similarly, PV levels exceeded the established guidelines in the filtration, fermentation, composite brewing, and raw wastewater samples. pH levels were also found to be high in packaging and raw wastewater samples. The research found no significant relationship between wastewater quantity and quality (PV, pH and Temperature). This indicated that there are other factors strongly associated with the changes in wastewater quality. To control wastewater generation, pH, and PV levels, the study found that the brewing processes can be optimised through implementing various effective strategies. The strategies include installing a closed circuit system, the reduction of cleaning frequency, replacement of packaging machinery, replacement of Plate and Frame with modernised BMF, use of surfactant-based cleaners (CIP-surf), maintenance of brewing machine twice a week, and weekly trub program review as optimising strategies. Further research is essential to identify all factors affecting wastewater generation, pH, and PV.

6.1Recommendations

- Continuously monitor and review the existing systems in place to effectively manage wastewater generation, pH and PV
- Investigate further to identify and manage other factors contributing to wastewater generation, pH and PV

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APPENDICES

APPENDIX 1: Questionnaire

1.What is your role in the brewery

- Process/machine operator
- Brewing management
- SHE practitioner
- Utilities

2. How many years of experience do you have in the brewery

- Less than 2 years
- 2 to 5 years
- 5 to 10 years
- More than 10 years

3.Did you receive any form of training in environmental management or sustainability in brewing

- Yes
- No

4.A closed circuit system of wastewater flocculation tank with a circulating pump, pre-filter and ultrafiltration system to reclaim and treat wastewater reduces its generation, improves its pH and PV

- Disagree
- Strongly disagree
- Neutral
- Agree
- Strongly agree

5.Reducing cleaning frequency will reduce wastewater generation and improve its pH

- Disagree
- Strongly disagree
- Neutral
- Agree

- Strongly agree

6.Substituting the Plate and Frame machine with a modernised BMF will reduce water usage and wastewater generation

- Disagree
- Strongly Disagree
- Neutral
- Agree
- Strongly Agree

7. Replacing packaging machinery with new ones (such as kerg fillers, pasteuriser) will reduce wastewater generation and improve its pH and PV

- Disagree
- Strongly Disagree
- Neutral
- Agree
- Strongly agree

8.Use of surfactant-based cleaners in CIP such as CIP-surf in place of caustic soda will improve wastewater pH

- Disagree
- Strongly Disagree
- Neutral
- Agree
- Strongly Agree

9.Brewing machine maintenance twice a week will improve its efficiency and help reduce wastewater generation and improve its pH and PV

- Disagree
- Strongly Disagree
- Neutral
- Agree
- Strongly Agree

10.Suction of dust (generated from malt movement from silos to millstars) by use of dust collection hoods will improve wastewater PV

- Disagree
- Strongly Disagree
- Neutral
- Agree
- Strongly Agree

11.Solar drying systems can be introduced as an alternative to provide energy for drying reclaimed yeast as a way to manage wastewater PV.

- Disagree
- Strongly Disagree
- Neutral
- Agree
- Strongly Agree

12.Weekly review of the trub program will improve its effectiveness and improve wastewater PV

- Disagree
- Strongly Disagree
- Neutral
- Agree
- Strongly Agree

13.Financial challenges can hinder the implementation of the proposed optimisation strategies

- Disagree
- Strongly Disagree
- Neutral
- Agree
- Strongly Agree

14.Resistance to change can be the cause for the failure of implementation of the process optimisation strategies

- Disagree

- Strongly Disagree
- Neutral
- Agree
- Strongly Agree

15.Use of government incentives for sustainability initiatives can help overcome the financial challenges

- Disagree
- Strongly disagree
- Neutral
- Agree
- Strongly Agree

16.Provision of training programs will help employees develop new skills and adapt to changes

- Disagree
- Strongly disagree
- Neutral
- Agree
- Strongly agree

17.Financial loans can help the organisation overcome financial challenges to implement the optimising strategies

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

APPENDIX 2 : SUMMARY OF STATISTICAL ANALYSIS

Table 4.1: Descriptive statistics

Report

Process		pH	PV	Temperature	SS
Composite brewing	Mean	6.800	136.33	28.00	3.67
	Std. Error of Mean	.1000	4.667	1.000	.333
Fermentation	Mean	6.600	136.33	28.67	4.67
	Std. Error of Mean	.1000	.882	.333	.667
Filtration	Mean	6.833	134.00	29.33	4.33
	Std. Error of Mean	.0333	6.000	.333	.333
Packaging	Mean	10.800	46.00	27.00	2.33
	Std. Error of Mean	.6083	1.732	.577	.333
Raw wastewater	Mean	11.133	111.33	28.33	3.33
	Std. Error of Mean	.3333	.667	.333	.333
Total	Mean	8.433	112.80	28.27	3.67
	Std. Error of Mean	.5668	9.370	.300	.270

Table 4.2: Pearson Chi-square Tests-Relationship between wastewater quantity and quality (pH, PV, SS and temperature)

Crosstab

Count

		Ph				
		6.6	6.8	10.8	11.1	Total
WQ	183	0	0	1	0	1
	191	1	0	0	0	1
	206	0	1	0	0	1
	1367	0	0	0	1	1
Total		1	1	1	1	4

Chi-Square Tests

	Value	Df	Asymptotic Significance (2-sided)
Pearson Chi-Square	12.000[a]	9	.213
Likelihood Ratio	11.090	9	.270
Linear-by-Linear Association	1.107	1	.293
N of Valid Cases	4		

a. 16 cells (100.0%) have expected count less than 5. The minimum expected count is .25.

