Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical & Industrial Engineering

Capacity utilization improvement for auxiliary machineries:

In case of BGI Ethiopia

A Thesis Submitted to the School of Graduate Studies of Addis Ababa Institute of Technology, Addis Ababa University in partial fulfillment for the Degree of Master of Science in Mechanical Engineering (Industrial Engineering)

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Declaration

I hereby declare that the work which is being presented in this thesis entitled “capacity utilization improvement for auxiliary machineries” is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis have been duly acknowledged.

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This is to certify that the above declaration made by the candidate is correct to the best of my Knowledge.

Your Advisor’s signature here

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Abstract

This study aims to improve the capacity utilization of auxiliary machines in brewery factories, focusing on the CO2 plant, boiler plant, cooling plant, and air plant at BGI Ethiopia. These machines are vital for supporting the brewing process, and any breakdown or inefficiency can significantly impact the overall brewery operation. The study identified underutilization of the capacity of auxiliary machines at BGI Ethiopia. Despite its potential to produce 3200 hectoliters per day, the factory is currently operating at 75% capacity, producing only 2400 hectoliters per day. The challenges contributing to this underutilization include auxiliary machine failures, high downtime, breakdowns, and inadequate application of monitoring and control systems. To address these challenges, the study adopts a research methodology that involves collecting quantitative and qualitative data. Quantitative measures such as breakdown and stoppage time, production output, shifts, and workers are used to assess the current state of auxiliary machine capacity utilization. Workplace site observations and expert opinions are also considered, along with secondary data from literature, reports, publications, logbooks, machine displays, and articles related to capacity utilization. The collected data is analyzed using statistical techniques, including mathematical analysis for quantitative data and thematic analysis for qualitative data. This analysis aims to identify root causes and trends to gain insights into the current state of auxiliary machine capacity utilization. The findings are presented through tables, charts, and graphs to support the analysis. Factors that positively or negatively impact auxiliary machine capacity utilization in brewery plants are highlighted. The discussion focuses on the main root causes of breakdowns and inefficiencies, the impacts of downtime on capacity utilization, potential solutions, and best practices to prevent breakdowns. Based on the research findings, recommendations are provided to improve auxiliary machine capacity utilization. These recommendations address factors such as equipment upkeep, operator training, scheduling, and system integration. Applying these recommendations can enhance capacity utilization, improve production efficiency, and increase revenue for BGI Ethiopia.

Key words: auxiliary machines, capacity utilization, downtime, factors affecting capacity utilization, root cause analysis.

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Acronym

BGI	Brothers Group
CO2	Carbon dioxide
CIP	Clean-in-place
CU	Capacity utilization
HVAC	Heating, ventilation, and air conditioning
WTP	Water treatment plant
OEE	Overall equipment effectiveness
TPM	Total productive maintenance
MTBF	Mean time between failures.
MTTR	Mean time to repair.
CMMS	Computerized maintenance management system
PdM	Predictive maintenance
RCM	Reliability-centered maintenance
FMEA	Failure mode and effects analysis
OEE	Overall equipment efficiency
KPI	Key performance indicator
LCC	Life cycle cost
PM	Preventive maintenance
CBM	Condition-based maintenance
RAM	Reliability, availability, and maintainability
RCA	Root cause analysis
HMI	Human-machine interface
PLC	Programmable logic controller
SOP	Standard operating procedure
MRO	Maintenance, repair, and operations
JIT	Just-in-time
SPC	Statistical process control

Chapter One

1. Introduction of the research

1.1 Introduction

Capacity utilization is an important index to evaluate the status of production capacity. Its value is the ratio of actual output to production capacity, that is, how much actual production capacity plays a role in operation. To enhance the total effective equipment performance capacity utilization, overall equipment efficiency should be fulfilled in such a way that an organization can satisfy its customer demand while increasing its marginal profit.

Capacity utilization can be used to indicate the degree of overcapacity and under capacity in industries. In theory, if the capacity utilization is lower than 1, which is 100%, it shows there is unutilized capacity in the industries (Berndt, 2007). However, in actual production, a capacity utilization equal to 1 cannot be realized. The reason is that, on the one hand, the factory equipment, and other means of production, from construction to having products, need a certain time delay. On the other hand, due to the influence of management level, market environment, weather, and other factors in the production process, the invested production capacity cannot be fully utilized. Low utilization of installed capacity results in low production capacity, and to improve its utilization, the main factors affecting capacity utilization in the specific industry need to be identified (Yeo, 2019).

The measurement methods of capacity utilization include micro surveys and methods with microdata. Micro surveys require large and accurate corporate databases of industries. According to the measurement method with macro data, capacity is the maximum or optimal output of an enterprise under a certain specific circumstance. The measurement methods of capacity utilization include micro surveys and methods with microdata. Micro surveys require large and accurate corporate databases of industries. According to the measurement method with macro data, capacity is the maximum or optimal output of an enterprise under a certain specific circumstance (Köberl, 2011).

Economic capacity is defined as the capacity when the enterprise's cost is minimum or profit is maximum. Thus, the ratio of actual output to capacity is used to get the value of capacity utilization. Technical capacity is the maximum output that an enterprise can achieve by incorporating certain factors of production into the production process at a given technical level (Ju, 2021). In the technical capacity, producer efficiency can be divided into two categories: the technology frontier and the technical efficiency. The technology frontier describes the boundary of the producer's input-output function, while the technical efficiency describes the gap between the producer's actual production and the technical frontier.

Overall equipment efficiency is an excellent indicator for tracking a company's performance, identifying opportunities for improvement, and enhancing the capacity of the company. It provides a direct focus on improvement efforts in areas related to equipment efficiency and effectiveness. It is also an effective instrument for increasing profit, reducing expenses or waste, improving customer satisfaction, and generally promoting the effectiveness of machinery in industries.

Capacity utilization is the ratio of the actual output of the product production unit to the production capacity. Differences in capacity utilization (CU) or technical efficiency (TE) can be concluded from variations in the output between similar plants. Capacity utilization is the ratio of the recorded output to the maximum output that can be achieved when the variable inputs change under the condition that the level of fixed inputs is known (Tsitsika, 2008). Technical efficiency is the degree to which the potential output is achieved given that fixed and variable inputs are constant at their observation level.

1.2 Background of the research

Capacity utilization helps to analyze and evaluate the operation status of production capacity. Capacity utilization is very important in industries because of its ability to show the extent to which factors of production are being utilized and which are not (Madueme, 2009)

Capacity utilization improvement refers to the process of increasing the efficiency and productivity of resources, specifically in terms of maximizing the use of available capacity within a system. This can apply to various areas, such as manufacturing, operations, and services (Chen T. W., 2017).

Improving capacity utilization is crucial for organizations as it allows them to generate more output without additional investments in resources or infrastructure (Javaid, 2022). By optimizing the utilization of existing resources, organizations can enhance their competitiveness, reduce costs, and improve overall performance. There are several strategies and techniques that can be employed to improve capacity utilization. Some of these include Process Optimization: Analyzing and redesigning processes to eliminate bottlenecks, reduce idle time, and minimize inefficiencies (Sibalija, 2019). This involves optimizing the flow of work, improving coordination between different stages of production, and streamlining operations. Demand Forecasting: Developing accurate demand forecasts allows organizations to plan and align their resources accordingly (Somu, 2021). By understanding future demand patterns, organizations can adjust their capacity utilization, ensuring that resources are utilized optimally to meet customer requirements.

Flexible Work Practices: Implementing flexible work arrangements such as flextime, remote work, or shift scheduling can help optimize capacity utilization (Wiatr, 2021). By aligning work schedules with demand fluctuations, organizations can effectively utilize resources during peak periods while minimizing idle time during low-demand periods.

Automation and Technology: Investing in automation and advanced technologies can significantly enhance capacity utilization (Haleem, 2021). By automating repetitive tasks, organizations can eliminate human error, increase production rates, and optimize resource allocation.

Training and Skill Development: Providing training and development programs for employees can improve their skills and knowledge. Well-trained employees are more efficient in utilizing resources, reducing waste, and improving capacity utilization.

Supply Chain Optimization: Collaborating with suppliers, partners, and stakeholders in the supply chain can facilitate smoother operations and reduce lead times (DayD., 2021). By developing efficient supply chain management processes, organizations can optimize the availability of inputs, reducing the risk of capacity constraints.

Continuous Improvement: Adopting a continuous improvement mindset, such as lean manufacturing or Six Sigma, enables organizations to identify and eliminate waste, improve processes, and optimize resource utilization continually (Cudney, 2020).

It is essential for organizations to study and analyze their current capacity utilization levels, identify bottlenecks, and implement targeted strategies to increase efficiency and optimize resource utilization. Continuous monitoring and evaluation of capacity utilization metrics allow organizations to make data-driven decisions and sustain improvements in the long run.

1.3 Background of the case Company

BGI (Brasseries ET Glaciers International), or Brothers Group International, has a long history dating back more than one hundred years in Indochina, when it was taken over by the Castle Group in 1990 under impetus. B.G.I. was present in Africa in the 20th century and operates more than 50 industrial plants directly.

During the age of enlightenment of technology in Ethiopia, one of the modern things that happened was the opening of the first brewery during the reign of emperor Menelik the Second. The brewery was set up with modern facilities to produce the country’s first bottled beer. 85 years ago, George Beer was founded by a Belgian national of Ethiopian descent named Mussie Hal. But currently, it's owned by a French company. The production capacity did not exceed 200 bottles per day. But slowly, St. George Brewery continued to grow. The 1940s and 1950s could be taken as the golden and remarkable years for St. George Brewery, in which it exceeded in every aspect of its service, like production, working hours, and number of workers, and even got its own transportation system that transports beer through the empire.

Main products and services

- St. George bottle beer (alcoholic content: 4.5%; size: 33 cl), St. George keg beer, Doppel beer & keg, Castel beer & keg, Meta beer, Malta, Sen'Q, Amber beer, Panache, Raya beer, Zebidar beer, and St. George castle beer at the Kombolcha branch
- Castel Winery (White, Rose, Red, Rift Valley, Soft to Hard Sweet) at the Zeway branch
- CO2 is used in restaurants and hotels that provide draft from kegs
- Spent grain is used as a by-product for animal feed, and they plan to pasteurize and sell the aged yeast for animal feed.

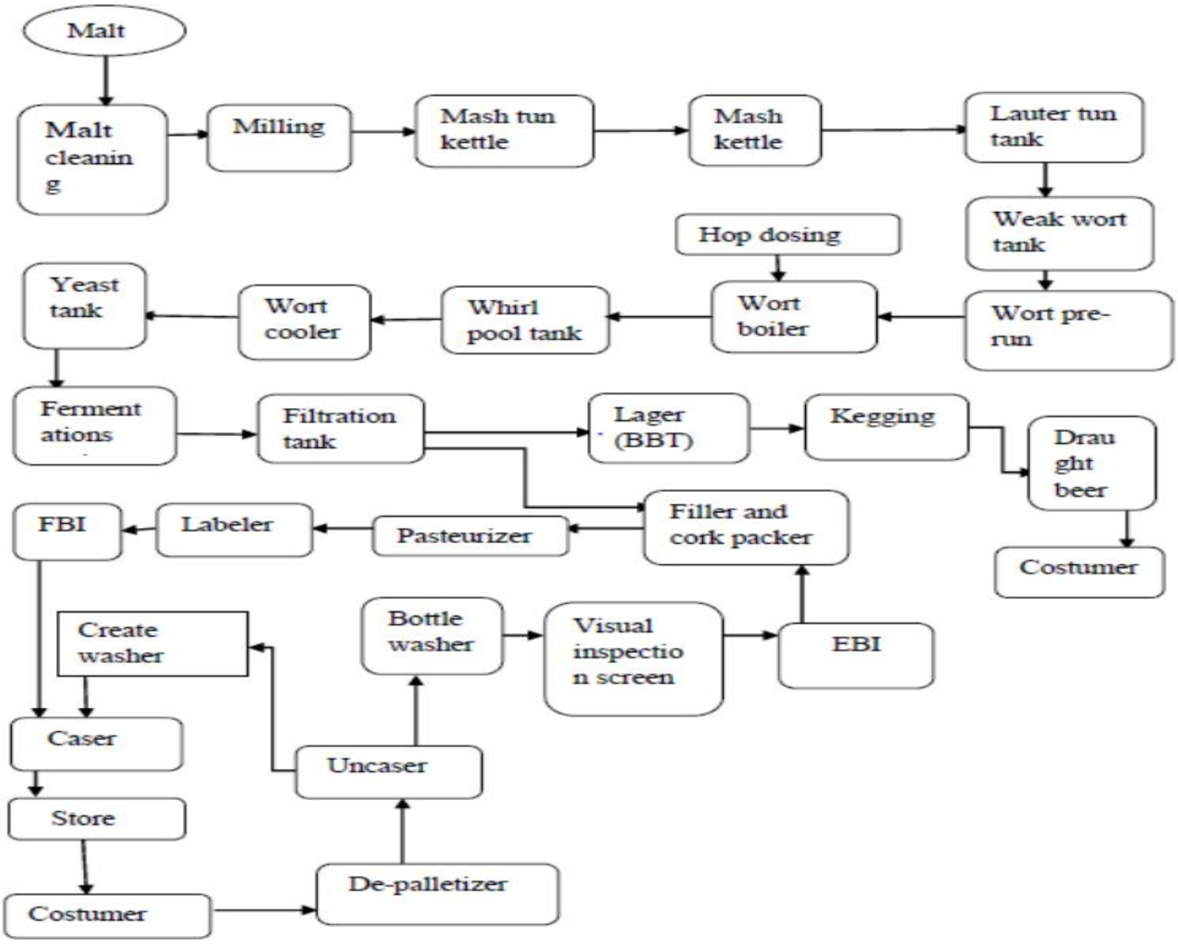

Figure 1.1 The workflow of BGI, Ethiopia

1.4 Research problem

According to the 2018 report of the Ethiopian Development Research Institute (EDRI), industries are not operating at their full capacity. Performing under capacity utilization indicates insufficient utilization of factors of production and the presence of idle factors such as machines, manpower, and resources, which causes profit losses and dissatisfaction among customers and creates crises such as increasing levels of unemployment, poverty, a reduction in the size of firms, and low levels of gross domestic product (GDP) at the national level. As idle capacity is a waste resource, it results in a decline in the rate of development for developing countries (Madueme, 2009) and (Snyder, 2009) also state that low utilization of the production capacity results in an increase in the cost of production per unit, which minimizes the profit of the industry.

Auxiliary machines are available in manufacturing industries to support the main production line or processes and contribute to efficiency, productivity, and quality control, Cost Reduction and also for Safety and Risk Mitigation.

Increased Efficiency: Auxiliary machines can automate repetitive tasks, reducing the need for manual labor and increasing production efficiency. They can perform tasks such as material handling, packaging, quality control, and machine maintenance, allowing workers to focus on more complex or specialized tasks.

Improved Productivity: By streamlining production processes, auxiliary machines can help increase overall productivity. They can perform tasks at a faster rate and with greater accuracy than manual labor, leading to higher output and reduced production time.

Enhanced Quality Control: Auxiliary machines often include sensors and monitoring systems that can detect defects or deviations from quality standards. This allows for real-time quality control and immediate corrective actions, ensuring that only products meeting the required specifications are released.

Cost Reduction: Auxiliary machines can help reduce production costs in several ways. They can minimize material waste, optimize energy consumption, and reduce the need for manual labor, which can be costly and prone to human errors. Additionally, the use of auxiliary machines can lead to fewer production errors and rework, saving both time and resources.

Safety and Risk Mitigation: Some manufacturing processes involve hazardous or repetitive tasks that can pose risks to workers. Auxiliary machines can be designed to handle these tasks, reducing the risk of accidents and injuries. This promotes a safer working environment and improves overall employee well-being.

BGI Ethiopia is one of the leading breweries in the country, known for its production of high-quality beverages. However, the company has been facing persistent issues with their auxiliary machines, specifically the CO2 plant, boiler plant, cooling plant, and air plant. These machines play a crucial role in supporting the primary brewing process, and any breakdown or inefficiency in these systems can have a significant impact on the overall production and profitability of the company. Therefore, it is essential to identify the root causes of these problems and propose effective solutions to ensure the uninterrupted and efficient operation of the auxiliary machines.

The CO2 compressors in the CO2 plant generate pure carbon dioxide gas, which is used in pasteurizing bottles, killing bacteria, filling bottles, and washing equipment. The air compressors are essential for pneumatic machines to run by producing oil-free compressed air, and the cooling plants require effective compressors to cool the fermented product. The failure of these auxiliary machines affects output quantity and quality.

Water is the primary resource for the company's alcoholic and non-alcoholic products, and it must be available in all production departments. Reverse osmosis technology is required for the purification of the water, but its high cost and frequent failures contribute to the factory's underutilized capacity. Inadequate maintenance strategies and the poor implementation of automatic monitoring and control systems result in unplanned downtime, resulting in underutilized capacity.

The research problem is to investigate and address the difficulties and barriers that collectively contribute to the underutilization capacity of the BGI Ethiopia brewery. Despite having the potential to produce 3200 hectoliters per day, the factory is currently operating at 75% capacity, which is producing only 2400 hectoliters per day, because of the ineffective utilization and impact of auxiliary machine failures, high maintenance costs, unskilled productivity, and inadequate application of automatic monitoring and control systems on the output quantity and quality of their production line.

1.5 Research question

- What are the main causes of downtime and inefficiency in auxiliary machines?
- How does auxiliary machines downtime affect capacity utilization?
- What are the potential solutions proposed in the help to prevent downtime and improve capacity utilization of auxiliary machine in the brewery manufacturing industry?

1.6 Objectives of the study

1.6.1 General Objectives

The general objective of the research is to improve capacity utilization of the auxiliary machines in the BGI Ethiopia Brewery industry using capacity utilization metrics and the root cause analysis method, with a focus on the CO2 plant, boiler plant, cooling plant, and air plant.

1.6.2 Specific Objectives

- To identify the common causes of breakdowns and inefficiencies in auxiliary machines.
- To analyse the downtime impact of auxiliary machines on capacity utilization.
- To develop potential solutions for preventing breakdowns in auxiliary machines.

1.7 Scope

The scope of the research focused on improving the capacity utilization of auxiliary machines using capacity utilization metrics, and the root cause analysis method included a wide range of activities such as identifying capacity utilization improvement methods and current auxiliary machine capacity, company overall capacity standards, calculating the relevance of the capacity utilization metrics, and the root cause analysis method. Moreover, it includes assessing the current privacy controls of the company platform, investigating analytics to monitor performance, and identifying current working processes and their capacity indicators. It also includes developing a method to organize solutions, conducting worker skills assessments, and monitoring and recommending key performance approaches and their potential solutions. And it focused on investigating the main root causes of downtime, breakdowns, and inefficiencies in the CO_2 plant, boiler plant, cooling plant, and air plant in the BGI Ethiopia Brewery industry. The research analyzed the impact of the resulting downtime of auxiliary machines on capacity utilization and explored potential solutions and best practices to prevent breakdowns, improve the performance of auxiliary machines, and enhance capacity utilization in the brewery industry. Furthermore, the research activities include:

- The focus of the study is the BGI Ethiopia Brewery Industry's CO_2 plant, boiler plant, cooling plant, and air plant, all of which are specifically examined. It investigates the underlying reasons for unplanned and planned downtime, malfunctions, and inefficiencies in these auxiliary machines.
- Geographical scope: the study took place in the BGI Ethiopia Brewery Industry. Although the conclusions and recommendations may be applicable to other sectors of the economy, the BGI Ethiopia Brewery is the primary focus of this study.
- Timeframe: The study considered the auxiliary machine’s present condition in the BGI Ethiopia Brewery sector. It looked at current trends and advancements as well as historical data on downtime, breakdowns, and inefficiencies. The amount of time the research takes depends on Addis Ababa University's schedule.

1.8 Limitations

The limitations of the research on improving capacity utilization of auxiliary machines in BGI Ethiopia include data privacy and security concerns, the need for a skilled workforce, the huge data analysis and interpretation, the potential for utilizing automatic monitoring and controlling equipment integrity issues on auxiliary machines, and the difficulty of integrating technologies and practices into existing systems. These factors make it difficult for financially constrained companies to adapt technologies and practices and may require significant expertise and resources to analyze and interpret capacity utilization data. These limitations are expressed as:

- Data availability: the research is limited by the availability and accessibility of data related to downtime, breakdowns, inefficiencies, and capacity utilization in the auxiliary machines of the BGI Ethiopia Brewery industry. The accuracy and reliability of the data collected also impact the findings and conclusions of the research.
- Resource constraints: the research is limited by the availability of resources, including time, budget, and personnel. The extent of data collection, analysis, and implementation of potential solutions may be constrained by these resources.
- External factors: the research conducted within the context of the BGI Ethiopia Brewery industry, which is subject to various external factors such as market conditions, regulatory changes, and technological advancements. These external factors may influence the findings and recommendations of the research.
- The findings and recommendations of the research may be specific to the BGI Ethiopia Brewery industry and may not be directly applicable to other industries or contexts without further validation and adaptation.

1.9 Significance

The research aims to address the main root causes of reduced capacity of auxiliary machines (downtime, breakdowns of auxiliary machines) and inefficiencies in the CO2 plant, boiler plant, cooling plant, and air plant in the BGI Ethiopia Brewery industry and aim to improve the capacity utilization of these machines. By identifying the issues, analyzing the impact of downtime on capacity utilization, and developing potential solutions, the research aims to improve the capacity and performance of auxiliary machines using capacity utilization metrics and the root cause analysis method.

The study is important for Ethiopia and also for abroad because it helps the brewery industry develop economically and benefits employees by enhancing their capacity for auxiliary machine, managers by teaching them how to do so and maintaining standard capacity, researchers by providing a reference for further research, and the organization itself by enhancing the performance and capacity of auxiliary machines, creating potential solutions, and maintaining the capacity of auxiliary machines.

Overall, the research aims to provide insights into the root causes of downtime, breakdowns, and inefficiencies in the auxiliary machines or capacity reduction of auxiliary machines in the BGI Ethiopia Brewery industry and propose potential solutions to improve capacity utilization. However, the scope and limitations of the research should be considered to ensure the findings are appropriately interpreted and applied.

Chapter Two
2. Literature review

2.1 Literature review

Under this section of the research, an extensive search was conducted using several academic databases, including Emerald and Google Scholar, to complete this literature review. Keywords including "capacity," "capacity utilization," "capacity utilization improvement," "factors that affect capacity utilization" and "auxiliary machinery" were used in the search. The last 10 years' worth of peer-reviewed papers, journal articles, conference papers, and business reports from both theoretical and empirical studies was discussed from different researcher points of view and considered in conducting this study.

2.2 Capacity and Capacity utilization

Capacity is defined as the ability to do something, an emergent combination of attributes that enables a human system to create developmental value, and finally, capacity refers to the overall ability of a system to create value (Morgan, 2006). And the United Nations Development Program defined capacity as the ability of individuals, institutions, and societies to perform functions, solve problems, and set and achieve objectives in a sustainable manner (Connor, 2015).

Capacity is classified as both design capacity and effective capacity. The design capacity is the maximum rate of output achieved under ideal conditions. Effective capacity is based on the realities of changing product mix, the need for periodic maintenance of equipment, which is usually less than the design capacity for lunch breaks and coffee breaks, problems in scheduling and balancing operations, and other similar circumstances.

The output that a workstation or process can produce in each period by using its installed capacity under normal operating conditions is called effective capacity (Barnes, 2018). Capacity utilization determinants are product processing time and set-up time of machinery, product defective rate, and maintenance downtime.

According to Morrison, capacity utilization is how an enterprise uses its installed productive capacity. A metric is used to measure the rate at which potential output levels are being met. Capacity utilization levels give insight into the overall slack that exists in the industries at a given time. If a company is running at a 75% capacity utilization rate, it has room to increase production up to 100% without increasing costs (Chandra, 2005).

Overall equipment efficiency (OEE) reveals how much the planned production time is truly productive, but total effective equipment performance (TEEP) takes utilization into account to show how much potential is there to increase throughput with the equipment that is already available.

Total Effective Equipment Performance (TEEP) is a performance metric that provides insights as to the true capacity of the manufacturing operation. It considers both equipment losses (as measured by OEE) and schedule losses (as measured by utilization).

Total Effective Equipment Performance is the ratio of fully productive time to all time, which considers schedule losses and the six big losses (availability, performance, and quality), whereas overall equipment efficiency is the ratio of fully productive time to planned production time, which considers the six big losses (availability, performance, and quality).

The six big losses in equipment or machines are generally thought to result from three basic factors of OEE. Source: Six Big Losses
Overall equipment effectiveness (OEE) is one of the metrics to measure the percentage of truly productive time and consists of three factors:

- Availability
- Performance
- Quality

Overall equipment effectiveness is a metric used to measure the percentage of the truly productive time from the planned production time of a plant or manufacturing process when the percentage is as close to 100% as the more productive the process.

Availability is the ratio of the runtime to the planned time of the production, and it takes into consideration the availability loss of machines, which are all the down times that the process faces during that time that it is supposed to be running. There are unplanned stops that may occur because of equipment failure or the lack of materials, and planned stops that may be caused by the changeover, and then the remaining time from the whole production time, deducting the availability loss, is called the runtime. Mathematically, availability can be expressed as:

$$Availability = \frac{Runtime}{Planned\ production\ time} \dots .\ equ\ (1)$$

The second factor of the OEE is the performance, which is the ratio of the actual runtime to the runtime, and this factor takes into consideration anything that may reduce the speed of the manufacturing to be less than the maximum speed, including minor stops and slow cycles that occur in the production and performance is expressed mathematically as:

$$Performance = \frac{ideal\ cycle\ time \times total\ count}{Runtime} \ldots..(equ2)$$

The other factor or stakeholder in the overall equipment efficiency is the quality; it is either in the setup rejection or after production takes place. In this case, the quality to influence the utilization of capacity may affect the output of auxiliary machines. Mathematically, quality is given by:

$$Quality = \frac{No.of\ acceptable\ products}{total\ No.of\ product\ that\ has\ been\ produced} \ldots.(equ\ 3)$$

2.3 Capacity utilization calculation

Calculating the capacity utilization of a machine is typically based on comparing the actual output of the machine to its maximum potential output. There are variations in how this formula is applied, depending on the specific context and industry.

Formula 1:

$$Capacity\ Utilization = \left(\frac{Actual\ Output}{Maximum\ Potential\ Output}\right) * 100 \ldots.(equ4)$$

This formula calculates the capacity utilization as a percentage by dividing the actual output of the machine by its maximum potential output and then multiplying by 100 to express it as a percentage.

Formula 2:

$$Capacity\ Utilization = \left(\frac{Actual\ Operating\ Hours}{Available\ Operating\ Hours}\right) * 100 \ldots..(equ5)$$

In some cases, the capacity utilization of a machine is calculated based on its operating hours. This formula divides the actual operating hours of the machine by the available operating hours (the total time the machine could have been in operation) and then multiplies by 100 to express it as a percentage.

Formula 3:

$$Capacity\ Utilization\ =\ \left(\frac{Units\ Produced}{Maximum\ Production\ Capacity}\right) *\ 100 \ldots\ldots (equ6)$$

For manufacturing processes, capacity utilization can also be calculated by dividing the number of units produced by the machine by its maximum production capacity and then multiplying by 100 to express it as a percentage.

It's important to note that the specific formula used may vary depending on the industry, the type of machine, and the context in which capacity utilization is being measured.

To calculate machine utilization, this formula can be used:

$$Machine\ Utilization\ =\ \left(\frac{Actual\ Operating\ hours}{Available\ Operating\ hours}\right) *\ 100 \ldots (equ\ 7)$$

Steps to calculate machine utilization:

1. Determine the actual operating time. This is the total amount of time the machine was actively running or producing output.
2. Determine the available operating time: This is the total time the machine could have been in operation, typically within a specific period.
3. Divide the actual operating time by the available operating time.
4. Multiply the result by 100 to express it as a percentage.

Machine capacity utilization calculation

The formula for calculating machine capacity can vary depending on the specific context and industry. However, a common formula used to calculate machine capacity is:

$$\begin{aligned}&Machine\ Capacity\\&=\ (Number\ of\ Machines)x\ (Operating\ Hours)x\ (Utilization\ Rate)..(equ\ 8)\end{aligned}$$

Where: Number of Machines refers to the total number of machines available for operation.

Operating hours refers to the total number of hours the machines are available for operation within a given period (e.g., a day, week, or month).

Utilization rate refers to the percentage of time the machines are in use compared to their total available time.

By multiplying the number of machines with the operating hours and the utilization rate, we can determine the overall capacity of the machines.

It's important to note that this formula provides a general framework for calculating machine capacity. In practice, industries and organizations may have additional factors and considerations that affect capacity calculations, such as downtime, maintenance, and efficiency rates. Therefore, it's always recommended to consider the specific requirements and context of the situation when calculating machine capacity.

2.4 Theoretical overview

Auxiliary machines are equipment or devices that support the main production processes and contribute to efficiency, productivity, quality control, Cost Reduction and Safety and Risk Mitigation.

A possible reason why auxiliary machines are important in the manufacturing industry and needs to be considered is due to:

1. Increased Efficiency: Auxiliary machines can automate repetitive tasks, reducing the need for manual labor and increasing production efficiency. They can perform tasks such as material handling, packaging, quality control, and machine maintenance, allowing workers to focus on more complex or specialized tasks.
2. Improved Productivity: By streamlining production processes, auxiliary machines can help increase overall productivity. They can perform tasks at a faster rate and with greater accuracy than manual labor, leading to higher output and reduced production time.
3. Enhanced Quality Control: Auxiliary machines often include sensors and monitoring systems that can detect defects or deviations from quality standards. This allows for real-time quality control and immediate corrective actions, ensuring that only products meeting the required specifications are released.
4. Cost Reduction: Auxiliary machines can help reduce production costs in several ways. They can minimize material waste, optimize energy consumption, and reduce the need for manual labor, which can be costly and prone to human errors. Additionally, the use of auxiliary machines can lead to fewer production errors and rework, saving both time and resources.
5. Safety and Risk Mitigation: Some manufacturing processes involve hazardous or repetitive tasks that can pose risks to workers. Auxiliary machines can be designed to handle these tasks, reducing the risk of accidents and injuries. This promotes a safer working environment and improves overall employee well-being.

Various manufacturing industries depend on auxiliary machines to assist and improve the performance of primary or main production systems. The degree to which this auxiliary equipment is efficiently used to optimize their output and boost overall productivity is referred to as capacity utilization. This study of the literature intends to investigate current research and expertise on enhancing auxiliary machinery capacity utilization.

To maximize the use of the capacity utilization that is currently available in the system, capacity utilization enhancement refers to the process of improving resource capacity and efficiency. This holds true for a variety of industries, including manufacturing, operations, and service-giving industries (Chen T. W., 2017).

In organizations, increasing capacity utilization is essential because it enables them to produce greater output without investing additional costs in resources or equipment (Javaid, 2022). Organizations can increase their competitiveness, cut expenses, and improve overall performance by maximizing the use of their existing resources. To increase capacity utilization, several tactics and methods can be used. From the different and various methods, these are some:

Process analysis and redesign to remove bottlenecks, decrease idle time, and minimize inefficiencies are known as process optimization (Sibalija, 2019). This entails streamlining processes, enhancing coordination between various production phases, and optimizing the flow of work.

Demand forecasting: by creating precise demand projections, companies can plan and allocate their resources appropriately (Somu, 2021). Organizations can modify their capacity utilization, ensuring that resources are used as efficiently as possible to satisfy and meet customer requirements, by knowing future demand patterns.

Flexibility in work practices: using flextime, remote work, or shift scheduling can help maximize and improve capacity utilization (Wiatr, 2021). Organizations can efficiently use resources during peak periods while avoiding idle time during low-demand periods by coordinating work schedules with demand changes.

Investments in automation and cutting-edge technologies can dramatically improve capacity utilization (Haleem, 2021). Organizations can reduce human error, boost output, and optimize resource allocation by automating repetitive processes.

Training and skill development: offering employees training and development opportunities can help them acquire new knowledge and skills. Employee efficiency in terms of resource use, waste reduction, and capacity utilization is improved by well-trained and highly qualified staff.

Supply chain optimization Working together with partners, suppliers, and other supply chain participants can promote more efficient operations and shorter lead times (DayD., 2021). Organizations can optimize input availability and lower the risk of capacity constraints of machinery by adopting effective supply chain management strategies.

Continuous improvement by adopting a continuous improvement attitude, such as that of lean manufacturing or Six Sigma, businesses may continuously find and eliminate waste, enhance their Capacity utilization operations, and maximize the use of their resources (Cudney, 2020). To boost capacity utilization of machinery and optimize resource usage, industries must research and assess the capacity utilization levels at which they currently operate, spot any bottlenecks, and put specific plans in place. Organizations may make data-driven decisions and sustain improvements over time with the help of continuous monitoring and review of capacity utilization indicators.

2.5 Empirical literature review

In the manufacturing sector, capacity utilization is a key element in maximizing production and efficiency. To increase productivity and revenue, it is imperative to improve auxiliary machine performance and make sure that machines are operating at their full potential to deliver the intended task. This review by the scholars attempts to investigate several approaches and methods that have been suggested for increasing machine capacity utilization.

Installing autonomous monitoring and control systems is one way to increase capacity utilization. These systems continuously monitor the machine's operational state, gather real-time performance information, and use it to plan maintenance, scheduling, and resource allocation. To prove their point, (Smith, 2017) carried out a study in which they installed an automated monitoring and control system in a manufacturing facility. They discovered that this method led to a notable increase in capacity utilization, a considerable decrease in downtime, and a 20% increase in overall machine efficiency.

Automation is another significant factor affecting capacity utilization. (Brown R. &., 2019) Present a comparative study of industries and the impact of automation on capacity utilization. The authors examine how production capacity can be increased and processes can be made more efficient using automation technologies like robotics and artificial intelligence.

Numerous studies have looked at methods for reducing machine downtime and inactivity in relation to capacity utilization. (Smith, 2017) studied the impact of preventative maintenance procedures on the amount of downtime and the machinery capacity in an industrial context. Their findings highlighted the value of regular inspections and maintenance to find and address any issues before they result in failures.

By using maintenance approaches, capacity utilization can be increased in yet another manner. To predict machine breakdowns before they occur, predictive maintenance uses analytics and machine learning algorithms. Manufacturers can minimize disruptions and increase machine availability by scheduling maintenance tasks during pre-planned downtime and evaluating their maintenance needs ahead of time. According to a study conducted by (Johnson R. W., 2019) the implementation of a maintenance system resulted in a 30% reduction in machine downtime. This improvement led to enhanced capacity utilization and overall operational efficiency.

In running and maintaining machines, skilled operators play a role that lowers the likelihood of errors, reduces downtime, and improves overall machine performance. A study conducted by (Davis, 2018) underlined the importance of operator training programs in increasing capacity utilization. The study found that by lowering operator-related errors and downtime, rigorous training programs that concentrate on both technical and operational abilities can significantly improve capacity utilization.

The performance and quality of auxiliary equipment in a manufacturing process are greatly improved by proactive maintenance, which includes preventive and predictive maintenance, real-time monitoring algorithms, and sensor installations. Companies can reduce unplanned downtime and increase capacity utilization by scheduling maintenance tasks in advance by employing proactive maintenance practices (Shagluf, 2014).

In order to minimize failures and increase the lifespan of equipment, preventive maintenance entails routinely planned inspections, repairs, and replacements of components. It lowers the likelihood of unanticipated failures and downtime by assisting in the identification of possible issues before they become serious concerns (Ramere, 2021).

Utilizing data analysis and monitoring techniques, predictive maintenance makes predictions about when equipment failure is most likely to happen. By monitoring factors such as oil levels, leaks, wire connections, and other defects in real-time, companies can identify potential issues and schedule maintenance activities before failures occur. This approach helps minimize downtime and optimize the performance of auxiliary machines (Gohel, 2020).

Continuous monitoring of equipment performance and condition is made possible by real-time monitoring algorithms and sensor installations. Companies can identify anomalies and probable failures by gathering and analyzing data in real-time, enabling prompt maintenance actions. This proactive approach helps prevent unexpected breakdowns and optimize the utilization of capacity (Wiesmeyr, 2020)

Several studies have highlighted the benefits of implementing proactive maintenance strategies. According to a study conducted by Kinsey, McRoberts, and Bashir, predictive maintenance can reduce maintenance costs by up to 30% and improve equipment availability, performance, and quality by 20%. IBM's study emphasizes the use of computer vision and machine learning for predictive maintenance, resulting in a 10% reduction in downtime and a 25% decrease in maintenance costs (Zeki Murat and Abdussalam Nuhu, 2020).

Cost Savings: By performing proactive maintenance, maintenance expenditures can be cut by 25 to 30 percent. (Wakjira, 2012) Reduction in downtime proactive maintenance can reduce downtime by 10% (Eti, 2006). Companies can reduce production stops and maintain a smooth workflow by resolving probable problems before they happen and preventing unexpected downtime due to equipment breakdowns. Improvement in quality and speed proactive maintenance can result in a 5% decrease in quality loss and a 5% improvement in speed (Tsarouhas, 2007). Industries maintain constant production speed and enhance the quality of their products by making sure that auxiliary machines are running efficiently. Utilization of Capacity Increased: Preventative maintenance can cut capacity losses by 20%. By minimizing downtime and optimizing equipment performance, companies can improve the utilization of their capacity and maximize production output (Shannon, 2021)

Optimizing capacity utilization also requires effective production schedule management. Manufacturers can closely examine demand patterns. To fulfill market demands, adjust production schedules accordingly. By doing this, machines are used efficiently without creating bottlenecks or unnecessary downtime. (Chen L. &., 2021) Proactive maintenance, which includes preventive and predictive maintenance, along with real-time monitoring algorithms and sensor installations, plays a crucial role in reducing downtime and improving the performance and quality of auxiliary machines in a production process. By implementing proactive maintenance strategies, companies can schedule maintenance activities proactively, reducing unplanned downtime and improving the utilization of capacity.

Optimizing capacity utilization for machines is crucial for manufacturers to enhance the overall effectiveness of their equipment, stay competitive in the market, and increase their marginal profit and market share. This literature review highlighted various strategies, such as implementing automatic monitoring systems, predictive maintenance, optimizing production schedules, and investing in operator training. These approaches have shown notable improvements in capacity utilization and overall operational efficiency. By implementing these strategies, manufacturers can maximize machine performance, improve productivity, and enhance their competitiveness in the market. Supply chain integration is another area of focus for capacity utilization enhancement. (Johnson M. &., 2017) Examine the connection between capacity utilization in manufacturing organizations and supply chain integration. Their study emphasizes the value of cooperative interactions, information exchange, and coordination throughout the supply chain to maximize capacity utilization.

In a study by (Johnson R. W., 2019) investigated was the application of predictive maintenance methods like condition monitoring and real-time data processing. The findings showed that preventative maintenance based on machine health monitoring can efficiently increase machine capacity by identifying early failure indicators and enabling prompt repairs. (DINSA, 2021) examined and concentrated on Ethiopia's textile and apparel sectors, and ways to improve capacity utilization were also investigated. The study stressed the necessity of supply chain management, market diversification, and talent development as essential factors for increasing capacity utilization in this industry.

In conclusion, increasing capacity utilization is essential for businesses looking to boost output, cut expenses, and maintain their competitiveness. Organizations can efficiently use their resources and achieve higher capacity utilization by putting into practice a variety of tactics, such as process optimization, demand forecasting, flexible work practices, automation, training, and continuous improvement.

Table 2.1 Empirical literature summary table

Author	Year	Method	Result
Smith	2017	Using automated monitoring and control system	A notable increase in capacity utilization, a considerable decrease in downtime, and a 20% increase in overall machine efficiency
Brown	2019	Using automation technologies like robotics and artificial intelligence	Production capacity can be increased, and processes can be made more efficient.
Smith et.al	2017	preventative maintenance procedures	Their findings highlighted the value of regular inspections and maintenance to find and address any issues before they result in failures.
Johnson	2019	implementation of a maintenance	resulting in a 30% reduction in machine downtime. This improvement led to enhanced capacity utilization and overall operational efficiency.
Davis	2018	operator training programs	The study found that by lowering operator-related errors and downtime, rigorous training programs that concentrate on both technical and operational abilities can significantly improve capacity utilization.

Chen	2021	a simulation-based optimization approach to improve production schedules	The results showed a 15% increase in capacity utilization, resulting in productivity and reduced lead times. To increase capacity utilization, machine operators' knowledge and abilities must also be improved.
Johnson M et.al	2017	Supply chain integration	Their study emphasizes the value of cooperative interactions, information exchange, and coordination throughout the supply chain to maximize capacity utilization.
Johnson R. W.	2019	application of predictive maintenance methods like condition monitoring and real-time data processing	The findings showed that preventative maintenance based on machine health monitoring can efficiently decrease machine capacity by identifying early failure indicators and enabling prompt repairs
DINSA	2021	Supply chain integration	The study stressed the necessity of supply chain management, market diversification, and talent development as essential factors for increasing capacity utilization in this industry.

2.6 Factor affecting capacity utilization.

The variables that affect the capacity utilization of auxiliary machines have been studied in several studies (Smith, 2017). In their 2017 study, Smith and Johnson explored how machine design affects capacity utilization. Their study found that machine attributes like size, speed, and dependability have a big impact on how much capacity is used overall. Utilization rates are often higher for equipment with greater reliability and faster running speeds.

2.6.1 Internal factor

In a study by (Sakib, 2018) the authors looked at how maintenance procedures affected capacity use. They discovered that condition-based monitoring and proactive maintenance, such as preventive maintenance, had a beneficial impact on machine uptime and overall capacity utilization. Effective maintenance procedures were shown to be a key element in lowering unplanned downtime and improving equipment availability. Capacity utilization can be considerably impacted by the introduction of cutting-edge technology and improvements to auxiliary equipment. Machine efficiency, idle time reduction, and capacity utilization can all be improved by replacing outdated equipment, applying automation, and incorporating smart technology as a study of (Brown C. &., 2019).

Other studies have emphasized how crucial operator training and skills are to capacity utilization. (Anderson, 2014) I looked into how operator skill affected the use of the auxiliary machines. According to their findings, skilled and knowledgeable operators can run equipment more effectively, resulting in higher capacity utilization rates. The capacity utilization of auxiliary machinery is influenced by the technical expertise of the operators and technicians. The effectiveness of machine operation, the reduction of errors, and the best possible capacity utilization can all be increased by offering proper training programs, skill development initiatives, and ongoing education. Additionally, (Johnson R. &., 2015), effective scheduling and production planning techniques are crucial to maximizing capacity utilization. Maximizing machine utilization and overall production efficiency can be achieved through efficient coordination between auxiliary machines, process sequence optimization, and reducing changeover times in production.

Plant layout design also has a major influence on plant productivity. A good layout design helps to find the most effective facility arrangement and minimize material handling. With well-organized material handling, the operation cost during manufacturing can be reduced from 15 to 30%. It is critical that the location of machines and workstations be arranged in a way that reduces the distance traveled by personnel or material handling (Ali Naqvi, 2016). Utility interruptions, power, and water supply seem to be the main and more persistent reasons for under capacity utilization. (Sanghvi, 2013)

2.6.2 External factor

The utilization of capacity is significantly influenced by external factors as well. For instance, market demand may have an impact on how auxiliary machines are used. The correlation between market demand trends and machine usage was examined by (Abulibdeh, 2022). Their study found that better capacity utilization and overall efficiency can result from matching production schedules to changes in market demand.

The capacity utilization of auxiliary machinery can be directly impacted by governmental policies and regulations such as industrial policy, trade restrictions, and environmental rules. Regulation compliance may call for modifications to production procedures, which may have an impact on capacity utilization rates (Brown D. &., 2018).

The capacity utilization of auxiliary machines may be impacted by the manufacturing industry's rapid technical improvements and disruptions. Changes in production procedures may be necessary in response to the adoption of new technologies or the advent of disruptive technologies, which could affect capacity utilization (Miller, 2019).

The product standards, unions, safety regulations, pollution control, and environmental standards, as well as the stability of society and the government, are external factors (Mol, 2016). To maximize production and improve overall operational effectiveness, auxiliary machines must be used to their fullest potential. The impact of variables like machine design, maintenance procedures, operator expertise, and market demand on capacity utilization was highlighted in this literature study. Future studies should focus on overcoming obstacles and creating comprehensive strategies to maximize the capacity utilization of auxiliary machines.

2.7 Literature summary

2.7.1 Utilizing capacity effectively is essential for improving organizational productivity.

Utilizing capacity effectively is essential for improving organizational productivity. Innovative approaches, techniques, and factors affecting capacity utilization, as well as the significance of enhancing it for enterprises, are explored in this literature review. Identifying methods and problems for increasing capacity utilization of machines has been discussed, and as main findings, the following are stated to maximize capacity:

- Various variables that affect capacity utilization Resource shortages, changes in demand, and supply chain disruptions can all influence how much capacity is being used. Automation and data analytics are two technological developments that could have a positive impact on capacity utilization improvement.
- Techniques to Improve Capacity Utilization The best ways to maximize capacity utilization have been shown to be through lean manufacturing methods, waste reduction, and continuous improvement activities. Utilizing capacity to its fullest helps reduce unscheduled downtime through predictive maintenance. Effective capacity optimization demands good departmental cooperation and precise demand forecasting.
- Problems with Increasing Capacity Utilization Inadequate training, a lack of departmental cooperation, and reluctance to change are a few obstacles that can obstruct efforts to increase capacity utilization. Strategies for capacity optimization must consider human aspects and the requirement to address these issues.
- Innovative Techniques to Enhance Capacity Utilization: Promoting products and developing new techniques to raise their value can increase production and capacity utilization.
- Improving capacity utilization is essential for organizations to enhance productivity and efficiency. The different elements, tactics, and difficulties involved in maximizing capacity utilization are highlighted in the above literature review. It highlights the significance of creative strategies, efficient coordination, and removing obstacles to enhancing capacity utilization.

2.7.2 Best Practices:

Various best practices have been identified to maximize capacity utilization or minimize downtime, changeover, and idleness of machinery. These include:

- putting proactive maintenance methods, such as preventive and predictive maintenance, into practice.
- Utilizing cutting-edge technology to enable real-time monitoring and predictive analysis of machinery health, such as the Internet of Things (IoT), machine learning, and data analytics.
- Making effective plans for resource allocation and scheduling to make the most of the equipment both during peak and off-peak hours

- giving adequate training for the employees to carry out routine maintenance and troubleshooting tasks successfully.
- analysing the workload thoroughly to understand the patterns and variations of demand that auxiliary machines could experience.
- Putting into practice efficient scheduling and resource allocation techniques to make sure that auxiliary machines are used effectively.
- Investing in technology that allows for real-time monitoring and data analytics to spot future capacity challenges and facilitate proactive decision-making.
- Examining and modifying capacity levels on a regular basis considering shifting demand patterns, market circumstances, and technical improvements

2.8 Challenges and upcoming directions

Despite the advancements made in maximizing capacity utilization or reducing machine downtime and idleness, several problems still exist. These include the high expenses of deploying cutting-edge technologies, the requirement for ongoing training and skill development of the workforce, and the difficulty of integrating maintenance techniques into current operations. Future studies concentrate on creating affordable solutions, investigating the potential of cutting-edge technology, providing skilled full-practical training, providing proactive maintenance, and solving the difficulties that various manufacturing industries are currently facing.

Maximizing capacity utilization or minimizing downtime and idleness of machinery is crucial for optimizing operational efficiency and maintaining a competitive edge. This literature review highlighted the importance of proactive maintenance, advanced technologies, effective resource allocation strategies, and adequate training by doing a need assessment to achieve this goal. Future research and industry practices should aim to address the challenges and embrace innovative approaches to further enhance machinery uptime and utilization.

2.9 Literature gap

From reviewing different empirical research that has been conducted on the area of capacity and capacity utilization, it‘s been established that there are many factors that affect the utilization of capacity, and many roadblocks are there to fully use the installed capacity. From those, the lack and poor implementation of IIOT, infrastructure facilities, market demand, skilled manpower, raw materials, and tax administration are factors covered in most of the studies as factors affecting capacity utilization in the manufacturing industry. From the observation of the case sector, there is a serious factor that affects the availability and performance of the auxiliary machines, and mainly that factor comes from the breakdown and downtime of equipment.

In conducting this study, the literature gap between different researchers indicates that there is a lack of literatures gap including evidence gap, knowledge gap and methodological gap to show the improvement of total plant capacity by improving the capacity utilization of auxiliary machineries, basically there are a very few studies are available in analyzing the impact of auxiliary machineries in the production if the fixed input cannot be fulfilled in the company then the production cannot be proceed these creates the idle or waste resource which leads to the unwanted losses of profit and dissatisfaction of employees and customers so these study aims to assess and analyze the factors that make these auxiliary machineries unavailable and why the performance losses occurs and what should be done to maximize the input of the products and uses the capacity fully.

Many scholars focus on measuring machine performance based on the output rather than considering machine status to see the impact of six big losses and how it affects the enhancement of the total effective equipment performance. And the other gap that has been considered in doing this research is that many studies depend on the output of the product without significantly considering the working hours of the machines. The working hours of a machine with full potential in the industry play a significant role in determining the capacity of the industry.

Chapter Three
3. Research design and methodology

3.1 Introduction

These chapters of the research include the research design and methodology that have been used in the study. To conduct this study, both quantitative and qualitative metrics, which are capacity utilization metrics, and the root cause analysis method were used. For the source of data, both primary and secondary data types were used. The primary data used in the research is from a direct observation of the workplace, recording of the necessary data, and interviewing the utility staff using a direct interview. The secondary data type that is used in the research is from previous literature that has been conducted on capacity, capacity utilization, capacity utilization improvement, utility department reports, and other related publications. A qualitative and quantitative data analysis tool is used to analyze the data that has been collected to come up with findings and solutions.

The study used potential solutions to prevent downtime in auxiliary machines by analyzing data on various auxiliary machines and identifying the factors that contribute to downtime and inefficiency. The study used techniques such as capacity utilization metrics and root cause analysis to identify the main reasons for equipment downtime and unutilized capacity. Additionally, the study aims to make data-driven decisions and maximize equipment performance and availability. Root Cause (Research Approach) method to improve the capacity utilization of auxiliary machines in the BGI Ethiopia brewery factory The research approach includes defining research objectives, reviewing existing literature, identifying important factors, and using data collection methods to gather relevant information. This approach aims to identify the root causes of breakdowns and inefficiencies and find possible solutions and best practices to prevent these factors.

3.2 Methodology

One way to improve the capacity utilization at BGI Ethiopia Brewery Company is by increasing the capacity utilization and efficiency of active auxiliary machines.

The organization's fundamental tasks and operations are supported with the help of this equipment, which includes boilers, CO_2 plants, chiller (cooling) plants, and air plants. To enhance the capacity utilization of auxiliary machines in the company, the following measures are taken into consideration:

1) Conduct a thorough analysis of the existing literature. Review books, articles, journals, business reports, and case studies related to enhancing capacity utilization in manufacturing settings, particularly in the context of brewery plants. Identify critical elements, winning tactics, and best practices for maximizing machine capacity.
2) Identify important factors: Determine the factors that may impact the capacity utilization of auxiliary machines in the brewery factory. This includes considerations such as scheduling, automation, workflow optimization, equipment maintenance, operator training, and system integration.
3) Collect relevant data: Use a combination of quantitative and qualitative data collection methods to gather information. This may involve collecting machine utilization data, machine logs, maintenance reports, hourly reports, and performance metrics.
4) Analyze the collected data: Apply appropriate statistical techniques, such as descriptive statistics, mathematical analysis, or thematic analysis for qualitative data, to analyse the collected data. Identify patterns, trends, and correlations within the data to gain insights into the current state of auxiliary machine capacity utilization.
5) Present findings and discussion: Present the research findings in a clear and organized manner using tables, charts, and graphs to support the analysis. Discuss the key findings, highlighting factors that positively or negatively impact auxiliary machine capacity utilization. Compare the findings with existing literature and industry best practices to identify areas for improvement and potential solutions.
6) Make recommendations: Based on the research findings and analysis, propose contextual and general recommendations to improve auxiliary machine capacity utilization in the brewery factory. These recommendations should address factors such as equipment upkeep, operator training, scheduling, automation, and system integration.