Crosstab

Count

		PV				
		46	111	134	136	Total
WQ	183	1	0	0	0	1
	191	0	0	0	1	1
	206	0	0	1	0	1
	1367	0	1	0	0	1
Total		1	1	1	1	4

Chi-Square Tests

	Value	Df	Asymptotic Significance (2-sided)
Pearson Chi-Square	12.000[a]	9	.213
Likelihood Ratio	11.090	9	.270
Linear-by-Linear Association	.019	1	.890
N of Valid Cases	4		

a. 16 cells (100.0%) have expected count less than 5. The minimum expected count is .25.

Crosstab

Count

		Temperature			
		27	28	29	Total
WQ	183	1	0	0	1
	191	0	0	1	1
	206	0	0	1	1
	1367	0	1	0	1
Total		1	1	2	4

Chi-Square Tests

	Value	Df	Asymptotic Significance (2-sided)
Pearson Chi-Square	8.000[a]	6	.238
Likelihood Ratio	8.318	6	.216
Linear-by-Linear Association	.079	1	.779
N of Valid Cases	4		

a. 12 cells (100.0%) have expected count less than 5. The minimum expected count is .25.

Crosstab

Count

SS				
2	3	4	5	Total

WQ	183	1	0	0	0	1
	191	0	0	0	1	1
	206	0	0	1	0	1
	1367	0	1	0	0	1
Total		1	1	1	1	4

Chi-Square Tests

	Value	Df	Asymptotic Significance (2-sided)
Pearson Chi-Square	12.000[a]	9	.213
Likelihood Ratio	11.090	9	.270
Linear-by-Linear Association	.188	1	.665
N of Valid Cases	4		

a. 16 cells (100.0%) have expected count less than 5. The minimum expected count is .25.

APPENDIX 3: Permission Letter for data collection

Permission Letter from Bindura University

DEPARTMENT OF ENVIRONMENTAL SCIENCE

Bindura University of Science Education

Bag 1020 **BINDURA, Zimbabwe**
Tel: 263 - 71 – 6505
Cell:0778371588
Email: tnyamugure@buse.ac.zw

BINDURA UNIVERSITY OF SCIENCE EDUCATION

13 December 2024

Dear Sir/Madam

REQUEST FOR PERMISSION TO COLLECT DATA FOR ACADEMIC RESEARCH PROJECT

PROJECT TITLE: ***OPTIMISATION OF BREWING PROCESSES TO REDUCE WASTEWATER GENERATION AND IMPROVE WASTEWATER pH. AND PV***

ACADEMIC SUPERVISORS: Mr P. Nhokovedzo

This letter serves to inform you that **Takudzwa Karimunhenga, Registration Number (B210612B)** is a fourth-year student at Bindura University of Science Education, in the Department of Environmental Science. During his fourth year of study, he is supposed to do a research project in his area of specialisation.

Please assist in any possible way. Data collected will be used for academic purposes only and will not be published without your prior consent.

Thank you for your assistance.

Yours faithfully.

____

Mr T. Nyamugure
DEPARTMENT OF ENVIRONMENTAL SCIENCE

CHAIRPERSON
Department Of Environmental Science
Faculty Of Agriculture And Environmental Science
Bindura University Of Science Education
P. BAG 1020, BINDURA
ZIMBABWE
OFFICIAL

Data Collection Approval letter from Delta Beverages

Delta Beverages

(PRIVATE) LIMITED

Sable House, Northridge Close, P.O. Box BW294, Harare, Zimbabwe;
Tel: 263-242-883865/72, Fax: 263-242-883864 Website: www.delta.co.zw

20 January 2025

Takudzwa Karimunhenga
C/o Bindura University
Bag 1020
Bindura

Dear Takudzwa

REQUEST TO CONDUCT ACADEMIC RESEARCH STUDY IN DELTA

Your request dated 13 December 2024, on the above subjects refers.

I am pleased to inform you that your request to conduct a Research Study within Delta has been granted. The permission is subject to the following conditions.

1. That Delta Corporation is given a copy of the final document.
2. That the information obtained from Delta is used for academic purposes only. The information (factual or implied) should never be divulged to the public or made public.
3. That Delta Corporation has the right to break the relationship as and when the above conditions had been violated.

Please revert should you require further clarification.

Yours Sincerely
For and on behalf of Delta Corporation

K.P. Munda
Human Resources Director

Registration Number: 226/60/48
Directors: M. M. Valela (Chief Executive Officer), A. Makamure, T. Rinomhota
Secretary: F. N. Musinga

I accept the conditions in this letter and commit to adhere to them
T. Karimunhenga
C. Karimunhenga