Specify the methods used to improve the capacity utilization of auxiliary machines in BGI Ethiopia:

- Observe and evaluate the current performance of auxiliary machinery and identify any areas that need improvement by doing an equipment analysis. Check to verify if the current equipment is insufficient, outdated, or ineffective for the needs of the organization.

- Identify auxiliary machines that need to be improved to have better performance, efficiency, and capacity. One option in BGI Ethiopia to increase capacity is by comparing cutting-edge technologies, such as treatment, more powerful and effective CO2 and air compressors, and autonomous regulating and monitoring systems.
- To maximize machine utilization, analyse how effectively auxiliary machines are used. Consider transferring workloads or consolidating equipment to boost efficiency and reduce costs.
- Determine and identify the company's maintenance and repair strategies: limit downtime, extend the life of auxiliary machinery, and set up regular maintenance and repair schedules. To do this, you need to make plans for routine maintenance, finish repairs quickly, and have a backup plan in case of equipment's sudden breakdown.
- Conducting a need assessment to provide adequate training and support for the employee who operates and maintains the auxiliary machines and other equipment in the company can reduce technical errors and increase effectiveness and efficiency.
- Compare and contrast the use of automation devices and integration techniques to automate the process and integrate the auxiliary machines with other systems in the operation. This can boost productivity, reduce errors, and streamline operations by enabling error-free data transfer and automating the procedures.
- Keep a tight eye on the capacity and performance of auxiliary machines, as well as the usage and functionality of the auxiliary machines. This helps to make decisions in areas for improvement using root cause analysis and gather data on machine uptime, print volumes, error rates, and other relevant factors.
- Practicing a suitable cloud-based solution using IIOT can reduce the extra resource needed for boosting auxiliary machine capacity.

By implementing these steps in the company, BGI Ethiopia boosts productivity, saves costs, ensures the effective operation of these essential resources, and finally improves the capacity of its auxiliary machines and overall efficiency.

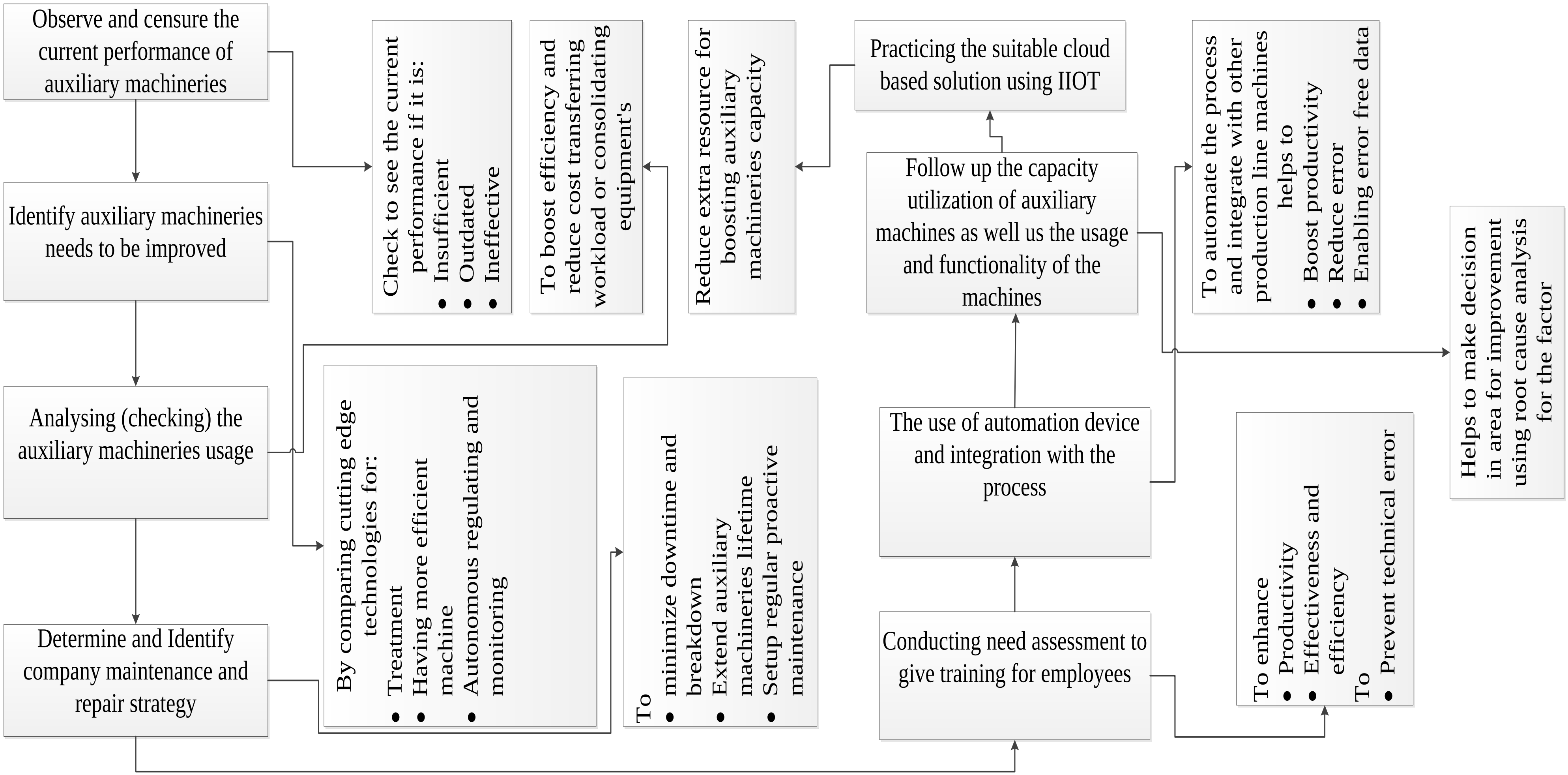

Figure 3.1 Methodology framework diagram

3.3 Research Design

The design of the research is intended to address the question stated in the research question section, and the design of the research is both descriptive and exploratory. The research design aims to provide and give the appropriate framework for the study, and the research approach has to be determined to know what kind of data is needed and how the data is obtained for the study.

The research will start with a description of the things that can be easily observed to get an actual picture of the state of things in the current working system of the BGI Ethiopia brewery factory. Next, the research looks for a fact finding to the research sought, collected, and studied to get the true picture of what is sought after. The study is concerned with specific predictions, a narration of facts and characteristics of the sectors regarding relative capacity utilization of machines, and factors affecting capacity utilization.

To conduct a study that addresses the questions stated in the research question section and meets the objectives, a mixed-methods approach is appropriate for the study. This involves collecting both numerical and qualitative data to gain a deeper understanding of the root causes of the brake down and inefficiency and the impact that these causes have on the capacity utilization due to the downtime of the machines, and then improving the capacity utilization of auxiliary machines by identifying possible solutions and best practices to prevent the factors.

Several important factors need to be considered in a research design for increasing the capacity utilization of auxiliary machines in BGI Ethiopia, a brewery industry. Outline of the research tactic:

1) Title: capacity utilization improvement for auxiliary machineries in BGI Ethiopia
2) Introduction:
   - Describe the issue in general, emphasizing the value of effective auxiliary machine use in BGI Ethiopia brewery production.
   - Describe the study's goals, which include boosting output, lowering downtime, maximizing resource use, and enhancing the operational capacity of auxiliary machines.

3) Literature Review:
   - Conduct a thorough analysis of the body of knowledge, including books, articles, journals, reports from the business world, and case studies, concerning the use of auxiliary machinery in the manufacturing industry.
   - Identify the important variables that affect capacity utilization, such as equipment upkeep, operator training, scheduling, automation, and system integration.
   - Analyse the challenges faced by manufacturing factories in optimizing auxiliary machine capacity utilization and explore successful strategies implemented to enhance the improvement in capacity utilization by other organizations.
4) Research Methodology:
   - Define the research approach, which can be quantitative, qualitative, or a mixed approach, based on the research objectives.
   - Describe The target group consists of the technique managers, machine operators, and maintenance personnel of BGI Ethiopia beer factory.
   - Outline the data collection methods, such as observations, referring manuals, inquiring workers and experts using formal and informal communication, and document analysis.
   - Collect relevant data on factors influencing auxiliary machine capacity utilization.
5) Data Collection and Analysis:
   - Collect data from the selected sample using the identified methods.
   - Analyse the collected data using appropriate statistical techniques, such as descriptive statistics, mathematical analysis, or thematic analysis for qualitative data.
   - Identify patterns, trends, and correlations within the data to gain insights into the current state of auxiliary machine capacity utilization in the brewery factory.
6) Findings and Discussion:
   - Present the research findings in a clear and organized manner, using tables, charts, and graphs to support the analysis.
   - Discuss the key findings, highlighting factors that positively or negatively impact auxiliary machine capacity utilization.
   - Compare the findings with the existing literature and industry best practices, identifying areas for improvement and potential solutions.
7) Recommendations:

- Based on the research findings and analysis, propose contextual and general recommendations to improve auxiliary machine capacity utilization in the BGI Ethiopia brewery factory.
- Prioritize the recommendations based on their potential impact, effect, and cost-effectiveness.
- Provide a roadmap for guiding other future research on the recommendations, including timelines, responsibilities, and resource allocation.

8) Conclusion:
   - Summarize the research study, emphasizing the significance of improving auxiliary machine capacity utilization in BGI Ethiopia brewery factory.
   - Highlight the key findings, recommendations, and potential benefits for the organization.

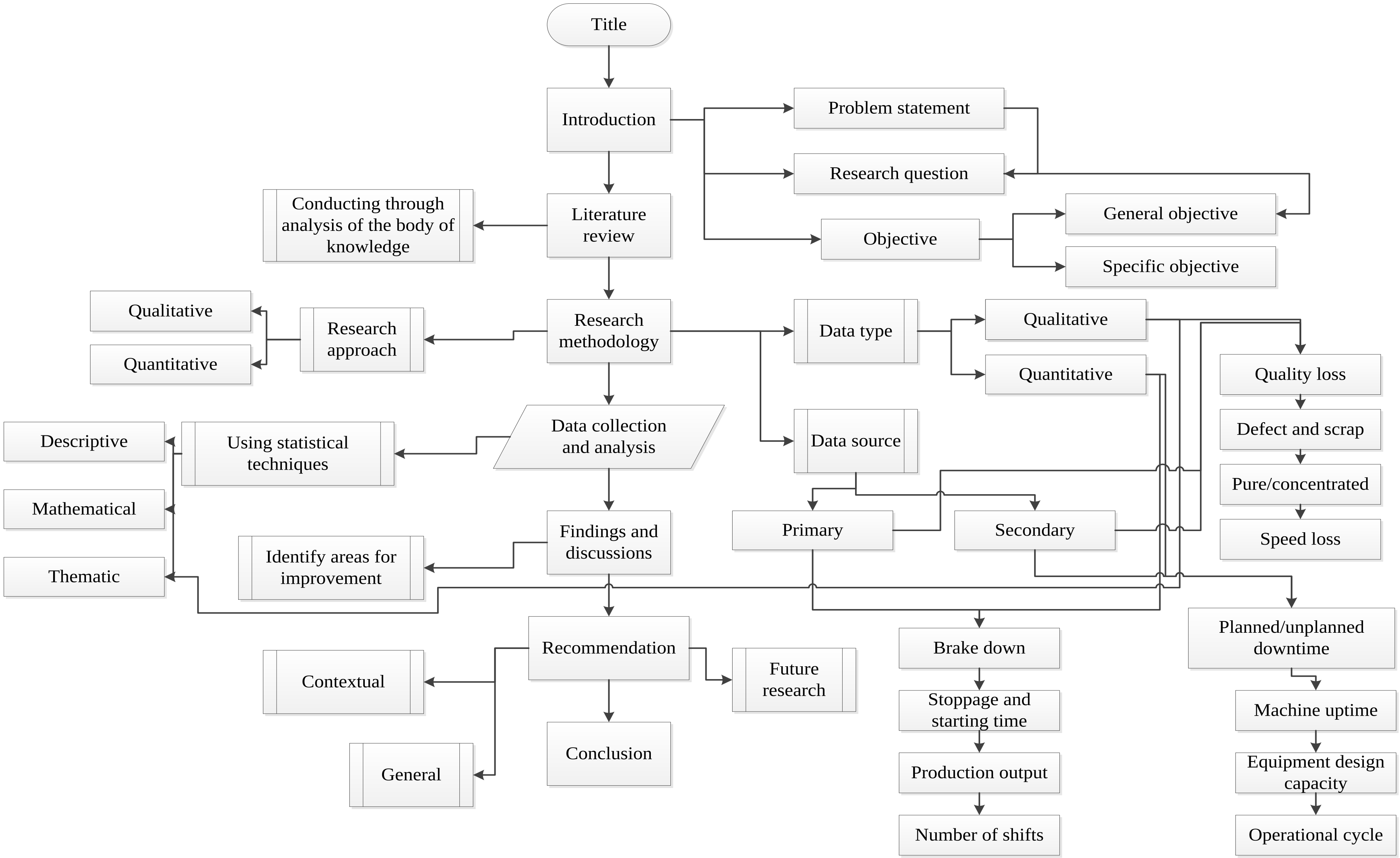

Figure 3.2 Research design framework

3.3.1 Research approach

Implementing the following research approach to address the research questions and improve the capacity utilization of auxiliary machinery in the BGI Ethiopia brewery factory:

1) Define the research objectives: clearly state the precise goals of the study, such as boosting auxiliary machine capacity utilization and lowering breakdown and downtime.
2) Review existing literature: carry out a complete analysis of the available literature, such as journals and articles, business reports, and case studies concerning enhancing capacity utilization in manufacturing settings, particularly in the context of brewery plants. Determine the critical elements, winning tactics, and best practices for maximizing machine capacity.
3) Identify important factors: ascertain the important factors that might have an impact on the auxiliary machines' capacity utilization in the brewing factory. This involves things like scheduling, automation, workflow optimization, equipment maintenance, operator training, and system integration.
4) Data collection methods: decide on the appropriate data collection methods to gather relevant information. This involves a combination of quantitative and qualitative approaches. Quantitative methods include collecting machine utilization data, machine logbooks, maintenance reports, hourly reports, channel groups, and performance metrics. Qualitative methods involve inquiry (direct interview), surveys, and observations with machine operators, maintenance staff, technique managers, and other relevant personnel.
5) Data analysis: employ the proper statistical methodologies and qualitative analytical approaches to examine the gathered data. Statistical tools like mathematical analysis, trend analysis, or statistical process control can be used to analyze quantitative data. To find recurring themes and patterns in qualitative data, thematic analysis or content analysis can be used.
6) Determine opportunities for improvement: determine the precise areas where capacity utilization can be increased based on the data analysis. To ensure that machines are being used to their full potential, look for patterns, bottlenecks, and inefficiencies. Finding maintenance problems, scheduling conflicts, knowledge gaps, or process inefficiencies could be part of this.
7) Create improvement tactics: create tactics and suggestions to increase capacity utilization in light of the opportunities found. This could involve putting proactive maintenance, which includes preventative maintenance plus predictive maintenance programs, in place,

training machine operators specifically, streamlining operations, and improving scheduling procedures.

8) Utilizing and evaluation: In the company, put the identified improvement approaches into practice while carefully observing how they affect capacity utilization. By monitoring key performance indicators like machine uptime, manufacturing output, and resource usage, we can help assess the success of the initiatives set in place. To further optimize capacity use, adjust as necessary.

3.3.2 Data type and Data source

Data type

The data types that are needed for this study are quantitative and qualitative data types, including the capacity of the auxiliary machines, which include information on machine uptime, production output, downtime, breakdown, stoppage, working hour, number of shifts, stopping and starting times, planned and unplanned downtime, machine uptime and equipment design status, actual equipment status in the numerical data type, and the actual performance of the machines. The speed losses, quality, scrap, defect, pure, and concentrated kinds of data were collected in qualitative data type form.

The data type of this study was used for problem identification and to evaluate the impact of independent variables on the dependent variables. It includes sensor data, production system and equipment data, quality data, and machine (log) data. This data will likely include information on machine uptime, production output, quality metrics, and other performance indicators.

Data in different formats will be collected, including digital, textual, symbolic, charts, reports, descriptive, and the incidence and non-occurrence of specific conditions. The data collection will include a literature review, primary data collection, and secondary data collection. A literature review will involve surveying published journal articles, electronic sources, and books to understand the concept and benefits of utilizing capacity to its installed capacity. Primary data will be obtained through assessing the production process or machines, through informal or formal communication with operators and managers to determine causes of machine failures, and through an interview to gather information from those directly involved in production, with managers and responsible people, stoppages, and other influences that have an impact on the ability and availability of the machines.

3.3.2.1 Primary data collection method and its source

Primary data was obtained through continuous evaluation of the operational process in the study area, formal and informal contact with respondents and managers, and data collected in advance of the operational process, often through technology, direct observation, sensors, and IIoT devices (about efficiency, effectiveness of machines, and overall equipment's effectiveness constraints). Use this information to identify areas that cause process delays or reduce effectiveness, predict potential issues before they occur, and take corrective action to improve capacity utilization. This has helped operators identify the root causes of problems or ineffectiveness and take proactive measures before they impact operations.

By the help of using Industry 4.0 technologies, such as sensors, IIoT devices, and computer learning algorithms, have played a vital role in primary data by providing real-time data and insights into the manufacturing process to gain a better understanding of the process and identify ineffectiveness. For illustration, data collected from sensors and counter devices has been used to measure machine performance, downtime, and maintenance requirements to identify manufacturing ineffectiveness and improve overall equipment effectiveness and enhance a utilized capacity in the auxiliary machineries. These were realized when making use of the following data collection methods:

a) Frequency event and recording, using a combination of a stopwatch, counting machine, and sensor recorders. Using cutting edge tool to increase the capacity utilization of the equipment's and measuring the frequency of an event involves counting the number of times it occurs in a given period of time. This is used to determine and monitor the frequency of equipment failures or maintenance requirements that affect the utilization of capacity. Recorded machine downtime or maintenance downtime is used.

b) As event recording is best for actions with a distinct beginning and ending, it was used to record the occurrence and cause of downtime.

Event recording was used for features that have a distinct start and end, such as recording the events and causes of downtimes. Keeping records of the duration and frequency of events, identifying patterns and root causes, and taking corrective actions to optimize processes and improve capacity. Combining event recording with other tools, such as machine and sensor recorders, as well as applying technologies, will further increase the accuracy and effectiveness of downtime monitoring and analysis.

• A frequency measure was used to identify how frequently each cause of failure was occurring.

This was used to identify the most dominant or important problems and identify the necessary corrective measures. To do this analysis, we collected information on the problems and failures in the process and noted the frequency of each failure. Computer learning & vision, or display on IIoT devices were used to collect the data manually or automatically.

• Observation

Overall, by using industry 4.0 technologies and observation techniques, manufacturers gain valuable insight into their manufacturing processes, which improves capacity and ultimately leads to better results. By observing the manufacturing process, managers and operators identify areas that cause process delays or reduce effectiveness and take corrective action to improve the utilization of capacity.

• Formal and informal interviews, enquires

Both communication systems with operators, technicians, managers, and other staff were used to get information on the causes of failures, the observed downtimes in the operational process, and possible solution. The questions or interviews were used as part of gathering information from 20 employees and supervisors contributing to improvement efforts. But more contexts were needed to determine their specific preferences regarding in the capacity utilization improvement. Mainly focus on the identification of equipment downtime, possible solution, and its impact on capacity. Through papers, research, and expert interviews, a total of six significant losses were identified as relevant improvement concerns that directly affect the capacity utilization and the OEE metrics in the manufacturing industry. Three chief, and one researcher were interviewed from different departments in the factory, including quality, data analysis, research and development, and maintenance (operator, mechanics, electrical, and production). The experts were selected based on their experience and willingness to participate. In addition, the correlation between waste, possible solution, and the many sources of waste in the organization was determined using the same method. All losses and waste are given to experts to identify the root cause of the problem.

The study is designed to collect data that helps achieve the objectives of the study, especially for research questions that has been stated above. All information provided is treated with the utmost confidentiality and used purely for research purposes. Questionnaires were used as part of gathering information from employees, supervisors, and managers who could contribute to these improvement efforts, data analyser but more context was needed to determine their specific use in relation to the combination of capacity utilization improvement. Furthermore, the specific use of questionnaires and the questions asked depend on the particular goals of the capacity utilization improvement of auxiliary machines effort, possible solution, and the specific context of the manufacturing operation. The questionnaire asks about the respondent's general characteristics, availability and performance of the auxiliary machineries.

3.3.2.2 Secondary data collection method and its source

Secondary data can be obtained from documents and records to calculate OEE values and identify the company's performance level. A literature review on secondary data sources involves surveying published journal articles, electronic sources, and books to understand the concept and benefits of improving capacity utilization of auxiliary machineries. In addition to the literature review, other secondary data from the manufacturing sector was gathered and is relevant to the study. The following secondary data sources were used to improve the utilization of capacity in the organization

- Used real-time data on equipment performance and maintenance, as well as articles, studies, and reports that study overall equipment effectiveness, to identify areas for improvement and drive continuous improvement efforts.

- Articles, research, and case study reports that provide best practices for improved capacity utilization.
- Research, articles, and studies from the manufacturing industry, industrial engineering management association (especially Toyota vehicle manufacturing company), and lean manufacturing tools to improve equipment efficiency and effectiveness, productivity, and quality, maximize profits, and reduce waste for the organization.

3.4 Population and sample size population

The study is conducted at BGI Brewery in Addis Ababa to assess and analyze the utilization of the auxiliary machinery's capacity and to improve their efficiency, since the assessment of factors affecting capacity utilization on the machinery’s selection encompasses employees and stakeholders who have experience in the sector. An employee with long experience on their work relative to others and who knows the machines, and those who have information about the installed capacity of these machines in the industry and those who have the concept of capacity utilization are chosen to give information about machine uptime, downtime, changeover, production quantity, and quality because they are well informed and know much about the factors affecting the capacity utilization in the sector in detail, so they are selected for this study for convenience of the study, so the participant of the research is chosen using a purposive sampling technique to get the data on machine uptime, downtime, and production capacity.

3.5 Data collection method

The primary and secondary data collection focusing on both qualitative and quantitative data.

3.5.1 Primary data collection method: Qualitative and Quantitative

- Qualitative: field observation, interview, informal discussion

Qualitative data like sensor readings, speed losses, quality, scrap, pure, or concentrated are substantially collected from field observation and interviews with the staff about stoppage frequency, unplanned down time, and brake.

- Quantitative: survey questions, interview questions for managers and utility department employees.

3.5.1.1 Data collection through interview

Conducting a direct interview with technical, production, and quality department managers and utility department staff to inquire about data.

3.5.1.2 Workplace site observation

By observing the work site and recording and collecting data like sensor data's (temperature, pressure), changeover, and machine stoppage time,

3.5.1.3 Data that obtained from expert opinion to use it for decision making prioritize the factor and to come up with an alternative solution.

3.5.2 Secondary data collection method

Using the secondary data collection method, like reviewing different literature on capacity utilization that has been conducted by researchers, factory reports, government publications, books, journals, and articles that can shed light on the research topic,

3.6 Data collection procedures

Various methodologies are employed to conduct this study and to meet the objectives of this research. Depending on the type and availability of data, both qualitative and quantitative data are collected. These data were gathered from the BGI Ethiopia Addis Ababa factory.

To improve the capacity utilization of the production system, the utilization of resources is a must, which includes the proper use of machines. The steps to collect the data types from each data source are:

- Identify the different data sources for each data type, like below.
    - Collect machine uptime, production output, downtime, breakdown, operation cycle speed and cycle times, stopping and starting times, planned and unplanned downtime, and actual equipment status in numerical data type.
    - Production department: Collect data related to production output, expected and actual product quantitative data types.
    - Technique department: collect data related to trends, planned and unplanned downtime, and breakdowns in the quantitative data type.
    - Human resources department: collect data related to the number of workers and working hours in the quantitative data type.
    - Experts and technical managers: Collect data related to equipment status and maintenance issues in the qualitative and quantitative data types.
    - Machine logbooks in the working area record events happening in the company related to maintenance, production, and other issues in the qualitative and quantitative data types.
- Determine the data points for each category and collect all the intended data.
- Enter the data into a centralized database or software system. This is used to organize and analyze the data more effectively.
- Analyze the data.
- Developing recommendations to improve the utilization of capacity for the auxiliary machines.

By following these steps, the required data types are collected from each data source for analysis.

3.7 Data summary

Table 3.1 Data collection method, and procedures

DATA		Data type	Data collection method	Data source
Primary	Quantitative	Brake down, stoppage and starting time, production output, number of shifts, number of workers	Workplace site observation, participants	Production department, computer displays, and HR departments
	Qualitative	Speed losses, quality losses, defects, scrap, pure or concentrated		Technical department, computer displays, and manual recorded data
Secondary	Quantitative	Planned or unplanned down time, machine up time, equipment capacity design, operation cycle and brake down frequency	Real-time data gathering using sensors and manual and electronic data recording systems in the company	Production and technical departments, expert opinions
	Qualitative	Speed losses, quality losses, defects, scrap, pure or concentrated, type of maintenance conducted	Direct interview with staff	Production and technical department, quality department, literature, and journals

Chapter four

4. Data presentation, analysis, and findings

4.1 Introduction

This chapter of the study focuses on answering the questions that have been stated in the research question. The first question in the study is what the main root causes are: breakdown and inefficiency in the plant, which is addressed in the literature review section by identifying the factors that include the internal and external factors that are barriers for the plant in enhancing capacity utilization. The second question that is going to be addressed in the study is: What are the impacts of the resulting downtime of auxiliary machines on capacity utilization? And the last research question that is going to be answered here is: What are the potential solutions and best practices that can be applied to prevent the breakdown of auxiliary machines in the company? To answer these questions and to meet the objective of the study, data was collected about steam boilers, CO2 plants, air plants, and cooling plants to see the actual output to their potential capacity. Research findings based on the data were summarized and presented in the form of percentages, tables, and graphs.

4.2 Data presentation & discussion

The study found that the downtime of auxiliary machinery, such as boilers and cooling plants, has a significant impact on the capacity utilization of the plant. Factors such as raw material shortages, maintenance issues, breakdowns, and a lack of employee motivation and skills contribute to the underutilization of these machines. The study emphasizes the need to address these issues to improve capacity utilization and increase the efficiency and effectiveness of the plant's operations.

4.2.1 Steam boiler

In a brewery factory, steam is used for washing and cleaning the ingredients and to sanitize cleaning equipment like kegs and bottles that have been returned to the company from the market for another filling process. The mashing process in BGI brewing industries, where the malt is mixed with hot water to extract the sugars that are turned into alcohol, is done with the help of steam. The steam helps raise the temperature of the mash and makes the process go faster to produce beers.

The efficiency of boiler is depends on many factors like the amount of water supply, water feed temperature, steam temperature, the amount and type of fuel used and working pressure of the boilers are some major factors that affect the efficiency of a boiler, in BGI Ethiopia

Addis Ababa factory there are two industrial boilers namely (Bosch and Loos) which is used for the production of steam, the equipment design capacity is to produce 12ton/h, assessing the actual output of these auxiliary equipment's to see and analyse their efficiency the data collected for nine months from November to July to measure the capacity and how these auxiliary machine performs.

The data presentation for both boilers considers the expected running hours according to the equipment design capacity, which is the installed capacity also, which is 12 tons/hour, and the expected running hour is given by (number of days in a month * 23 hours), and these give the expected steam production by multiplying it with the hourly capacity of the machine, which is given by (month days * 23 hours * 12 tons/hour) to compute with the actual or observed production capacity to analyze the capacity utilization of this auxiliary machine.

The capacity utilization ratio is given by the actual (observed) output divided by the installed capacity.

$$CU\% = \text{actual output}/\text{installed capacity}$$

Table 4.1 The overall nine-month Bosch boiler capacity utilization

Boiler One (BOSCH)									
Month	Boiler Running hour(hr)	Expected boiler working hour (month days*23hour)	Burner running hour(hr)	Volume of water received (m3)	Actual Steam produced. (ton)	Expected steam production	Capacity (T/h)	Capacity utilization ratio%	Root cause for capacity decline
November	341	690	520	4346	4087	8,280	12	49.36%	Unplanned downtime due to breakdown, water shortage, skill, environment, or defect
December	376	713	597	4802	4509	8,556	12	52.70%	Unplanned downtime due to breakdown, water shortage, skill, environment, or defect
January	252	713	365	3148	3023	8,556	12	35.33%	Unplanned downtime due to breakdown, water shortage, skill, environment, defect
February	323	644	488	4015	3876	7,728	12	50.15%	Unplanned downtime due to breakdown, water shortage, skill, environment, defect
March	240	713	401	3296	2874	8,556	12	33.60%	Unplanned downtime due to breakdown, water shortage, skill, environment, defect
April	251	690	371	3194	3006	8,280	12	36.30%	Unplanned downtime due to breakdown, water shortage, skill, environment, defect
May	324	713	492	4083	3882	8,556	12	45.37%	Unplanned downtime due to breakdown, water shortage, skill, environment, defect
June	388	690	587	4532	4124	8,280	12	49.80%	Unplanned downtime due to breakdown, water shortage, skill, environment, defect

July	369	713	496	4155	3877	8,556	12	45.31%	Unplanned downtime due to breakdown, water shortage, skill, environment, defect
Total	**2,864**	**6,279**	**4,317**	**35,571**	**33,258**	**75,348**		**44.14%**	

Source: BGI utility department book log, technical department

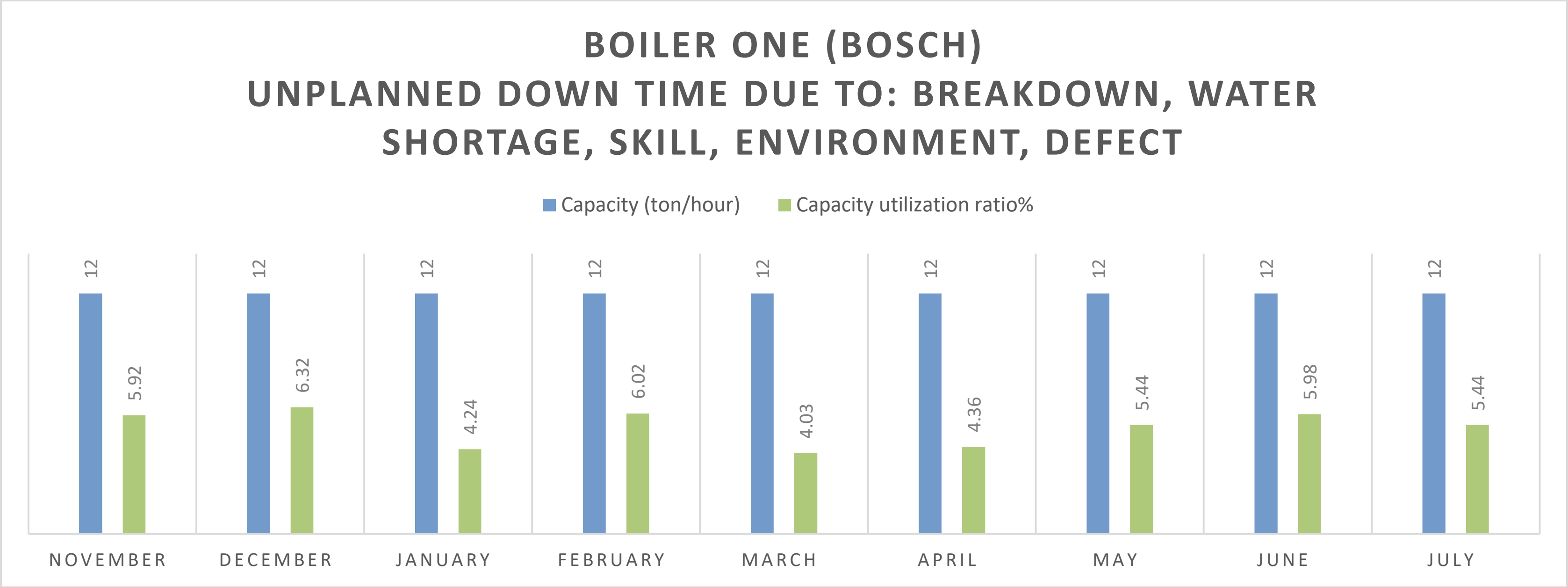

Figure 4.1 Boiler One (BOSCH)

Table 4.2 The overall nine-month loos boiler capacity utilization

Boiler Two (LOOS)									
Month	Boiler Running hour(hr)	Expected working hour (month days*23hour)	Burner running hour(hr)	Volume of water received (m3)	Actual Steam produced. (ton)	Expected steam production	Capacity (T/h)	Capacity utilization ratio%	Root cause for capacity decline
November	303	690	403	2952	2196	8,280	12	26.52%	Unplanned downtime due to breakdown, water shortage, skill, environment, defect
December	361	713	424	3345	3136	8,556	12	36.65%	Unplanned downtime due to breakdown, water shortage, skill, environment, defect
January	342	713	488	3532	3089	8,556	12	36.10%	Unplanned downtime due to breakdown, water shortage, skill, environment, defect
February	214	644	375	2912	2697	7,728	12	34.90%	Unplanned downtime due to breakdown, water shortage, skill, environment, defect
March	329	713	491	3371	3101	8,556	12	36.24%	Unplanned downtime due to breakdown, water shortage, skill, environment, defect
April	378	690	517	3597	3431	8,280	12	41.43%	Unplanned downtime due to breakdown, water shortage, skill, environment, defect
May	318	713	431	2959	2875	8,556	12	33.60%	Unplanned downtime due to breakdown, water shortage, skill, environment, defect
June	277	690	409	3765	3207	8,280	12	38.73%	Unplanned downtime due to breakdown, water shortage, skill, environment, defect

July	291	713	438	2980	2531	8,556	12	29.58%	Unplanned downtime due to breakdown, water shortage, skill, environment, defect
Total	**2,813**	**6,279**	**3,976**	**29,413**	**26,263**	**75,348**		**34.86%**	

Source: BGI utility department book log, technical department

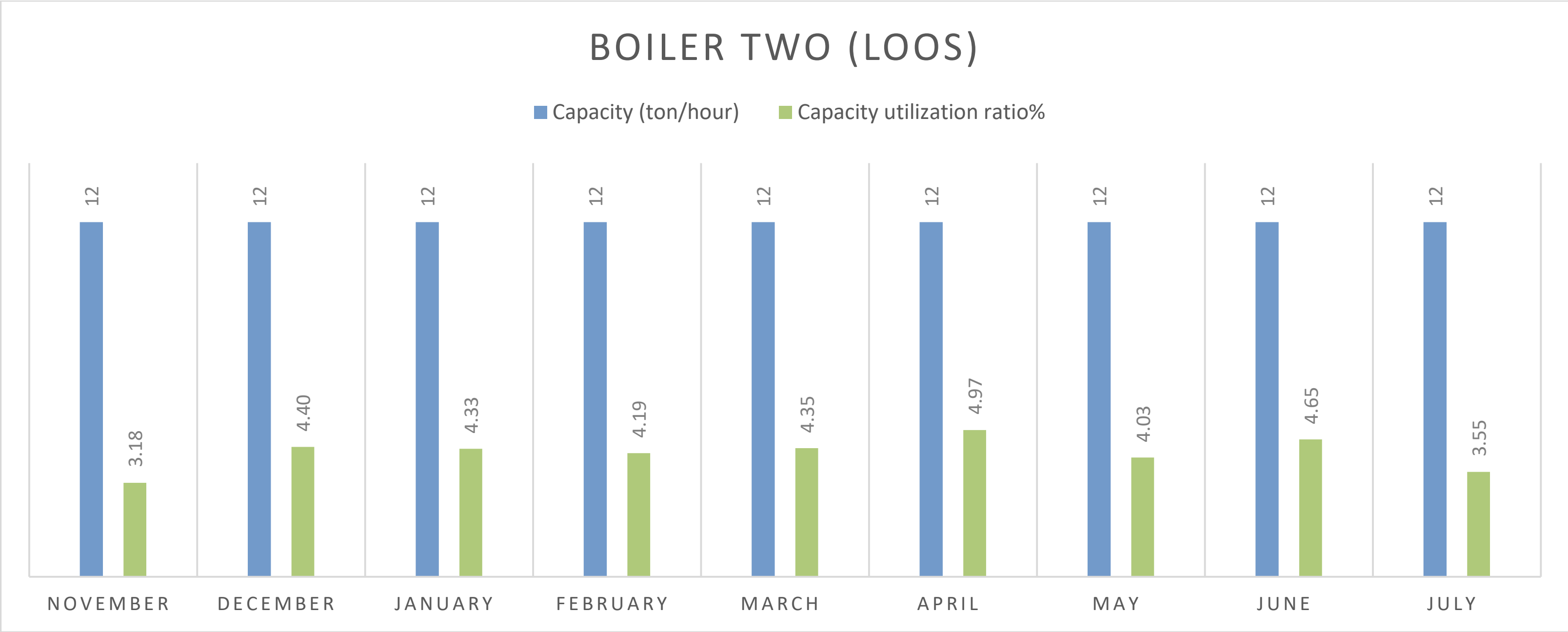

Figure 4.2 Boiler Two (LOOS)

The average boiler running hours (318.22 hr.) are significantly lower than expected (697.66 hr.), suggesting operational inefficiencies.

The capacity utilization averages 44.21%, which is below 50%, indicating underutilization of resources.

Every month reports downtime issues such as breakdowns and water shortages, which may be causing low-capacity utilization.

- The average capacity utilization ratio is 44.21%, with a range spanning 19.1%.
- The expected steam production averages 8372 tons, with the highest at 8556 tons.
- Actual steam produced shows variation between 2874 and 4509 tons at an average of 3695 tons.

Boiler Operations Data

This dataset provides key operating metrics related to boiler operations, including running hours, water, and steam volumes, planned vs. actual outputs, and capacity utilization. Note trigger factors like downtime and defects impacting operations.

- Divergence from Expectations in Operational Hours

The actual boiler and burner running hours are notably less than the expected boiler working hours. This could be due to the stated "unplanned downtime" reasons, such as breakdowns or water shortages.

- Inconsistent Capacity Utilization

The capacity utilization ratio varies significantly, ranging from 33.6% to 52.7%. This fluctuation might be due to varied operational hours or external factors like environmental conditions, the skill level of the operators, or potential defects.

- Mismatch in Water and Steam Volume

There's a mismatch between the volume of water received and the actual steam produced. Although water supply varies, it doesn't linearly translate into equivalent steam output. This could hint at inefficiencies in the conversion process.

- Concluding Observations

This data reflects notable inconsistencies in operational hours, capacity utilization, and water-steam conversion, potentially due to various issues including breakdowns, resource shortages, or operational shortcomings. Measures targeting these issues may drive operational efficiency.

The capacity utilization of both boilers in the company is under their installed (design) capacity, which is for the BOSCH boiler (44.14%) and for the LOOS boiler (34.86%). These both boilers are working under their capacity due to some factors that cause brake down of equipment's and high down time in the boilers. High down time of equipment leads to under capacity utilization factors that lead to high down time, as stated in the diagram below.

Boiler Downtime Causes and Effects

Covering nine months of data, which includes quantitative and qualitative data types, these data include information on machine uptime, production output, downtime, breakdown, stoppage, idleness, operation cycle speed and cycle times, working hour, break time, stopping and starting times, planned and unplanned downtime, machine uptime and equipment design status, and actual equipment status in the numerical data type, while speed losses. And the data source includes both the primary and secondary data source then we assess the total downtime for two boilers across three different causes: brake down, supply shortage, and factors related to operator skill, environment, and others. The data includes total downtime in hours, cumulative hours, percentage contribution per cause, and cumulative percentage.

- Brake Down as Main Cause

Breakdown, with 4,159 hours of downtime, accounts for the largest share of total downtime, roughly 60.44%. As the most significant cause, it indicates potential maintenance issues or wear and tear, warranting an in-depth investigation into the boiler's conditions.

- Impact of Supply Shortage

While supply shortages resulted in 2,143 hours of downtime, significantly less than breakdowns, they still covered 31.15% of the total downtime. This suggests that logistics and supply chain management could be areas for further improvement.

- Human and Environmental Influences

The least amount of downtime, 579 hours, was attributed to operator skill, environment, and other unknown factors, contributing only 8.41%. This indicates a relatively proficient operator skill set and appropriate working conditions, suggesting these areas are less of a concern.

Table 4.3 common factors for downtime in boilers

Common causes that cause downtime in boilers				
Cause for downtime	Total down time in nine months for two boilers (hr.)	Cumulative	Percentage	Cumulative Percentage
Breakdown	4,159	4,159	60.44%	60.44%
Supply shortage	2,143	6,302	31.15%	91.59%
Operator skill, Environment, and other unknown factors	579	6881	8.41%	100%

Data source: technical and production department

- Highest boiler downtime was due to Breakdown (4159 hrs.)
- Supply shortages account for 31.15% of total boiler downtime.
- The lowest contributor to downtime is operator skill and other factors (8.41%).
- The total down time in nine months for two boilers (hr) for operator skill, environment, and other unknown factors' is significantly lower (579) compared to the overall average (2293.66). It might suggest better management or less problems in these areas.
- The breakdown cause shows a percentage of downtime (60.44%) that is notably higher than others. This high value is an outlier, which indicates significant issues with boiler breakdowns.
- The supply shortage has an unusual cumulative percentage (91.59%), which is closer to 100% compared to its individual percentage (31.15%). This could indicate a miscalculation or the accumulation of multiple issues.

Prioritizing Solutions for Downtime Causes

Overall, breakdowns emerge as a significant factor in boiler downtime, followed by supply shortages and operator and environmental factors. Focusing resources on improved maintenance and supply chain management should see a decrease in overall downtime.

4.2.2 CO2 plant

Carbon dioxide has no taste, no colour, and no odder CO2 has many advantages in the brewery, from putting frothy bubbles in brews to blocking oxidation that makes beer taste stale. CO2 is frequently added after filtration in kegs, bottles, and cans of beer. When a beer is made with CO2 from the fermentation process, as BGI Ethiopia produces beer, it is sometimes referred to as “brewery conditioned.” CO2 will dissolve readily in beer, whereas its solubility will rise as the temperature falls. Carbon dioxide is the primary gas used to dispense draft from the keg.

Carbon dioxide generally used in different production place in brewery industry Co2 used in BGI Ethiopia for:

- Bottling
- Kegging
- Filtration
- Brew house
- Wastewater treatment

In BGI Ethiopia, carbon dioxide is produced from the two compressors, which have a capacity of producing 500 kg/h and have 20- and 30-ton storage tanks. This CO2 is also produced in the fermentation room, which has 40 fermentation tanks. The CO2 is collected and passed through different processes to purify it, which include the separation of foam, hydrogen, and oxygen gas to produce pure CO2. The purified CO2 is then used in fermentation, Brewhouse, kegging, bottling, and wastewater treatment.

The wastewater treatment plant is an essential plant in the factory to utilize and recycle resources and to protect the environment from hazardous factors. Co2 is used in wastewater treatment for PH control and remineralization of the water. The working mechanism of the system is that CO2 is injected into the wastewater to form the carbonic acid that helps to lower the water PH without releasing any harmful substances, and CO2 can also be dosed with desalinated water to pass through a bed of limestone that adds bicarbonate alkalinity and calcium hardness to the water.

The water that has been used in factories is treated rather than drained into the environment. This is for two major reasons: the first is to protect the environment, and the second is to utilize resources effectively and efficiently by recycling this scarce resource. By using reverse osmosis, a water purification process is taken place, which involves using a semi-permeable membrane to separate the water molecules from other unwanted substances to purify them. The reverse osmosis applies pressure to overcome the osmotic pressure, which favors even distribution in the process. The reverse osmosis can dissolve or block chemical species and also suspend biological substances, mainly bacteria. The solute is on the pressurized side of the membrane, and the purified solvent passes on to the other side. In general, reverse osmosis is an agent that decides what passes through and what shouldn't pass through, which is used for the purification of water.

The CO_2 plant data which include the actual CO_2 production with the two compressors, expected CO_2 production with two compressors and the actual consumption of CO_2 in the company from November to July for nine months is collected and summarized in the table below to see the actual output of the plant and the capacity utilization of the compressors.

Compressor Capacity Utilization Overview The dataset reviews the compressor capacity utilization (in %), its applications in several brewery operations, and the actual vs. expected CO_2 production in a beer brewery over 9 months.

- Downward Trend: Low Compressor Capacity Utilization

Capacity utilization is below the average level (49.38%) for 5 out of the 9 months, showing a potential inefficiency.

- Peak Utilization - Highest in June

June recorded the highest compressor capacity utilization at 53.77%, which could be due to increased production demand during the summer season.

- Improving Capacity Utilization - April to June Upswing

There's a rising trend in capacity utilization from April (51.65%) to June (53.77%). This could correspond to a seasonal effect or operational improvements made during this period.

Table 4.4 CO2 compressors capacity utilization and CO2 demand in the company for nine months.

				CO2 consumption						
Month	Capacity (kg/h)	Actual CO2 production with the two compressors (kg)	Expected CO2 production with two compressors (no of days in month*23hr*2*500kg/h)	Bottling	Kegging	Filtration	Wastewater treatment	Brew house	Total cylinder filled	Compressors Capacity utilization %
November	500	352,968 kg	690,000 kg	3,095 kg	98,863kg	91,348kg	28,293 kg	13,142 kg	96,825 kg	51.15%
December	500	381,946kg	713,000 kg	3,682 kg	101,566kg	94,501kg	30,536 kg	15,614 kg	95,892 kg	51.33%
January	500	377,682kg	713,000 kg	3,355 kg	99,843kg	90,792kg	29,605 kg	13,525 kg	82,984 kg	52.16%
February	500	341,986kg	644,000 kg	3,304 kg	100,220kg	87,649kg	33,682kg	15,064 kg	66,369 kg	50.89%
March	500	329,642 kg	713,000 kg	2,411 kg	101,273kg	91,590kg	28,334 kg	9,080kg	71,564 kg	45.91%
April	500	356,553 kg	690,000 kg	1,872kg	83,103kg	70,261kg	21,671kg	9,456kg	99,219 kg	51.65%
May	500	302,657 kg	713,000 kg	1,981kg	86,046kg	76,437kg	23,103 kg	12,087 kg	69,025 kg	42.32%
June	500	371,846 kg	690,000 kg	2,045 kg	88,712kg	71,211kg	22,321kg	11,388	79,032kg	53.77%

								kg		
July	500	322,910 kg	713,000 kg	1,833 kg	79,341kg	69,439kg	19,764kg	15,977 kg	65,437kg	45.28%
Total		**3,138,190**	**6,279,000 kg**	**21,745**	**838,967**	**743,228**	**237,309**	**115,333**	**726,347**	**49.98%**

Source: BGI utility department book log, technical department

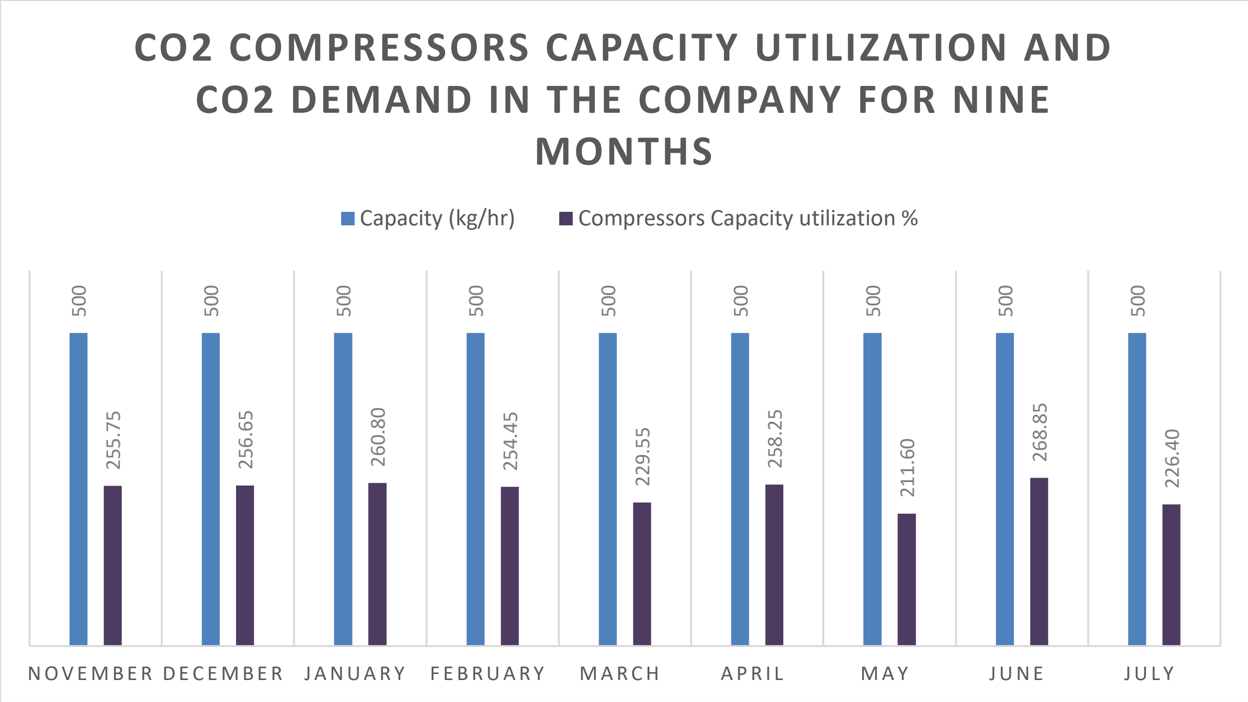

Figure 4.3 CO2 compressors capacity utilization and CO2 demand in the company for nine months.

- The average Compressors Capacity utilization % is approximately 49.38.
- The highest recorded Compressors Capacity utilization % was 53.77.
- The lowest recorded Compressors Capacity utilization % was 42.32.
- The trend is an underutilization of the compressors' capacity in CO2 production, as evidenced by an average capacity utilization of ~49.38%.
- In May, there's a noticeable drop in capacity utilization to a minimum of 42.32%. This could be due to operational issues or lower demand.
- In June, there's an unexpected peak with a maximum capacity utilization of 53.77%. This may be due to a temporary surge in demand.
- A slight decrease in the total number of cylinders filled from January to February could suggest a slow-moving period.

Therefore, this shows that.

- The compressor capacity utilization percentage has a relative low average of 49.38%, which might indicate semi-efficient production processes.
- June has the highest compressor capacity utilization at 53.77%; this suggests potentially more efficient operations during these periods.

- The lowest compressor capacity utilization is in May (42.32%), which could denote production inefficiencies or lesser demand during this time.

Conclusion – Opportunities for Efficiency Improvement

- The consistently low utilization across different months indicates opportunities for process optimization. Recognizing these variances and their root causes can drive efficiency, ultimately increasing operational productivity and reducing costs.

4.2.3 Air Plant

Air compressors are intended to produce compressed air for different purposes in the factory. The main purpose of having compressed pure air is to run the pneumatic machines and for fermentation, packaging, and wastewater treatment.

Use of air in fermentation Compressed air supplies oxygen to bacteria during the fermentation process. This helps convert carbon hydrates to alcohol using microorganisms. It is important during the process to deliver the exact amount of compressed air and maintain the correct oxygen level to determine the quality of the yeast in the fermentation and help deliver a quality product. Use of air in packaging and labeling

Compressed air is used to control the valves and actuators in automated lines for packaging, labeling, and other pneumatic machines. Oil-free air prevents automated components from jamming, thereby lowering maintenance costs; otherwise, the quality of the air will affect the equipment's lifetime and production quality.

Use of air in wastewater treatment Water is used during the brewing process, and after finishing the process, it must be treated before it returns to the water cycle to minimize its impact on the environment. Naturally, the air needed for this treatment must be oil-free, or the water would be contaminated again and affect the environment.

There are four air compressors in BGI Ethiopia to produce compressed air for the above production sections, and those are:

1. Air compressor 1-SM 90
2. Air compressor 2- SM150
3. Air compressor 3-SL150

The nine-month data from November to July for the active three compressors is collected to see the capacity and utilization of their capacity and is summarized in the table below. Overview of Capacity Utilization

This presentation outlines the operating statistics of various types of industrial machines over several months, focusing on two key areas: operating hours and capacity utilization percentage. Models include Ingersoll SM90, Ingersoll SM150, and Ingersoll SL150.

- Variation in Operating Hours

The differences in average running hours across the different machines are noteworthy. The Ingersoll SL150 has the highest average run time (466.33 hours), followed by the Ingersoll SM150 (381.89 hours), and the Ingersoll SM90 falls last (316.44 hours). This could suggest an inherent reliance on the more robust SL150, possibly due to its greater efficiency or production capacity.

- Divergences in Capacity Utilization

Despite the Ingersoll SM90 having the lowest average running hours, it isn't the model with the lowest capacity utilization. Interestingly, the model with the lowest capacity utilization is the Ingersoll SM150 at 54.82%, whereas the model with the highest is the Ingersoll SL150 at 66.70%. This could indicate that the Ingersoll SL150, despite operating longer hours, is more efficient, hence its higher capacity utilization rate.

- Widest Range of Capacity Utilization

The Ingersoll SL150 machine's capacity utilization varies the most, with a range of 32.17%. This could be attributed to seasonal demand changes, maintenance schedule fluctuations, or inconsistencies in shift employment. The capacity utilization of Ingersoll SM150 and SM90, conversely, shows less variability.

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Table 4.5 Air plant compressors capacity utilization for nine months

Month	Expected running hour (no days in month*23 hr.)	Ingersoll SM90 Running hour	Capacity (m3/hr.)	Capacity utilization %	Ingersoll SM150 Running hour	Capacity (m3/hr.)	Capacity utilization %	Ingersoll SL150 Running hour	Capacity (m3/hr.)	Capacity utilization %
November	690	303	816	43.91%	388	1500	56.23%	457	1560	66.23%
December	713	346	816	48.52%	489	1500	68.58%	508	1560	71.24%
January	713	318	816	44.60%	428	1500	60.02%	488	1560	68.44%
February	644	215	816	33.38%	411	1500	63.81%	322	1560	50.00%
March	713	346	816	48.52%	354	1500	49.64%	408	1560	57.22%
April	690	297	816	43.04%	321	1500	46.52%	436	1560	63.19%
May	713	330	816	46.28%	240	1500	33.66%	480	1560	67.32%
June	690	382	816	55.36%	397	1500	57.53%	567	1560	82.17%
July	713	311	816	43.61%	409	1500	57.36%	531	1560	74.47%
Total	**6279**	**2848**		**45.35%**	**3437**		**54.73%**	**4197**		**66.84%**
The overall air plant capacity utilization ratio for the nine months is 55.64%										

Source: BGI utility department book log

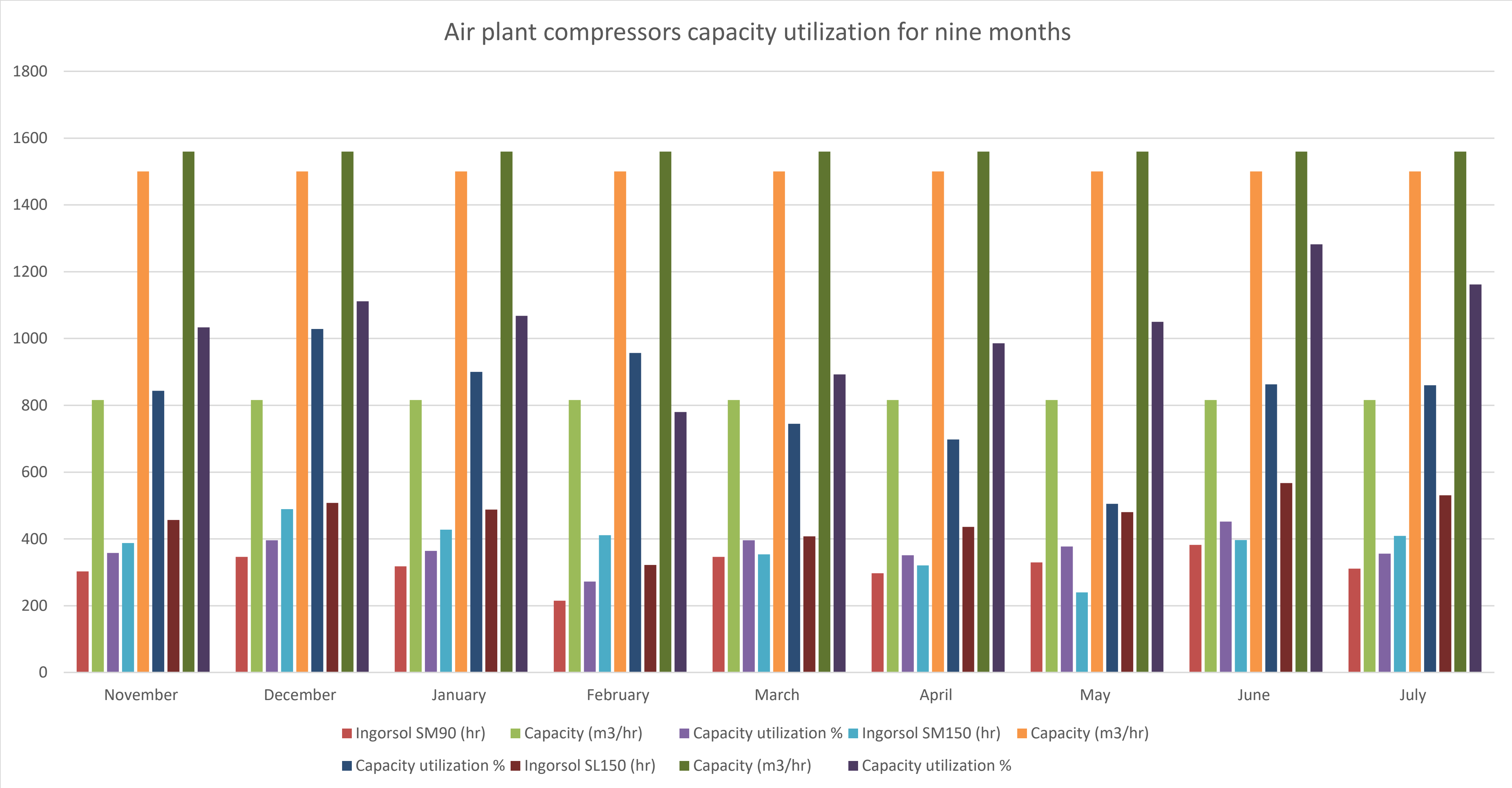

Figure 4.4 Air plant compressors capacity utilization for nine months

- Expected running hour' ranges from 644 to 713 with an average of 697.67.
- Ingersoll SM90' has an average operational hour of 316.44 and a maximum of 382 hours.
- The Capacity utilization %' of Ingersoll SL150' ranges from 50% to 82.17%
- The average running hours are consistently increasing, from Ingersoll SM90 to SM150 and finally to SL150. This suggests the 'SL150' model has the highest usage.
- Notably, the Ingersoll SM150 had a minimum running hour of 240 in May, which is significantly lower than its average of 381.88 hours. This could have been due to maintenance or lower demand.
- In February, the capacity utilization percentage of 'Ingersoll SL150' dropped to 50%, which is significantly below its average of 66.69%. This outlier might be due to a decrease in operational requirements or a machine failure.

Therefore

- The average capacity utilization for the machines is Ingersoll SM90 at 45.25%, Ingersoll SM150 at 54.82%, and Ingersoll SL150 at 66.70%. This implies that the Ingersoll SL150 commonly utilized.
- The capacity utilization of Ingersoll SM150 is least consistent, having the highest standard deviation of 9.76%. This suggests that its usage is less predictable.
- The Ingersoll SL150 machine seems to be the most efficient, with the highest average running hours (466.33 hours) and a higher capacity utilization percentage (66.70%). This could indicate it's most suitable for sustained use.

Conclusion Enhanced Machine Utilization Efficiency

- The data indicates varying efficiencies and usage patterns among the Ingersoll machines. It suggests the need for improved scheduling and maintenance practices, particularly for the SM90 and SM150. With proper allocation, running hours can be maximized, leading to higher capacity utilization and, ultimately, a more efficient operation.

4.2.4 Cooling plant

One of the production sections in the BGI brewery factory is a cooling plant. There are three cooling plants in the factory.

- Glycol cooling plant 1
- Glycol cooling plant 2
- Glycol cooling plant 3

Each of the cooling plants is powered by two compressors. In a glycol cooler system, beer passes through tubes to a chiller plate, where it becomes cold. The chilling process works by forcing a cold liquid (glycol) along tubes to a chiller plate, which is usually cast aluminum, and then through the tap system, thereby keeping the beer cold. The glycol never actually meets the beer; it is a thermodynamically heated exchange between the beer and the glycol.
Glycol is a non-evaporating refrigeration liquid. Its properties allow it to achieve cold temperatures without freezing. In a glycol beer system, the multiple beer lines are combined side by side with glycol lines, which are, in turn, bundled inside an insulating foam rubber tube. By chilling the liquid glycol and pumping it into lines that run alongside the beer lines, the beer is becoming cool and being maintained within one degree of the temperature in the walk-in cooler. And the glycol is cooled using ammonia. After the glycol heat exchange with hot beer, it returns to the return tanker and is cooled with ammonia in a closed cooling system that has compression, condensation, expansion, and evaporation. In these systems, mass drops usually occur at some point because it is a closed system, so correcting the losses by adding the right amount of ammonia to continue the cycle of the cooling system The cooling plant data from November to July for nine months is collected to see the capacity of the plant and the actual output to see the capacity utilization of the compressors.

Compressor Utilization and Ammonia Levels on Colling plant one

This slide provides an overview of the expected and actual running hours for two compressors (A and B), their utilization ratios, and ammonia percentage readouts over the period from November to July.

- Operational Insight

Compressor A has a distinct utilization spike in June, operating at 75.5% capacity - its highest. This may correspond with elevated demand or operational requirements in the summer months.

- Performance Comparison

Compressor B tends to have lower utilization rates compared to Compressor A. For example, in April, compressor A operated at 46.23% while compressor B operated at 58.98%. This could suggest a possible over-reliance on Compressor A or inefficiency in Compressor B's operation.

- Chemical Level Observations

Ammonia percentage readings vary from a minimum of 40% to a maximum of 50%. The variability is minimal (with a range of 10%), suggesting consistent levels of ammonia. This can indicate effective chemical management within the system.

Table 4.6 Cooling plant one compressors capacity utilization ratio.

Cooling plant one							
Month	Capacity (m3/h)	Expected running hour (no days in month*23hour)	Compressor A		Compressor B		Ammonia %
			Running hour	Capacity utilization ratio %	Running hour	Capacity utilization ratio %	
November	147	690	431	62.46%	338	48.98%	50
December	147	713	412	57.78%	347	48.66%	44
January	147	713	456	63.95%	413	57.92%	43
February	147	644	397	61.64%	322	50.00%	46
March	147	713	449	62.97%	388	54.41%	49
April	147	690	319	46.23%	407	58.98%	45
May	147	713	438	61.43%	356	49.92%	42
June	147	690	521	75.50%	453	65.65%	40
July	147	713	473	66.34%	481	67.46%	44
Total		**6279**	**3,896**	**62.05%**	**3,505**	**55.82%**	
Cooling plant two has a capacity utilization rate of 58.94%							

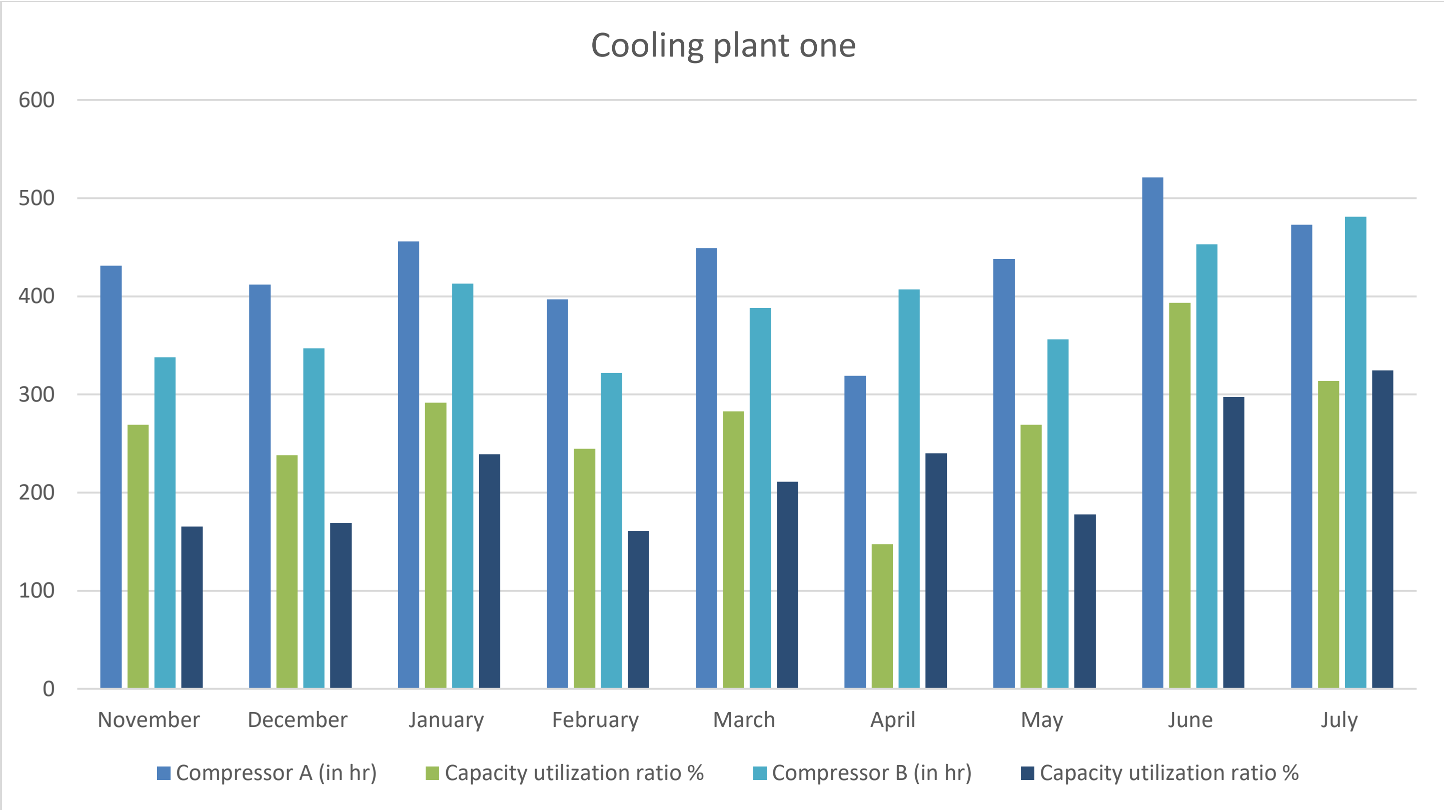

Figure 4.5 Cooling plant one.

- The expected running time ranges from 644 to 713 hours, with an average of 698 hours.
- Compressor A works for an average of 433 hours, with the highest being 521 hours.
- Ammonia% has the least variation, ranging from 40% to 50% with an average of 45%.
- The compressor A (in hr.) has an average of around 433 hours, but in April it fell significantly to 319 hours. This could mean there was a technical issue or maintenance.
- There's a notable increase in the "capacity utilization ratio" for compressor A in June at 75.5%, which greatly surpasses the average of 62%. This may be due to increased demand or optimized operations.
- The capacity utilization ratio % for compressor B is consistently less than compressor A. In December, it hit the lowest at 48.66%, indicating it's underperforming compared to Compressor A.

The expected running hour' has the smallest range of 69, indicating relatively stable operating hours across months. Compressor A and Compressor B' show significant use variation with ranges of 202 and 159 hours, respectively, hinting at alternating usage. While both compressors show similar average utilization ratios, 'Compressor A' has a higher maximum utilization ratio at 75.5%.

Efficiency and Monitoring

Overall, both compressors show reasonable utilization, with compressor A generally used more heavily. Ammonia levels remain consistently within an acceptable range. Moving forward, strategies can be investigated to balance usage between compressors while maintaining optimized chemical levels.

Compressor Utilization and Ammonia Levels on Colling plant two

Today's dataset includes the following key figures: expected running hours monthly average of 697.67 hrs., compressor A's monthly usage averages 419.33 hrs. with a 60.16% utilization rate, and compressor B averages 409.11 hrs. with a 58.78% utilization rate. The average ammonia level is 44.77%.

- Expectation vs Reality in Compressors Operation

We see both compressors A and B running significantly less than the expected running hours. This indicates efficient machine usage or a potential overestimation in initial scheduling.

- Comparative Performance of Compressors

Compressor A seems to show more consistent utilization, with a smaller standard deviation of 43.80 hrs. compared to Compressor B's 84.47 hrs. It suggests greater predictability in Compressor A's usage.

- Correlation between Compressor Use and Ammonia Level

There is no obvious relationship between a compressor’s operation time and ammonia levels, with an average 44.77% ammonia content present. Further investigation might be needed to explore this aspect.

Table 4.7 Cooling plant two compressors capacity utilization.

Cooling plant Two							
Month	Capacity (m3/h)	Expected running hour (no days in month*23hour)	Compressor A		Compressor B		Ammonia %
			Running hour	Capacity utilization ratio %	Running hour	Capacity utilization ratio %	
November	147	690	442	64.05%	447	64.78%	50
December	147	713	388	54.41%	511	71.66%	44

January	147	713	395	55.40%	437	61.29%	43
February	147	644	422	65.52%	455	70.65%	46
March	147	713	503	70.54%	301	42.21%	49
April	147	690	343	49.71%	289	41.88%	45
May	147	713	409	57.36%	305	42.77%	42
June	147	690	465	67.39%	521	75.50%	40
July	147	713	407	57.08%	416	58.34%	44
Total		**6279**	**3,774**	**60.10%**	**3,682**	**58.63%**	
Cooling plant two has a capacity utilization rate of 59.36%							

Source: BGI utility department book log, technical department

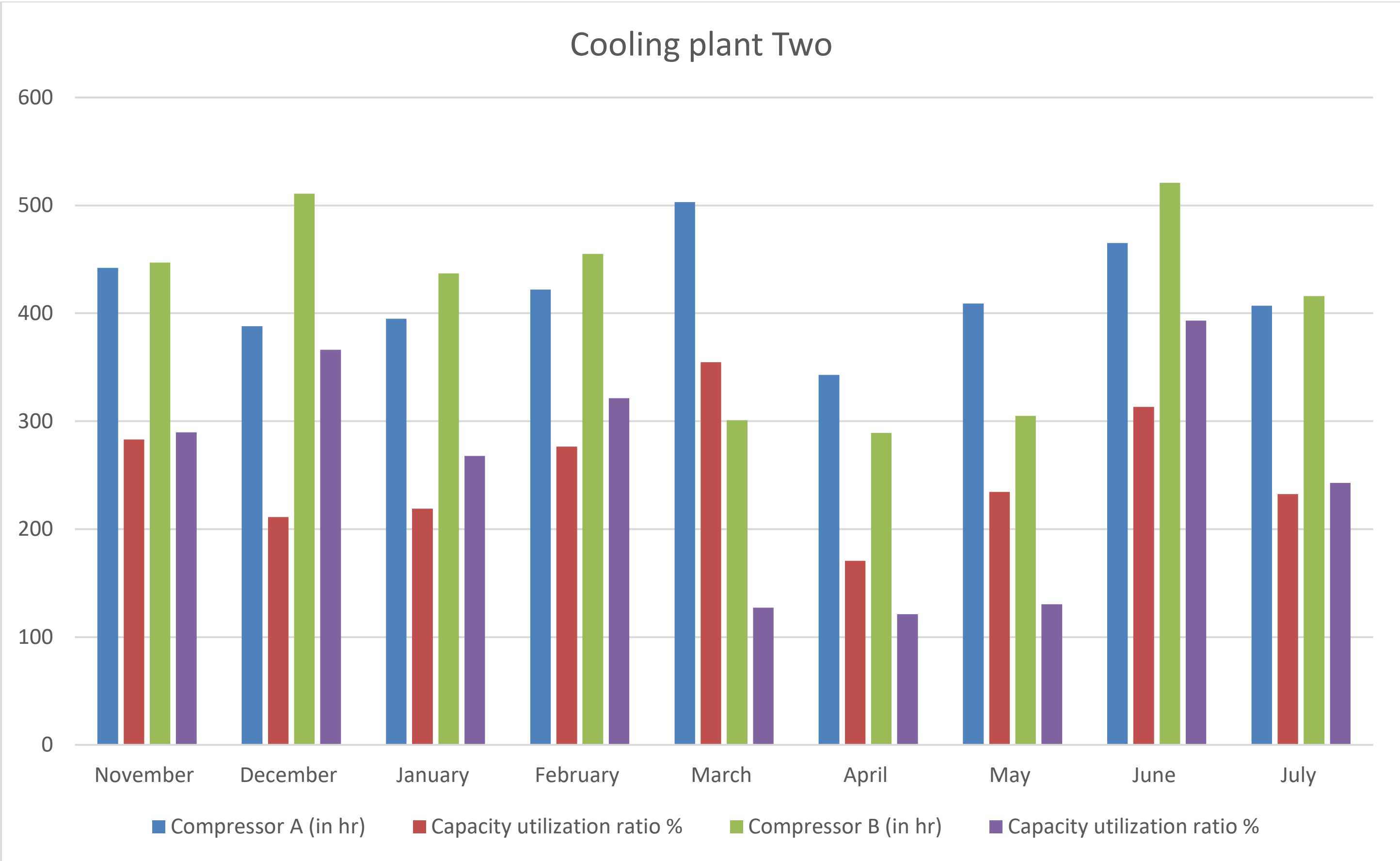

Figure 4.6 Colling plant two

- The expected running hour ranges from 644 to 713 hours, with an average of 697.67 hours.
- Compressor A has a higher use average (419.33 hrs) than Compressor B (409.11 hrs).
- Ammonia% maintained a narrow range of 40–50%, with an average of 44.78%.
- The average running hours for compressors A and B are 419.3 and 409.1 hours, respectively, showing a general trend of similar utilization between the two.
- An anomaly in March shows Compressor A with an unusually high hour count of 503, corresponding to a high utilization ratio of 70.54%, while Compressor B shows a significantly lower than average hour count and utilization ratio (301 hours, 42.21%).
- Another outlier is found in April, where both compressors A and B have unusually low running hours (343 and 289 hours, respectively) and capacity utilization percentages (49.71% and 41.88%, respectively), possibly due to system maintenance or reduced demand.
- In June, the ammonia percentage drops to its lowest point (40%), while the running hours of compressor B (521), and its capacity utilization ratio (75.5%) reach their maximum, suggesting a possible negative correlation between these measurements.

Compressor B has the highest operation hour variability. With a range of 232 hours, usage can vary greatly from month to month. Despite differences in running hours, both compressors show similar average capacity utilization: Compressor A averages 60.16%, while Compressor B averages 58.78%. The lowest ammonia% and highest capacity utilization ratio% for Compressor B occurred in the same month. This may suggest a relationship between these two factors.

Both compressors are utilized far less than the expected running hours, with Compressor A more consistently so. Meanwhile, ammonia levels remain steady, regardless of compressor use. This invites further study to optimize machine scheduling and maintenance operations.

Compressor Utilization and Ammonia Level Analysis for cooling plant three

In this presentation, examine and break down the performance of two compressors (A and B) and the changes in ammonia levels over the span of months from November to July. Highlight interesting insights we can draw from the data.

- Difference in Average Utilization, Expected Running Hours Averages reveal that Compressor A (Avg: 290.56 hrs.) is generally utilized more than Compressor B (Avg: 118.44 hrs.). This could be due to Compressor A being more efficient, or perhaps it's simply used more frequently.

- Highest Utilization in February for Compressor A, In February, Compressor A recorded a 51.39% utilization ratio, which is the maximum in the report. This might have been driven by increased production needs during that month.
- Ammonia Increase According to Compressor A, the highest recorded ammonia percentage is in May, which closely follows the times when Compressor A has high utilization percentages, like in April. This correlation could suggest that more use of compressor A leads to higher ammonia levels.

Table 4.8 Cooling plant three compressors capacity utilization.

Cooling plant Three							
Month	Capacity (m3/h)	Expected running hour (no days in month*23hour)	Compressor A		Compressor B		Ammonia %
			Running hour	Capacity utilization ratio %	Running hour	Capacity utilization ratio %	
November	147	690	281	40.72%	75	10.86%	23
December	147	713	223	31.27%	122	17.11%	30
January	147	713	306	42.91%	117	16.41%	26
February	147	644	331	51.39%	98	15.21%	31
March	147	713	226	31.69%	87	12.20%	27
April	147	690	344	49.85%	118	17.10%	38
May	147	713	237	33.24%	147	20.61%	40
June	147	690	308	44.63%	194	28.11%	38
July	147	713	359	50.35%	108	15.14%	39
Total		**6,279**	**2,615**	**41.64%**	**1,066**	**16.98%**	
Cooling plant three has a capacity utilization rate of 29.31%							

Source: BGI utility department book log, technical department

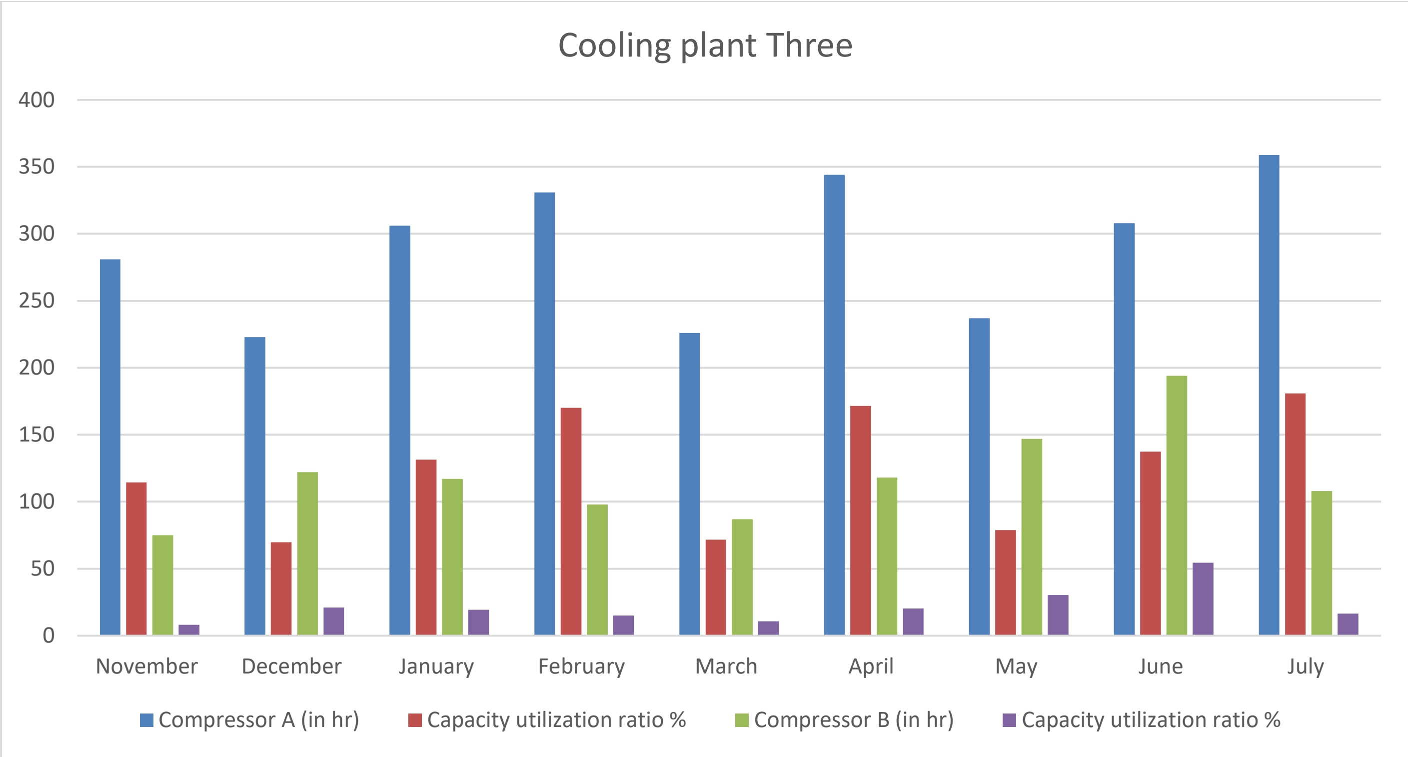

Figure 4.7 Cooling plant three.

- Expected running hours vary from 644 to 713 hours, averaging around 698 hours.
- The use of Compressor A largely varies, ranging between 223 and 359 hours.
- Ammonia concentration averages about 32%, with a minimum of 23% and a maximum of 40%.
- The data generally indicates a greater utilization of Compressor A than B, with a higher average hour range and % capacity utilization.
- Notable outlier: 'December' has conspicuously low usage hours for both compressors. This could be due to holiday plant shutdowns.
- Another outlier: 'June' shows a significant jump in compressor B usage hours. This may be prompted by increased cooling demands during the summer months.

The average running hours for Compressor A (290.6 hrs.) are more than double that of Compressor B (118.4 hrs.). This suggests compressor A is utilized more. Ammonia% varies between a minimum of 23% and a maximum of 40%, with an average value of 32.4%. This range indicates fluctuations in ammonia concentration. The capacity utilization ratio for compressor A (41.8%) is significantly higher than for compressor B (17.0%). This illustrates that compressor A is potentially more efficient.

Our analysis suggests a disparity in utilization between compressors A and B, with A being used more heavily. Interestingly, a potential correlation was observed between the utilization of compressor A and ammonia percentage, hinting at their possible relationship. Further investigations may be needed to substantiate these findings.

4.2.5 Water demand and consumption

Table 4.9 The nine-month data of water supply for different production departments

Month	Main line (m3)	Filtration (m3)	Bottling (m3)	Washer (m3)	Kegging (m3)	Brew house (m3)
November	21,898	6110	6684	1102	4311	2713
December	23,914	7211	7072	1301	4972	2906
January	18,977	6008	5212	896	3117	1942
February	18,814	6229	5112	688	3228	3121
March	16,726	5914	4648	509	3108	2411
April	16,858	6108	4421	611	3416	2107
May	17,422	5847	4213	712	4083	2042
June	18,911	6213	5043	723	4281	2044
July	17,983	6022	5149	694	3928	1987
Total	**171,503 m3**	**55,662 m3**	**47,554 m3**	**7,236 m3**	**34,444 m3**	**21,273 m3**

Source: BGI production and utility department

Table 4.10 Water consumption

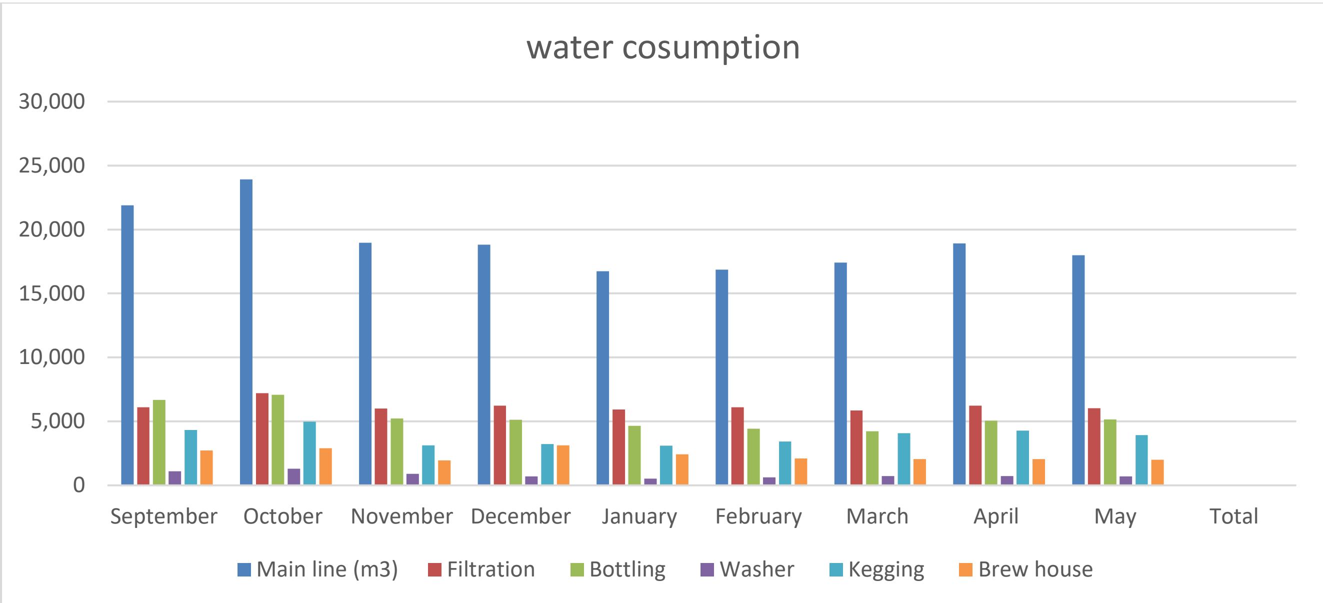

Figure 4.8 Water consumption

Table 4.110 Water consumption and production line

04/04/23		Beginning counter	Ending counter	Hector liter produce	Line efficiency
8:00	8:30	322262	333810	38.11	39%
8:30	9:30	333810	349883	51.10	52%
9:30	10:30	349283	360055	37.20	38%
10:30	11:30	B.W OUT FEED			
11:30	12:30	360556	366413	19.1	20%
12:30	13:30	366413	381887	50.97	75%
13:30	14:30	381857	391850	52.78	71%
MORNING SHIFT YIELD					
14:30	15:30	397850	413745	52.46	79%
15:30	16:30	413745	431954	60.09	61%
16:30	17:30	431934	450625	61.62	63%
17:30	18:30	450625	460441	32.40	54%
18:30	19:30	CIP caustic+HD+H2O			
19:30	20:30				
20:30	21:30				
AFTERNOON SHIFT YIELD					
21:30	22:30	163422	173129	32.04	34%
22:30	23:30	173129	187096	46.10	48%
23:30	0:30	187096	205298	60.07	67%
0:30	1:30	203798	221992	55.09	57%
1:30	2:30	221992	240301	60.42	62%
2:30	3:30	240301	259791	64.38	66%
3:30	4:30	259791	278238	61.04	63%
4:30	5:30	278233	295262	56.1	58%
5:30	6:30	295245	310458	55.15	35%
6:30	7:30	310487	322262	38.96	40%
NIGHT SHIFT YIELD				858.75	54.1

Source: BGI production department

Table 4.11 Water consumption and production line

07/04/23		Beginning counter	Ending counter	Hector liter produce	Line efficiency
8:00	8:30	170765	186008	50.22	48.8%
8:30	9:30	186008	197255	36.05	33.4%
9:30	10:30	197255	211166	44.83	40.1%
10:30	11:30	211166	224411	42.63	45.7%
11:30	12:30	224411	237656	42.7	47.8%
12:30	13:30	237656	250998	43	51%
13:30	14:30	250901	270636	62.04	65%
MORNING SHIFT YIELD					
14:30	15:30	270636	289765	50.8	63%
15:30	16:30	289765	302543	43.9	51%
16:30	17:30	302543	318754	60.3	65%
17:30	18:30				
18:30	19:30	318765	336534	42.7	45%
19:30	20:30	336534	354312	50.6	55.6%
20:30	21:30	354312	367521	46.1	45.7%
AFTERNOON		367521	368976	57.3	61.4%
21:30	22:30	CIP caustic+HD+H2O			
22:30	23:30				
23:30	0:30				
0:30	1:30	377543	389784	50.7	57%
1:30	2:30	389784	401436	52.3	62%
2:30	3:30	401436	420534	57.9	66%
3:30	4:30	420534	431754	41.3	63%
4:30	5:30	456324	456324	54.2	58%
5:30	6:30	456324	472155	46.9	35%
6:30	7:30	472155	491018	47.3	40%
NIGHT SHIFT YIELD				1023.07	64.45%

Source: BGI production department

In BGI Ethiopia, it requires 4.5 to 5 liters of water to produce one bottle of product (alcoholic or non-alcoholic). One bottle of BGI Ethiopia is 330 ml in this case to produce 858.75 hectoliters, which is equivalent to 85,875 liters or 85,875,000 ml.

$$330\ ml = 4.5L\ of\ water\ is\ needed$$

$$85{,}875{,}000\ ml$$

$$386{,}437{,}500/330\ ml$$
$$= 1{,}171{,}022.7\ liters\ of\ water\ is\ needed\ which\ is\ 1{,}171 m3\ is\ required\ for\ table\ 4.10$$

And following the same calculation to determine the amount of water required for producing 1023.07 hectoliters, which is 64.5% of the installed capacity, 1,395,095.45 liters of water are required, which is equivalent to 1395 m3.

The factory needs 1838 to 2162 m3 of water to work with the optimal installed capacity, which is 85–100%, and this shows a limited supply shortage of water resources with brake down, skill of labor, environment, and other unknown factors that are stakeholders in the unutilized capacity in the factory.

The unavailability of the auxiliary machines is due to the time needed for corrective maintenance and other stoppage factors for the auxiliary machines that cause the equipment's unavailability to perform the intended task, affecting the production line.

- Performance of machines Even if the equipment's are available, unless they perform their tasks fully with the installed capacity, the quality and quantity of the production line are affected, and the reason for this is inadequate or a lack of proper maintenance most of the time due to the lack of predictive maintenance, the age of the equipment's, and disturbance of the power supply.
- Utility supply shortage is one major factor in using the installed capacity, mainly the shortage of these resources, to produce its product with the capacity and efficiency that factories have.
- Idle time of machines is one key factor in the industry's capacity utilization that arises from shortages of raw materials and utilities, change in overtime time, breakdowns, and a lack of skilled manpower.

4.3 Data analysis & discussion

In the BGI Ethiopia brewery industry, issues such as raw material and spare shortages and delays, inadequate operator skill that creates error or misalignment, or blancher adjustment and maintenance are not easily detectable via machine metrics and, consequently, are not fully accounted for in capacity utilization calculations. Thus, more investigation is needed to identify and measure these less obvious sources of downtime and develop more effective strategies to mitigate them. Additionally, there is a need for more hard and standardized methods to measure and compare the capacity utilization of auxiliary machines and data across different manufacturing processes to facilitate benchmarking and best practice sharing, like using new cutting-edge technologies. That is, following manufacturing processes, data is often collected manually, automatically, and retrospectively, which leads to delays in identifying issues that affect capacity utilization, and this is the major reason for capacity losses in the company.

By contrast, cutting-edge technologies such as advanced analytics, microtechnology, and tip trace machines allow for real-time data collection and analysis, which help operators quickly identify and address issues that affect capacity utilization of these auxiliary machines. Large but unrecognized data gaps in manufacturing operations are primarily due to raw material shortages, mainly water supply, maintenance, breakdown, and spare parts shortages, and a lack of employee motivation and skill, all of which are accountable for not using the installed capacity or the lack of using these auxiliary machines effectively and efficiently in the organization.

$$Down\ time\ \%\ losses\ \ for\ each\ AM = \frac{down\ time\ of\ each\ auxilary\ machinery}{planned\ working\ time\ for\ the\ nine\ months} \ldots.\ \text{(equ 4.1)}$$

Where:

$$Planned\ working\ time\ is\ 23hr\ a\ day * \ number\ of\ days\ for\ nine\ month\ (November\ to\ July)\ which\ is\ 273\ days = \ 6279\ hours.$$

Down time for boilers:

$$Down\ time\ \%\ for\ boiler\ 1 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ for\ boiler\ one = \ 3445hr/6279hr = 54.38\%$$

$$Down\ time\ \%\ for\ boiler\ 2 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ for\ boiler\ two = 3466hr/6279hr = 55.2\%$$

Down time for CO2 plant compressors:

$$Down\ time\ \%\ for\ CO2\ comp\ 1\&2 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ CO2\ comp\ 1\&2 = 6090hr/12558hr = 48.5\%$$

Down time for air plant compressors:

$$Down\ time\ \%\ forair\ comp\ 1 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ air\ comp\ 1 = 3431hr/6279hr = 54.64\%$$

$$Down\ time\ \%\ forair\ comp\ 2 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ air\ comp\ 2 = 2842hr/6279hr = 45.26\%$$

$$Down\ time\ \%\ forair\ comp\ 3 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ air\ comp\ 3 = 2082hr/6279hr = 33.15\%$$

Down time for cooling plant compressors:

$$Down\ time\ \%\ for\ cooling\ plant\ one\ comp\ 1 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ cooling\ plant\ one\ comp\ 1 = 2383hr/6279hr = 37.95\%$$

$$Down\ time\ \%\ for\ cooling\ plant\ one\ comp\ 2 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ cooling\ plant\ one\ comp\ 2 = 2774hr/6279hr = 44.18\%$$

$$Down\ time\ \%\ for\ cooling\ plant\ two\ comp\ 1 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ cooling\ plant\ two\ comp\ 1 = \ 2505hr/6279hr = 39.9\%$$

$$Down\ time\ \%\ for\ cooling\ plant\ one\ comp\ 1 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ cooling\ plant\ two\ comp\ 2 = \ 2579hr/6279hr = 41.07\%$$

$$Down\ time\ \%\ for\ cooling\ plant\ three\ comp\ 1 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ cooling\ plant\ three\ comp\ 1 = \ 3664hr/6279hr = 58.35\%$$

$$Down\ time\ \%\ for\ cooling\ plant\ three\ comp\ 2 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ cooling\ plant\ three\ comp\ 2 = \ 5213hr/6279hr = 83.03\%$$

The data highlights several critical areas of machine operations that could benefit from maintenance strategies or better operator training. Addressing these concerns may significantly enhance operational efficiency, reduce downtime, and potentially yield more reliable machine performance over time.

Table 4.12 Down time summary for auxiliary machineries in nine months by known and unknown factors

Auxiliary machine losses		Reason for stoppage	Expected working hour for nine months (hr.)	Actual working time (hr.)	Downtime (hr.)	Downtime percentage
Boilers	BOSCH Boiler	Breakdown, supply shortage, other unknown factors	6,279 hr.	2,864	3,415	54.38%
	LOOS Boiler	Breakdown, supply shortage, other unknown factors	6,279 hr.	2,813	3,466	55.2%
CO_2 compressors	Comp 1 & 2	Breakdown, Operator skill, other unknown factors	12,558 hr.	6,468	6,090	48.5%
Air plant	Compressor 1	Brake down, Operator skill,	6,279 hr.	2,848	3,431	54.64%

		other unknown factors				
	Compressor 2	Brake down, Operator skill, other unknown factors	6,279 hr.	3,437	2,842	45.26%
	Compressor 3	Brake down, Operator skill, other unknown factors	6,279 hr.	4,197	2,082	33.15%
Cooling plant one	Compressor 1	Breakdown, Operator skill, other unknown factors	6,279 hr.	3,896	2,383	37.95%
	Compressor 2	Breakdown, Operator skill, Environment, other unknown factors	6,279 hr.	3,505	2,774	44.18%
Cooling plant two	Compressor 1	Brake down, Operator skill, mass drop, other unknown factors	6,279 hr.	3,774	2,505	39.9%
	Compressor 2	Breakdown, Operator skill, Environment, other unknown factors	6,279 hr.	3,700	2,579	41.07%
Cooling plant three	Compressor 1	Breakdown, Operator skill, Environment, other unknown factors	6,279 hr.	2,615	3,664	58.35%
	Compressor 2	Breakdown, Operator skill, mass drop	6,279 hr.	1,066	5,213	83.03%

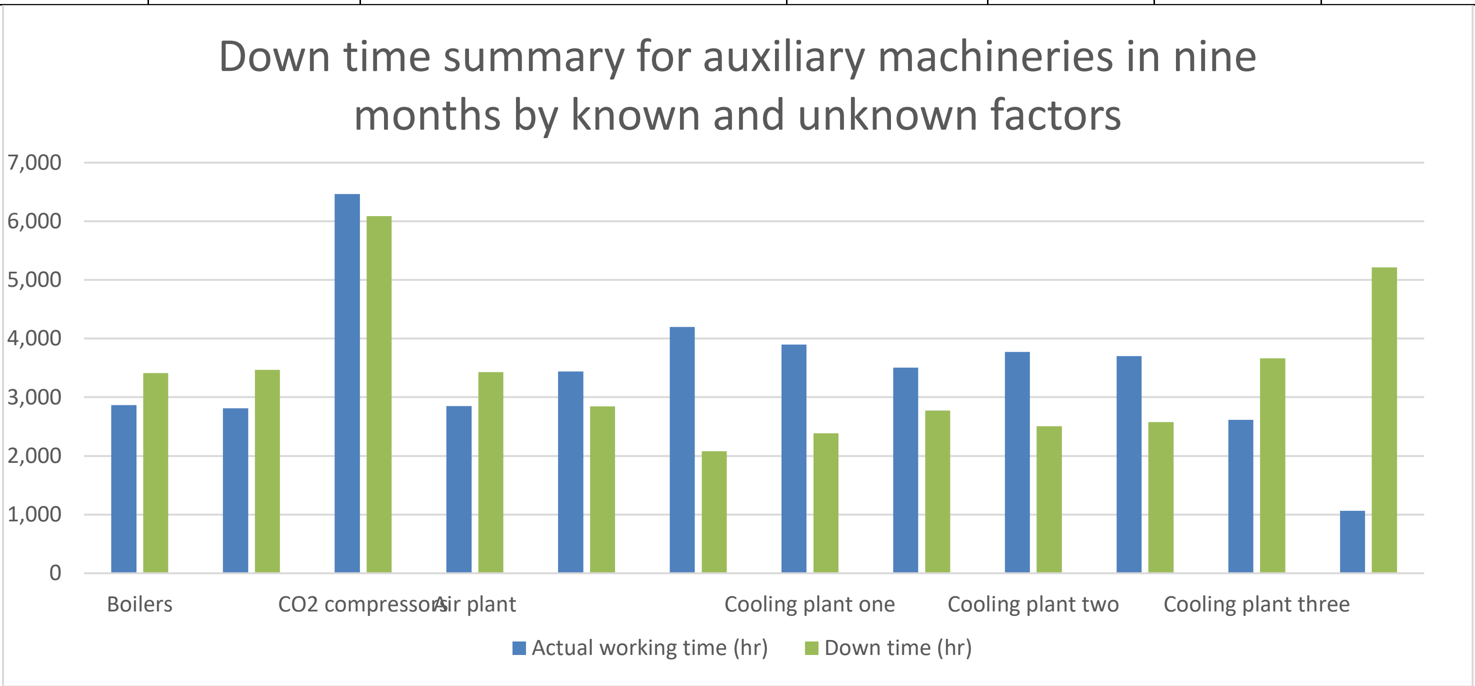

Figure 4.9 Down time summaries for auxiliary machineries in nine months by known and unknown factors

The data analysis provides a detailed overview of machine downtime metrics in a factory. It includes information related to the actual working times, down times, and downtime percentages for various machinery items over a nine-month period.

- Downtime Variances

Downtime percentages display a broad variance, ranging from 33.15% to a staggering high of 83.03%. The cooling plant three's Compressor 2 notably suffers the most with 83.03% downtime, possibly due to frequent breakdowns and issues such as mass drops.

- Highest and Lowest Actual Working Times

The CO_2 compressors 1 and 2 demonstrate the highest actual working time with 6468 hours, although they also have a high downtime of 6090 hours. The least performing machine was again in Cooling Plant Three: Compressor 2, with only 1066 working hours, perhaps due to persistent breakdowns and performance difficulties.

- Downtime as a Factor of Performance

Most machines have downtime percentages above average (49.63%). Notably, all boilers and compressors in the cooling plant have downtime percentages higher than 50%. It seems as if operator skill is repeatedly stated as a cause, suggesting that improvements in training may directly enhance machine uptime.

4.3 Analysis trends and findings of the organization on auxiliary machineries capacity utilization

By gathering data and analyzing the data to find out the factors and reasons that cause losses like manufacturing performance, scrap rates, and downtime in machines, a manufacturing company can control those factors that affect capacity utilization in the organization and increase the performance and availability of equipment to use effectively and efficiently in the process. By using databases or Google Sheets to manually track the capacity utilization and display the data in different formats, like tables, graphs, and charts, these can help identify trends in the data and evaluate the consequences of changes in the system.

By recording capacity utilization data and analyzing patterns over time, industries can easily identify areas for improvement, make data-driven decisions to maximize their equipment performance and availability, and reduce losses. Combining data analysis tools and process optimization approaches will help a manufacturing organization identify the underlying reasons for the capacity losses and monitor trends over time.

From the various techniques and approaches, one is to use capacity utilization metrics, which have a high impact on auxiliary equipment. These can offer real-time insights on equipment performance and losses while automating data collection and processing technology like tip track equipment’s. By identifying patterns and trends in the data, we can make intelligent decisions about how to reduce losses and increase the utilization of capacity. Determine the main reasons for downtime equipment using Pareto charts, and then apply root cause analysis approaches to identify root causes that create the unutilized capacity and come up with the best solutions. Another approach or technique involves identifying and removing waste throughout the manufacturing process using the concepts of lean manufacturing. By decreasing downtime, lowering scrap rates, and increasing manufacturing capacity, this helps to have a high utilization capacity in the manufacturing industries by finding areas for improvement and making changes in production.

Root cause analysis (RCA) is a widely and frequently applied technique that aids in determining the initial cause of a problem that leads to any loss. It identifies and locates the core of a problem by using a certain set of procedures and related tools. This can help in the determination of what has occurred, why it occurred, and what to do to avoid the cause or factor. In the root cause analysis, the events are interrelated with the whole system, which means the cause and the effect are interrelated with each other to determine the factors that influence the system easily.

In order for BGI Ethiopia Brewery Company to maximize the capacity of the auxiliary machines, the factors that have been affecting the machines should be determined from their root causes. In that way, an adequate solution can be given for the problems and the capacity utilization can be improved.

Recurring Issues in Boiler Maintenance

The dataset which stated below in the table, provided records issues experienced with different boiler equipment over several weeks. The key pieces of data are the week of occurrence, the specific boiler and its equipment affected, the symptoms presented, and the final diagnosis of the problem.

- Leakage is a Dominant Issue

There's an apparent trend in the dataset, with leakage being a recurring symptom across different weeks for both boiler #1 and boiler #2. The causes varied from pipe problems to issues with gaskets and valves and loose components.

- Boiler #1 More Problem-Prone than Boiler #2

Comparing the data, Boiler #1 seems to experience more problems than Boiler #2. Various issues like leakage, not starting, bad noise, and vibration were reported for boiler #1, with multiple instances of each symptom. This could point to larger reliability issues.

- Lone Power Supply Issue with Boiler Cabinet

The dataset shows a variety of issues diagnosed; however, there was one lone instance of the symptom No Supply tied to the boiler cabinet, potentially an outlier. This may indicate that power supply issues are rare or that they have been underdiagnosed.

Table 4.13 Root cause factors in boiler plant for failure and diagnosis type

Boiler plant equipment failure and diagnosis			
Failure frequency	BTS (Equipment)	Symptom	Diagnosis
13	Boiler #2	Leakage	Pipe problem
9	Boiler #1	Leakage	Pipe problem
3	Boiler #1	Doesn’t start	Sensor problem
18	Boiler #2	Wrong reading	Wire connection problem
14	Boiler cabinet	No supply	Power supply problem
6	Boiler #1	Bad noise	Loos component
4	Boiler #1	Leakage	Gasket problem
9	Boiler #1	Leakage	Gasket problem
21	Boiler #1	Leakage	Loos component
18	Boiler #1	Leakage	Pipe problem
7	Boiler #2	Leakage	Gasket problem
16	Boiler #2	Leakage	Valve problem
12	Boiler #1	Vibration	Loos component
19	Boiler #1	Vibration	Dirt accumulation
9	Boiler #1	Doesn’t start	Ignition element problem
4	Boiler #2	Doesn’t start	Hose problem
13	Boiler #1	Leakage	Gasket problem

The failure frequency is collected and determined from the company technical department data recording manual.

- There is an ongoing trend of persistent issues, particularly related to 'Leakage' and 'Doesn't Start' in Boiler #1 and #2.
- Week 4 encounters different problems with Boiler #2 and Boiler #1 simultaneously. This could be due to maintenance neglect or operational overload.
- Boiler #1 shows symptoms of 'leakage' due to different reasons such as 'pipe problem', 'gasket problem', and 'loss component'. This mismatch in the cause could imply inconsistency in boiler installation or maintenance.
- Week 36 exhibits issues in Boiler #1 and Boiler #2, suggesting potential system-wide issues affecting both boilers and positing a problem that could be related to shared resources or processes.
- Boiler #1 has the most issues, with leakage being the most frequent symptom.
- Pipe problem is the most common diagnosis for leakage in both boilers.
- Boiler cabinet had an issue once, pointing to a Power supply problem.

Boiler #1 seems to have more issues compared to Boiler #2. This might indicate more wear and tear or a lack of maintenance. From the dataset analysis, it's noticeable that leakage problems in both boilers are recurring almost every few weeks. This suggests a systemic issue. Most issues with boiler #1 are related to leakage, mainly due to pipe and gasket problems. A component malfunction may require an equipment overhaul. In general, the boiler maintenance data The dataset shows dominant symptoms, comparative equipment reliability, and outliers that all inform preventative and remedial actions. Further analysis should consider the frequency of problem occurrences to prioritize maintenance and replacements for greater system reliability. Based on the provided information, we can create a fishbone diagram for the frequent symptoms and diagnosis of boilers. The symptoms include leakage, vibration, wrong reading, doesn't start, and no supply. The diagnosis includes a pipe problem, a valve problem, a gasket and seal problem, loose components, a hose problem, a sensor and wire connection problem, dirt accumulation, and a power supply problem.

Fishbone Diagram for Boilers Frequent Symptoms and Diagnosis:

The fishbone diagram above illustrates the main categories or branches of potential causes for each symptom and diagnosis. The main branches are labeled as follows:

Boilers frequent symptoms

- Leakage
- Vibration
- Wrong reading
- Doesn't start.
- No supply

Boilers frequent diagnosis

- Pipe problem
- Valve problem
- Gasket and seal problem
- Loose components
- Hose problem
- Sensor and wire connection problem
- Dirt accumulation
- Power supply problem

From the data that has been collected which have failure type, frequency, symptom and diagnosis each main branch can be further expanded to identify specific causes or factors that contribute to the symptoms or diagnosis. This diagram can serve as a visual aid to help identify potential areas of concern and guide troubleshooting efforts for boilers. It's important to note that this fishbone diagram is based on the provided information or data and may not cover all possible causes or factors due to some other unknown factors which has not been covered due to the absence of data. It's always recommended to consult with experts or refer to specific boiler manuals and guidelines for a comprehensive understanding of symptoms and diagnosis and also to validate the data.

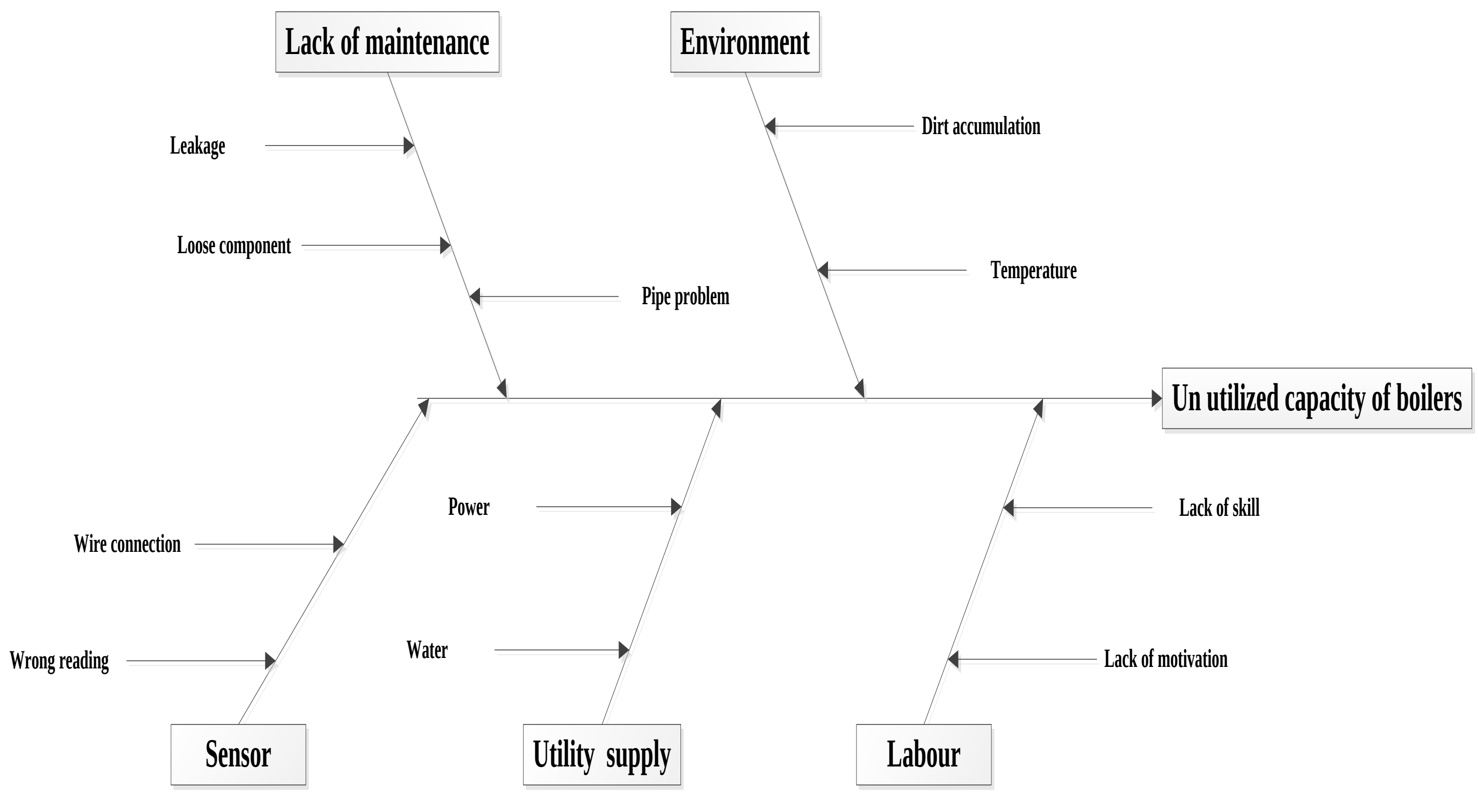

Figure 4.14 The fish bone diagram for boilers capacity loss

Table 4.14 Root cause factors in CO2 plant for failure and diagnosis type

CO2 plant equipment failure and diagnosis type			
Failure frequency	BTS (equipment)	Symptom	Diagnosis
8	CO2 comp #2	Leakage	Valve problem
11	CO2 buffer tank #2	Leakage	Gasket problem
23	CO2 distribution gas	Wrong reading	Sensor problem
17	CO2 buffer tank #1`	Insufficient cleaning	Dirt accumulation
9	CO2 distribution liquid	High flow	Sensor problem
18	CO2 filtration #1`	Low flow	Valve problem
27	CO2 comp #1	High temperature	Filter element problem
12	CO2 comp #1	Leakage	Dirt accumulation
4	CO2 distribution gas	Low pressure	Pipe problem
10	CO2 comp #2	Leakage	Vent problem
8	CO2 buffer tank #1`	Leakage	Dirt accumulation
16	CO2 comp #2	Low flow	Loose element

3	CO_2 comp #1	Leakage	Cylinder problem
22	CO_2 filtration #1`	Leakage	Seal problem
13	CO_2 comp #1	Leakage	Pipe problem
7	CO_2 comp #2	Insufficient cooling	Filter element problem

(Source BGI Ethiopia utility department)

Based on the provided information, we can create a fishbone diagram for the symptoms and diagnosis of BTS (Base Transceiver Station) equipment. The symptoms include leakage, wrong reading, insufficient cleaning, high flow, low flow, high temperature, and low pressure. The diagnosis includes valve problem, gasket problem, sensor problem, dirt accumulation, filter element problem, pipe problem, vent problem, loose element, cylinder problem, and seal problem.

The fishbone diagram above illustrates the main categories or branches of potential causes for each symptom and diagnosis. The main branches are labeled as follows:

CO_2 plant frequent symptoms

- Leakage
- Wrong reading
- Insufficient or inadequate cleaning
- High flow and low flow
- High temperature
- Low pressure
- Insufficient amount of cooling

CO_2 plant frequent diagnosis

- Valve problem
- Pipe and seal problem
- Cylinder problem
- Dirt accumulation
- Filter element problem
- Gasket problem
- Sensor problem
- Loose element and vent problem

Each main branch can be further expanded to identify specific causes or factors that contribute to the symptoms or diagnosis. This diagram can serve as a visual aid to help identify potential areas of concern and guide troubleshooting efforts for BTS equipment. It's important to note that this fishbone diagram is based on the provided information and may not cover all possible causes or factors. It's always recommended to consult with experts or refer to specific equipment manuals and guidelines for a comprehensive understanding of symptoms and diagnosis.

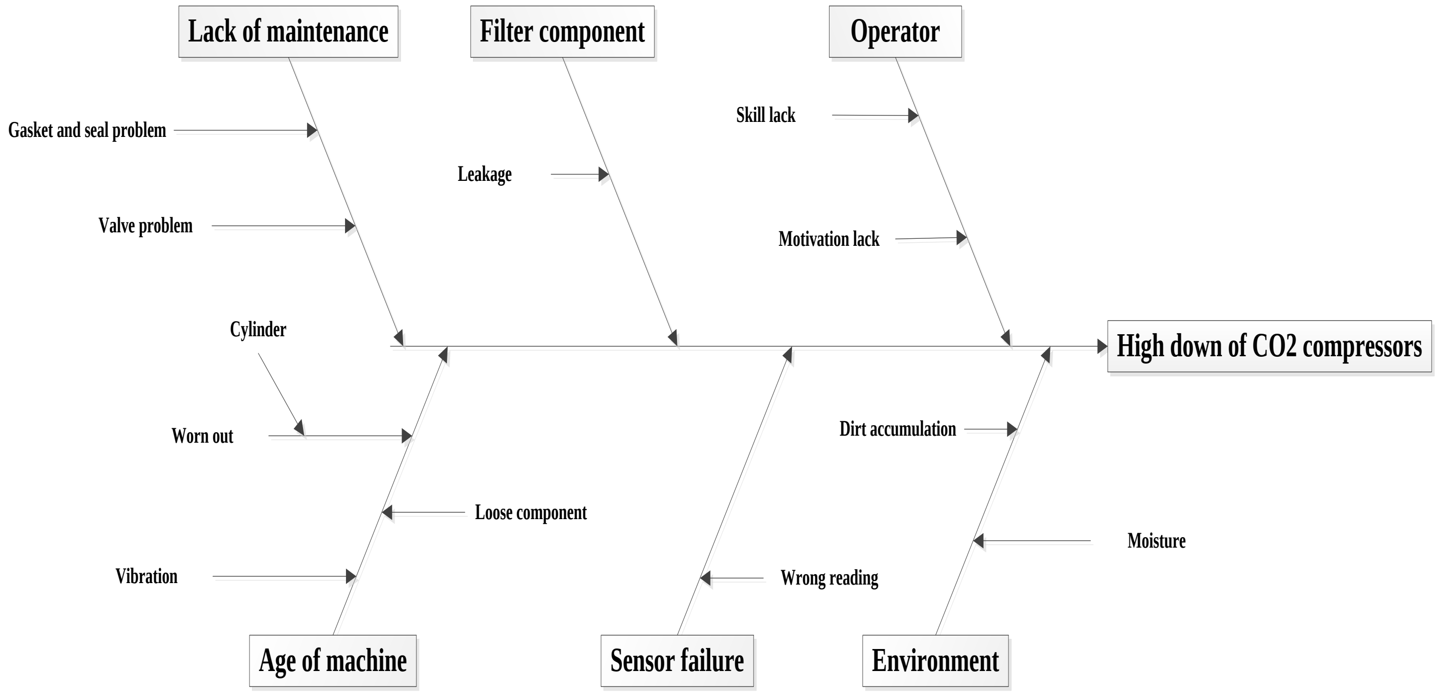

Figure 4.11 Fish bone diagram for CO2 compressors high down time and capacity loss

Table 4.15 Root cause factors in air plant for failure and diagnosis type

Air plant equipment failure and diagnosis type			
Failure frequency	BTS (equipment)	Symptom	Diagnosis
8	Air comp #1	Overheat	Loose component
11	Air comp #2	Leakage	Valve problem
6	Air compressor cabinet #1	Power interrupted	Circuit breaker problem
5	Air comp #2	Low capacity	Pipe problem
15	Air comp #2	No lubrication	Lubrication problem
9	Air comp #3	Bad noise	Bearing problem

2	Air comp #3	No lubrication	Lubrication problem
2	Air comp #1	Doesn’t start	Valve problem
7	Air comp #1	No lubrication	Lubrication problem

(Source BGI Ethiopia utility department)

Air plant frequent symptoms

- Overheat
- Leakage
- Lack of lubrication
- Doesn’t start.
- Bad noise
- Power interrupted.

Air plant frequent diagnosis

- Loose component
- Valve and pipe problem
- Circuit breaker
- Bearing problem
- Lubrication problem

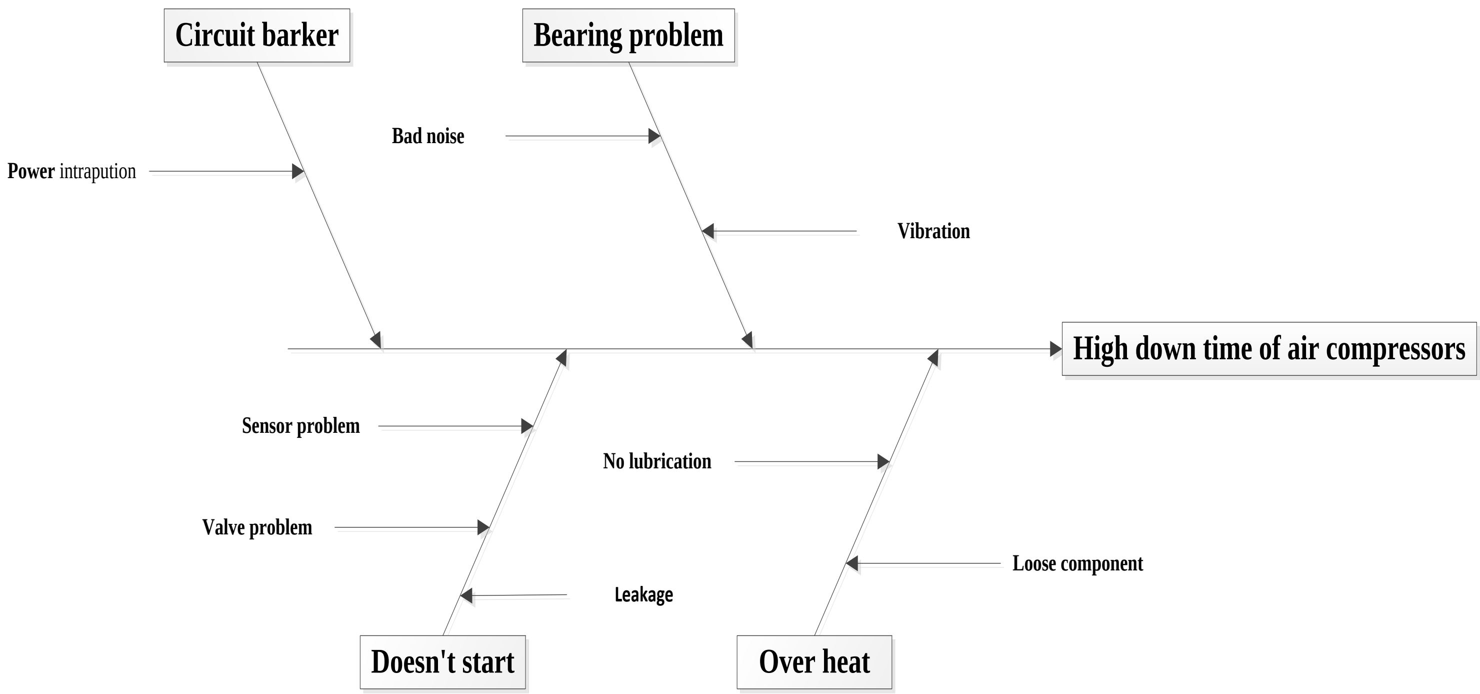

Figure 4.12 Fish bone diagram for air compressors high down time and capacity loss

When it comes to air plant systems, it is important to be aware of common symptoms and their potential diagnoses. The symptoms mentioned include overheating, leakage, lack of lubrication, failure to start, bad noise, and power interruptions. These symptoms can indicate underlying issues within the air plant system. The diagnosis for these symptoms can include loose components, valve and pipe problems, circuit breaker issues, bearing problems, and lubrication problems. These potential diagnoses should be considered when troubleshooting and addressing the symptoms. It is important to note that this is a general overview based on the provided information. For a more accurate diagnosis and resolution, it is recommended to consult with experts or refer to specific air plant system manuals and guidelines. Proper maintenance and regular inspections can help prevent and address these symptoms, ensuring the efficient and reliable operation of the air plant system.

Table 4.16 Root cause factors in cooling plant for failure and diagnosis type

Cooling plant equipment failure and diagnosis type			
Failure frequency	BTS (equipment)	Symptom	Diagnosis
23	Ammonia comp #1A	Leakage	Loose components
5	Ammonia comp #1B	No lubricant	Loose components
8	Ammonia comp #2A	Low capacity	Bearing problem

14	Ammonia comp #2B	Low capacity	Seal problem
3	Cooling unit cabinet #1	No actuation	Electronic card problem
24	Ammonia comp #2A	High pressure	Wire connection problem
13	Ammonia comp #2A	Overheat	Gasket problem
9	Ammonia comp #2B	Leakage	Gasket problem
14	Ammonia comp #3A	Doesn’t work	Sensor problem
11	Cooling unit cabinet #2	Insufficient supply	Power supply problem
17	Cooling unit cabinet #3	Wrong reading	Sensor problem
8	Ammonia distribution liquid	Low flow	Lubrication problem
5	Cooling unit cabinet #1	No supply	Isolation controller problem
4	Cooling unit cabinet #3	No actuation	Switch problem
6	Glycol distribution	Bad noise	Coupling element problem
19	Ammonia comp #3A	Leakage	Seal problem
12	Ammonia comp #3B	Doesn’t start	Switch, sensor problem
14	Ammonia comp #1A	Low flow	Circulation pump problem
5	Ammonia comp #3A	Vibration	Bearing problem

(Source BGI Ethiopia utility department)

Cooling plant frequent symptoms

- Leakage
- No lubricant and no supply
- Low capacity and No actuation
- High pressure and overheat.
- Doesn’t start and wrong reading.
- Vibration
- Low flow

Cooling plant frequent diagnosis

- Sensor and switch problem
- Seal and bearing problem.
- Isolation controller problem
- Loose component and gasket problem
- Wire connection and electronic card problem

When it comes to cooling plants, there are several common symptoms that can indicate underlying issues. These symptoms include leakage, lack of lubricant and supply, low capacity and no actuation, high pressure and overheating, failure to start and wrong readings, vibration, and low flow. The diagnosis for these symptoms can include sensor and switch problems, seal and bearing problems, isolation controller issues, loose component and gasket problems, as well as wire connection and electronic card problems. These potential diagnoses should be considered when troubleshooting and addressing the symptoms. It is important to note that this is a general overview based on the provided information. For a more accurate diagnosis and resolution, it is recommended to consult with experts or refer to specific cooling plant system manuals and guidelines. Regular maintenance and inspections can help prevent and address these symptoms, ensuring the efficient and reliable operation of the cooling plant system.

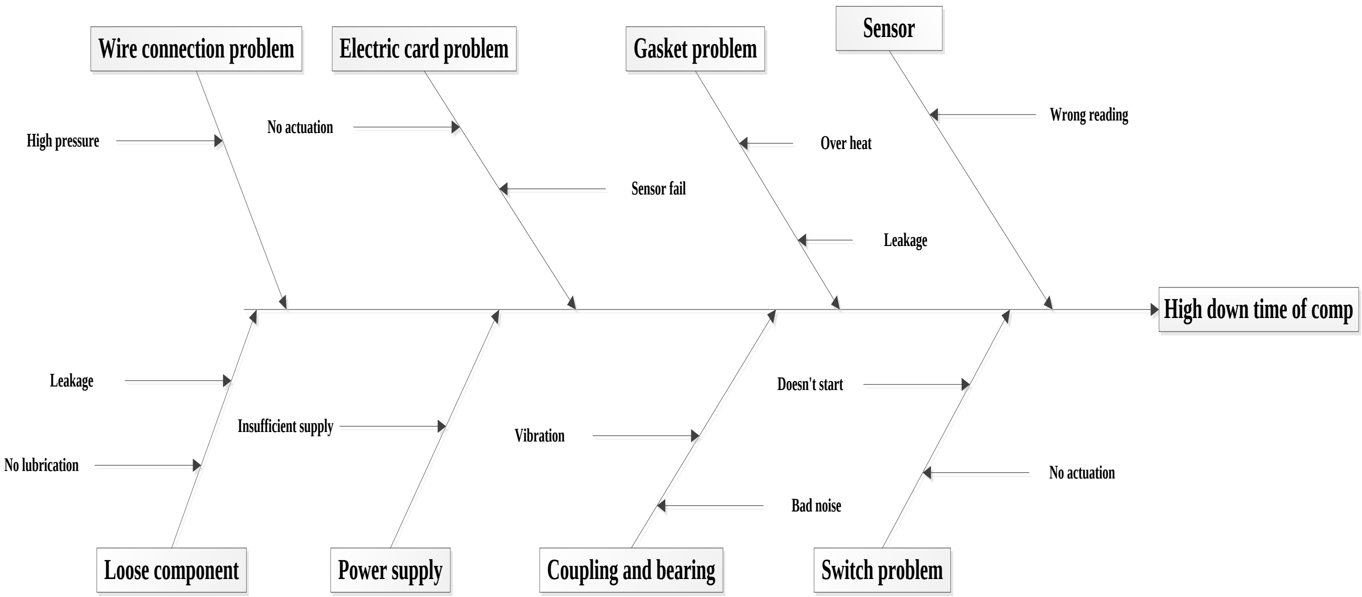

Figure 4.13 Fish bone diagram for cooling compressors high down time and capacity loss

What are the main causes of downtime and inefficiency in the auxiliary machine?

Solution

- Varied operational hours or external factors like environmental conditions, the skill level of the operators, or potential defects can lead to fluctuations in plant performance.
- There is a mismatch between the volume of water received and the actual steam produced, indicating inefficiencies in the conversion process.

- Downtime percentages of most machines, including boilers and compressors, are above average, suggesting that operator skill is a repetitive cause of breakdowns.
- Raw material and spare shortages, inadequate operator skill, misalignment or error in blancher adjustment, and maintenance issues are not easily detectable through machine metrics, leading to downtime and inefficiency.
- Data collection and analysis in the manufacturing processes are often manual and retrospective, causing delays in identifying issues that affect capacity utilization.
- Lack of standardized methods to measure and compare capacity utilization across different manufacturing processes hinders benchmarking and best practice sharing.
- Large data gaps in manufacturing operations, mainly due to raw material shortages, contribute to breakdowns and inefficiency.

Factors that affect capacity utilization of auxiliary machineries. The key findings are as follows:

- The efficiency of the boiler is influenced by factors such as the amount of water supply, water feed temperature, steam temperature, the amount and type of fuel used, and the working pressure of the boilers.
- The document mentions two industrial boilers in the BGI Ethiopia Addis Ababa factory, namely Bosch and Loos, with a design capacity to produce 12 tons/hour of steam.
- The data collected for the steam boiler indicates that there are notable inconsistencies in operational hours, capacity utilization, and water-steam conversion.
- The average running hours of the boiler are significantly lower than expected, suggesting operational inefficiencies.
- There is a mismatch between the volume of water received and the actual steam produced, indicating potential inefficiencies in the conversion process.
- The capacity utilization ratio of the boiler averages 44.21%, which is below 50%, indicating underutilization of resources.
- Factors such as breakdowns, resource shortages, or operational shortcomings may be causing the low-capacity utilization.
- Operator Training and Skills: Skilled and knowledgeable operators can run equipment more effectively, resulting in higher capacity utilization rates. Providing proper training programs, skill development initiatives, and ongoing education can increase the effectiveness of machine operation and reduce errors.

- Technical Expertise: The capacity utilization of auxiliary machinery is influenced by the technical expertise of the operators and technicians. Enhancing their technical skills can lead to improved machine operation and better capacity utilization.
- Scheduling and Production Planning: Effective scheduling and production planning techniques are crucial for maximizing capacity utilization. Efficient coordination between auxiliary machines, process sequence optimization, and reduction of changeover times can maximize machine utilization and overall production efficiency.
- Plant Layout Design: Plant layout design plays a significant role in plant productivity. A well-organized layout can minimize material handling and reduce operation costs. Proper placement of machines and workstations can improve capacity utilization.

The findings suggest that there are inefficiencies in the operation of the steam boiler, including lower running hours, mismatches in water and steam volume, and underutilization of resources. Addressing these issues could improve the efficiency and capacity utilization of the boiler. These findings highlight the importance of operator training, technical expertise, efficient scheduling, and plant layout design in improving the capacity utilization of auxiliary machines.

4.4 Estimating improved capacity utilization of auxiliary machines based on a possible solution.

Auxiliary machines play a crucial role in the smooth operation of production processes. These machines, such as boilers, CO2 plants, air plants, and cooling plants, provide essential support to the main production line. When these auxiliary machines experience downtime, it can have a significant impact on the overall performance and quality of the production process. Downtime affect the performance and quality of auxiliary machines, boilers, CO2 plant, air plant and cooling plant machines and the factor that causes in a production process that is due to the fact that when the auxiliary machines experience downtime, the main production line is affected for instance when down time occur in the air plant the pneumatic machines like the filer machine stops due to the lack of providing an efficient oil free compressed air which cause the production stop. And also, if the other auxiliary machines can’t perform properly it result in the creation of down time or capacity utilization drop.

Implementing a proactive maintenance which is preventive and predictive maintenance and real-time monitoring algorithms and installing sensors to monitor the oil levels, leaks due to seal and gasket, wire connection and other defects in real-time, maintenance activities can be scheduled proactively which can reduce unplanned downtime and improve the utilization of capacity in the company.

According to the study conducted by Kinsey (2018), McRoberts (2018), and Bashir (2022), the company has shown that predictive maintenance can reduce maintenance costs by up to 30% and improve equipment availability, performance, and quality by 20%. Another study that has been conducted by IBM emphasizes the use of computer vision and machine learning for predictive maintenance, resulting in a 10% reduction in downtime and a 25% decrease in maintenance costs (IBM, 2017).

In general, according to (Abeyratne, 2014), (Kinsey, 2018), and (IBM, 2017), Proactive maintenance has a 25 to 30 percent reduction in maintenance cost, a 10 percent reduction in downtime, a 5% reduction in speed loss, and a 5% reduction in quality; the total reduction in capacity losses is 20% (the total increment in utilization of capacity is then about 20 percent).

These scholars is selected due to its legit estimation in capacity improvement and also it is suitable for the case company as its focus is in manufacturing industries and the percentage that they state is can be achieved because one of the major lack in the company that leads to unutilized capacity is not implementing the proactive maintenance strategy to enhance the improvement of capacity utilization.

Implementing proactive maintenance can improve downtime by ten percent, which results in an improvement of 10% for every auxiliary machinery that has been analyzed in the company, which is:

$$Down\ time\ \%\ losses\ \ for\ each\ AM = \frac{down\ time\ of\ each\ auxilary\ machinery}{planned\ working\ time\ for\ the\ nine\ months}$$

Down time for boilers:

$$Down\ time\ \%\ for\ boiler\ 1 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ for\ boiler\ one = 3445hr/6279hr = 54.38\%$$

Improving this by 10% reduce time to 48.95%

$$Down\ time\ \%\ for\ boiler\ 2 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ for\ boiler\ two = 3466hr/6279hr = 55.2\%$$

Improving this by 10% reduce time to 49.68%

Down time for CO2 plant compressors:

$$Down\ time\ \%\ for\ CO2\ comp\ 1\&2 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ CO2\ comp\ 1\&2 = \ 6090hr/12558hr = 48.5\%$$

Improving this by 10% reduce time to 43.64%

Down time for air plant compressors:

$$Down\ time\ \%\ forair\ comp\ 1 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ air\ comp\ 1 = \ 3431hr/6279hr = 54.64\%$$

Improving this by 10% reduce down time to 49.18%

$$Down\ time\ \%\ forair\ comp\ 2 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ air\ comp\ 2 = \ 2842hr/6279hr = 45.26\%$$

Improving this by 10% reduce time to 40.73%

$$Down\ time\ \%\ forair\ comp\ 3 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ air\ comp\ 3 = \ 2082hr/6279hr = 33.15\%$$

Improving this by 10% reduce time to 29.84%

Down time for cooling plant compressors:

$$Down\ time\ \%\ for\ cooling\ plant\ one\ comp\ 1 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ cooling\ plant\ one\ comp\ 1 = \ 2383hr/6279hr = 37.95\%$$

Improving this by 10% reduce time to 34.14%

$$Down\ time\ \%\ for\ cooling\ plant\ one\ comp\ 2 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ cooling\ plant\ one\ comp\ 2 = \ 2774hr/6279hr = 44.18\%$$

Improving this by 10% reduce time to 39.76%

$$Down\ time\ \%\ for\ cooling\ plant\ two\ comp\ 1 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ cooling\ plant\ two\ comp\ 1 = \ 2505hr/6279hr = 39.9\%$$

Improving this by 10% reduce time to 35.9%

$$Down\ time\ \%\ for\ cooling\ plant\ two\ comp\ 2 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ cooling\ plant\ two\ comp\ 2 = \ 2579hr/6279hr = 41.07\%$$

Improving this by 10% reduce time to 36.96%

$$Down\ time\ \%\ for\ cooling\ plant\ three\ comp\ 1 = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ cooling\ plant\ three\ comp\ 1 = \ 3664hr/6279hr = 58.35\%$$

Improving this by 10% reduce time to 52.52%

$$Down\ time\ \%\ for\ cooling\ plant\ three\ comp\ 2a = \frac{recorded\ down\ time\ of\ boiler\ one}{planned\ working\ time\ of\ boiler\ one\ \ for\ the\ nine\ months}$$

$$DT\ \%\ for\ cooling\ plant\ three\ comp\ 2 = \ 5213hr/6279hr = 83.03\%$$

Improving this by 10% reduce time to 74.72%

This analyzes the expected working hours, actual working time, downtime, and downtime percentage for various auxiliary machines, such as boilers, CO2 compressors, air plant compressors, and cooling plant compressors. The analysis highlights the significant downtime percentages and the potential for improvement through proactive maintenance.

The BOSCH Boiler and LOOS Boiler have downtime percentages of 54.38% and 55.2%, respectively. By implementing proactive maintenance strategies, such as preventive and predictive maintenance, these downtime percentages can be improved by 10%, resulting in reduced downtime and improved performance.

Similarly, the CO2 compressors, air plant compressors, and cooling plant compressors also experience significant downtime percentages. By implementing proactive maintenance measures, such as real-time monitoring and timely maintenance interventions, the downtime percentages can be reduced, leading to improved efficiency and utilization of capacity.

Overall, the study demonstrates the potential benefits of proactive maintenance in reducing downtime, improving equipment performance, and optimizing the utilization of capacity in a company's production process. By using preventive and predictive maintenance strategies, along with real-time monitoring and sensor installations, companies can achieve cost savings, increased equipment availability, improved quality, and enhanced overall performance.

When downtime occurs in auxiliary machines, it can cause the main production line to be affected. If downtime occurs in the air plant, the pneumatic machines, like the filer machine, may stop working due to the lack of efficient oil-free compressed air. This can lead to a halt in production. Similarly, if other auxiliary machines cannot perform properly, it can result in downtime or a drop in capacity utilization. To address the issue of downtime and improve the utilization of capacity, implementing proactive maintenance strategies is crucial. Proactive maintenance includes preventive and predictive maintenance, as well as real-time monitoring algorithms and the installation of sensors to monitor various aspects of the machines in real-time.

In general, proactive maintenance has been found to have a 25 to 30 percent reduction in maintenance costs, a 10 percent reduction in downtime, a 5% reduction in speed loss, and a 5% reduction in quality. This leads to a total reduction in capacity losses of 20%, effectively improving the utilization of capacity by approximately 20%. Based on the detailed analysis provided, utilizing proactive maintenance can improve downtime by ten percent for each auxiliary piece of machinery. This improvement can be seen in the expected working hours for nine months, actual working time, downtime, and downtime percentage. Implementing proactive maintenance on the boilers can reduce downtime by 3073.5 hours, resulting in a downtime percentage of 48.95%. Similarly, for the air plant compressors, proactive maintenance can reduce downtime by 3087.9 hours for compressor 1, 2557.8 hours for compressor 2, and 1873.8 hours for compressor 3.

What are some potential solutions proposed to prevent downtime in the auxiliary machine?

The study proposed a possible solution to prevent downtime and breakdowns in the plant. These solutions include:

- Improved scheduling and maintenance practices: The study suggests that proper allocation of running hours can maximize capacity utilization and improve efficiency. By implementing better scheduling and maintenance practices, the plant can reduce breakdowns and ensure smooth operations.
- Focus on maintenance and supply chain management: The study identifies breakdowns as a significant factor in downtime. Therefore, focusing resources on improved maintenance practices and supply chain management can help decrease overall downtime and prevent breakdowns.
- Utilize cutting-edge technologies: The study highlights the importance of using advanced analytics, micro technology, and tip trace machines to collect real-time data and analyse it. By adopting cutting-edge technologies, operators can quickly identify and address issues that affect capacity utilization, thereby preventing breakdowns.
- Identify and measure less obvious sources of downtime: The study suggests that there may be less obvious sources of downtime, such as raw material and spare shortages, inadequate operator skill, or maintenance issues. It recommends conducting further investigation to identify and measure these sources of downtime and develop effective strategies to mitigate them.

Overall, the study emphasizes the importance of proactive maintenance practices, efficient scheduling, and the use of advanced technologies to prevent breakdowns in the plant and enhance capacity utilization.

In conclusion, auxiliary machines play a critical role in production processes, and downtime in these machines can have a significant impact on the overall performance and quality of the production line. Instigating proactive maintenance strategies, such as preventive and predictive maintenance, real-time monitoring, and sensor installation, can help reduce unplanned downtime and improve the utilization of capacity in the company. Studies have shown that proactive maintenance can lead to a reduction in maintenance costs, downtime, and quality issues while improving equipment availability and performance. By analyzing the specific downtime for each auxiliary machine and implementing proactive maintenance, the overall downtime can be improved, resulting in increased production efficiency and capacity utilization.

Table 4.17 Improved auxiliary machine downtime.

Auxiliary machine losses		Reason for stoppage		Expected working hour for nine months (hr.)	Actual working time (hr.)	Down time (hr.)	Down time percentage	Improved down time by 10%	
		Known	Unknown					Down time (hr)	Down time %
Boilers	BOSCH Boiler	Breakdown, supply shortage	Unknown	6,279 hr.	2,864	3,415	54.38%	3073.5	48.95%
	LOOS Boiler	Breakdown, supply shortage	Unknown	6,279 hr.	2,813	3,466	55.2%	3119.4	49.68%
CO2 compressors	Comp 1 & 2	Breakdown, Operator skill	Unknown	12,558 hr.	6,468	6,090	48.5%	5481	43.64%
Air plant	Compressor 1	Breakdown, Operator skill,	Unknown	6,279 hr.	2,848	3,431	54.64%	3087.9	49.18%
	Compressor 2	Breakdown, Operator skill	Unknown	6,279 hr.	3,437	2,842	45.26%	2557.8	40.73%
	Compressor 3	Breakdown, Operator skill	Unknown	6,279 hr.	4,197	2,082	33.15%	1873.8	29.84%
Cooling plant one	Compressor 1	Breakdown, Operator skill	Unknown	6,279 hr.	3,896	2,383	37.95%	2144.7	34.14%
	Compressor 2	Breakdown, Operator skill, Environment	Unknown	6,279 hr.	3,505	2,774	44.18%	2496.6	39.76%
Cooling	Compressor 1	Breakdown, Operator skill,	Unknown	6,279 hr.	3,774	2,505	39.9%	2254.5	35.9%

plant two		mass drop							
	Compressor 2	Breakdown, Operator skill, Environment	Unknown	6,279 hr.	3,700	2,579	41.07%	2321.1	36.96%
Cooling plant three	Compressor 1	Breakdown, Operator skill, Environment	Unknown	6,279 hr.	2,615	3,664	58.35%	3297.6	52.52%
	Compressor 2	Breakdown, Operator skill, mass drop	Unknown	6,279 hr.	1,066	5,213	83.03%	4691.7	74.72%

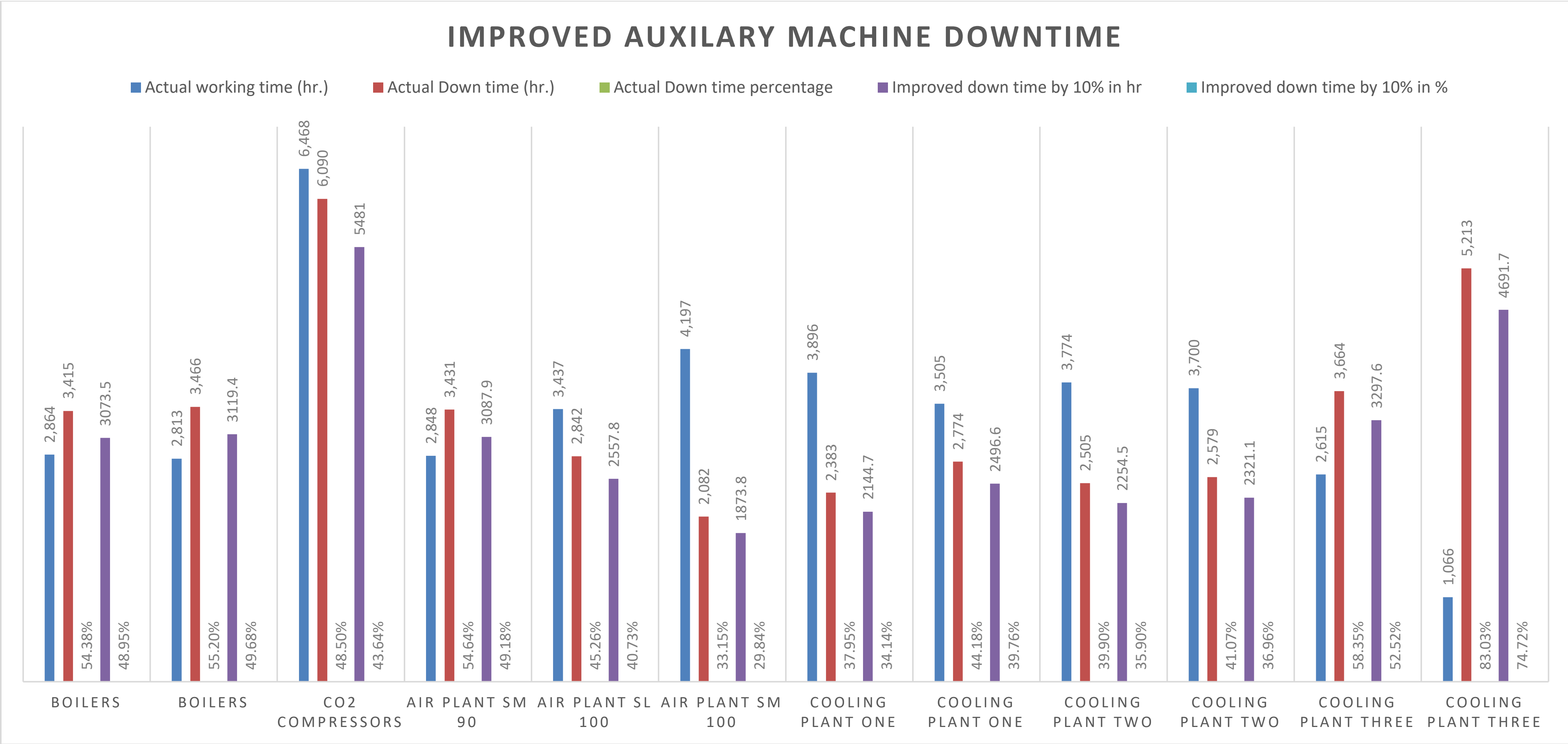

Figure 4.14 Improved auxiliary machine downtime.

Chapter Five
5. Conclusion and Recommendation

5.1 Conclusion

The efficiency of the boiler is influenced by factors such as the amount of water supplied, the water feed temperature, the steam temperature, the amount and type of fuel used, and the working pressure of the boilers. The study mentions that there are two industrial boilers (Bosch and Loos) in the BGI Ethiopia Addis Ababa factory, with an installed capacity of 12 tons per hour. The data collected over a period of nine months shows the actual output of these boilers and their capacity utilization. The capacity utilization ratio is calculated by dividing the actual (observed) output by the installed capacity. The average boiler running hours are significantly lower than expected, indicating operational inefficiencies. The capacity utilization ratio averages at 44.21%, which is below 50%, suggesting underutilization of resources. Downtime issues such as breakdowns and water shortages are reported every month, which may be causing low-capacity utilization. The existing downtime in the auxiliary machines, which include the steam boilers, CO_2, air, and cooling plants, is 49.63%, and the improved capacity utilization reduces the downtime to 44.66%.

The conclusion of this research, based on the document, is to improve the capacity utilization of auxiliary machines in the BGI Ethiopia brewery factory. The research aims to address the gaps in previous studies that did not consider the working hours of the machines and focused solely on the output of the product. The research approach involves defining the research objectives, reviewing existing literature, identifying important factors, and using a combination of quantitative and qualitative data collection methods. The research design is descriptive and exploratory, aiming to provide a framework for the study. The study recommends implementing strategies such as scheduling, automation, workflow optimization, equipment maintenance, operator training, and system integration to maximize machine capacity. The conclusion emphasizes the significance of improving auxiliary machine capacity utilization and highlights the key findings, recommendations, and potential benefits for the organization.

5.2 Recommendation

Propose contextual and general recommendations based on the research findings and analysis to improve auxiliary machine capacity utilization. These recommendations may include factors such as scheduling, automation, workflow optimization, equipment maintenance, operator training, and system integration. Prioritize the recommendations based on their potential impact, effect, and cost-effectiveness. Provide a roadmap for guiding future research and implementation of the recommendations, including timelines, responsibilities, and resource allocation.

5.2.1 General recommendation

The general recommendations for improving the capacity utilization of auxiliary machines are as follows:

- Conduct an equipment analysis to identify areas that need improvement and determine if the current equipment is insufficient, outdated, or ineffective for the organization's needs. And compare with existing literature and industry best practices: Compare the research findings with the existing literature and industry best practices. Identify areas of improvement and potential solutions based on the insights gained from the literature review.
- Consider implementing cutting-edge technologies, such as treatment, more powerful and effective CO_2 and air compressors, and autonomous regulating and monitoring systems, to enhance the performance, efficiency, and capacity of auxiliary machines.
- Analyse the effectiveness of how auxiliary machines are currently being used and consider transferring workloads or consolidating equipment to boost efficiency and reduce costs.
- Develop and implement maintenance and repair strategies to minimize downtime, extend the life of auxiliary machines, and establish regular maintenance and repair schedules. This includes making plans for routine maintenance, promptly completing repairs, and having a backup plan in case of equipment breakdowns.

These recommendations aim to optimize the utilization of auxiliary machine capacity and improve overall productivity in the brewery factory.

5.2.2 Contextual recommendation

The contextual recommendations for improving the capacity utilization of auxiliary machines in the BGI Ethiopia brewery factory are as follows:

- Use appropriate statistical techniques and thematic analysis to identify patterns, trends, and correlations within the data. This will provide insights into the current state of auxiliary machine capacity utilization.

- Provide operator training and skill development initiatives. Skilled and knowledgeable operators can run equipment more effectively, resulting in higher capacity utilization rates. Offering proper training programs, skill development initiatives, and ongoing education can increase the effectiveness of machine operation, reduce errors, and optimize capacity utilization.
- Implement effective scheduling and production planning techniques: Efficient coordination between auxiliary machines, process sequence optimization, and reduction of changeover times can maximize machine utilization and overall production efficiency. Effective scheduling and production planning are crucial for maximizing capacity utilization.
- Optimize plant layout design: A well-organized plant layout design can minimize material handling and reduce operation costs during manufacturing. Finding the most effective facility arrangement and strategically locating machines and workstations can improve capacity utilization.
- Conduct regular equipment maintenance: Proper maintenance procedures and timely repairs can minimize breakdowns and downtime, leading to improved capacity utilization. Regular maintenance checks and preventive maintenance programs should be implemented.
- Analyse and utilize data: Collecting machine utilization data, machine logs, maintenance reports, and performance metrics can provide insights into the current state of auxiliary machine capacity utilization. Analysing this data using appropriate statistical techniques can help identify patterns, trends, and correlations, leading to informed decision-making and potential improvements.
- To rectify this issue, it is of utmost importance to establish a reliable and consistent water supply for the company. At present, the factory has resorted to renting six water trucks, each capable of carrying 20,000 litters, to transport water from Meta to the factory situated at Mexico Square. Each truck makes three trips per day, incurring a cost of 11,000 birr per trip, totalling 198,000 birr per day. This process is repeated twenty times per month, resulting in a monthly expense of 3,960,000 birr. Annually, the factory incurs an expenditure of approximately 47,520,000 birrs solely on water truck transportation. Instead of relying on the inadequate truck supply that fails to meet production demand,

the most optimal solution is to install a water pipeline spanning 25 kilometres from Meta to the factory, effectively utilizing the nearby water source from the river.

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Annex

Annex I
CO2 plant data

Date	Capacity of each compressor (kg/h)	CO2 generation after two compressors	Storage tank 1,20 ton	Storage 2,30 ton	Bottling	New Kegging	Filtration	Wastewater treatment	Brew house	Total cylinder filled
Month/ year		Index	Index	Index	Index	Index	Index	Index	Index	
01/11/22	500	426490	11336	11432	1865628	4115625	1796735	2612032	78641	3853
02/11/22	500	437887	12160	13186	1865712	4118708	1799700	2612769	78938	4526
03/11/22	500	448872	11326	12453	1865796	4121791	1802665	2613506	79235	5124
04/11/22	500	459432	11110	11669	1865880	4124874	1805630	2614243	79532	3731
05/11/22	500	470623	9552	10823	1865964	4127957	1808595	2614980	79829	4012
06/11/22	500	481604	13309	10701	1866048	4131040	1811560	2615717	80126	3123
07/11/22	500	492585	11023	9967	1866132	4134123	1814525	2616454	80423	3067
08/11/22	500	503566	11183	12719	1866216	4137206	1817490	2617191	80720	4722
09/11/22	500	514547	13078	11466	1866300	4140289	1820455	2617928	81017	3851
10/11/22	500	525528	10178	12430	1866384	4143372	1823420	2618665	81314	3325
11/11/22	500	536509	9774	9608	1866468	4146455	1826385	2619402	81611	2317
12/11/22	500	547490	12331	9538	1866552	4149538	1829350	2620139	81908	3190
13/11/22	500	558472	12117	11950	1866636	4152621	1832315	2620876	82205	3051

14/11/22	500	569452	10850	12431	1866720	4155704	1835280	2621613	82502	3176
15/11/22	500	580434	10478	10738	1866804	4158787	1838245	2622350	82799	3016
16/11/22	500	591415	13392	11551	1866888	4161870	1841210	2623087	83096	2027
17/11/22	500	602396	9582	13368	1866972	4164953	1844175	2623824	83393	2312
18/11/22	500	613377	9954	9507	1867056	4168036	1847140	2624561	83690	1980
19/11/22	500	624358	12230	10414	1867140	4171119	1850105	2625298	83987	1875
20/11/22	500	635339	13045	9602	1867224	4174202	1853070	2626035	84284	1342
21/11/22	500	646321	11067	10717	1867308	4177285	1856035	2626772	84581	1732
22/11/22	500	657301	10870	12149	1867392	4180368	1859000	2627509	84878	1886
23/11/22	500	668282	10838	11935	1867476	4183451	1861965	2628246	85175	3067
24/11/22	500	679263	10917	11758	1867560	4186534	1864930	2628983	85472	2145
25/11/22	500	740245	11626	9643	1867644	4189617	1867895	2629720	85769	3219
26/11/22	500	741226	9557	10216	1867728	4192700	1870860	2630457	86066	4121
27/11/22	500	752207	10724	10985	1867812	4195783	1873825	2631194	86363	2855
28/11/22	500	753188	11438	11491	1867896	4198866	1876790	2631931	86660	5097
29/11/22	500	764169	13290	12004	1867980	4201949	1879755	2632668	86957	2412
30/11/22	500	768402	12574	10628	1868138	4208088	1884174	2634156	87540	2087
	Total	**341,912 kg**			**2510 kg**	**92463kg**	**87439 kg**	**22124 kg**	**8899kg**	**92241 cylinders**

Then the capacity for both compressors to produce a Co2 gas in a month is 500*2*23*30=690,000

The observed capacity or the actual output for a month is 356553 kg so the capacity utilization for the compressor 1 and 2 is.

$$\boldsymbol{CU = 341,912 /720000 = 0.4952}$$

Which is 47.48% of the capacity is utilized?

The total cylinder filled per month is 92241 from this 35% of 10kg, 25% of 15kg, 25% of 20kg and 15% of 25kg cylinders.

Which are

- 32,284.35 of 10kg cylinders
- 23,060.25 of 15kg cylinders
- 23,060.25 of 20kg cylinders
- 13,836.15 of 25kg cylinders

322,843.5+345,903.75+461,205+345,903.75= **1,475,856 kg**

The total Co2 gas used per month is

$$\boldsymbol{2510\ kg + 92463kg\ + 87439\ kg\ + 22124\ kg\ + 8899kg\ + 1,475,856\ kg = 1,689,291\ kg}$$

Date	Capacity of each compressor (kg/h)	Co2 generation after two compressors	Storage tank 1,20 ton	Storage 2,30 ton	Bottling	New Kegging	Filtration	Wastewater treatment	Brew house	Total cylinder filled
Month/ year		Index	Index	Index	Index	Index	Index	Index	Index	
01/12/22	500	768402	9840	19096	1868138	4208088	1884174	2634156	87540	4121
02/12/22	500	780650	10957	27835	1868231	4211508	1887096	2634959	87927	3456

03/12/22	500	792898	10043	23363	1868324	4214928	1890018	2635762	88314	4213
04/12/22	500	805146	13891	13015	1868417	4218348	1892940	2636565	88701	3987
05/12/22	500	817394	9906	18990	1868510	4221768	1895862	2637368	89088	2312
06/12/22	500	829642	10481	19528	1868603	4225188	1898784	2638171	89475	4376
07/12/22	500	841890	10515	17099	1868696	4228608	1901706	2638974	89862	4325
08/12/22	500	854138	12904	13076	1868789	4232028	1904628	2639777	90249	5176
09/12/22	500	866386	11510	16979	1868882	4235448	1907550	2640580	90636	3425
10/12/22	500	878634	12576	23774	1868975	4238868	1910472	2641383	91023	4321
11/12/22	500	890882	10293	10158	1869068	4242288	1913394	2642186	91410	2654
12/12/22	500	903130	9252	20192	1869161	4245708	1916316	2642989	91797	2876
13/12/22	500	915378	13678	28426	1869254	4249128	1919238	2643792	92184	2887
14/12/22	500	927626	14386	22316	1869347	4252548	1922160	2644595	92571	3215
15/12/22	500	939874	13479	11029	1869440	4255968	1925082	2645398	92958	2378
16/12/22	500	952122	12020	17653	1869533	4259388	1928004	2646201	93345	3421
17/12/22	500	964370	11266	18888	1869626	4262808	1930926	2647004	93732	5432
18/12/22	500	976618	14421	26945	1869719	4266228	1933848	2647807	94119	2153
19/12/22	500	988866	11842	29160	1869812	4269648	1936770	2648610	94506	1765
20/12/22	500	1001114	13005	10089	1869905	4273068	1939692	2649413	94893	2013

21/12/22	500	1013362	12657	25773	1869998	4276488	1942614	2650216	95280	1543
22/12/22	500	1025610	13605	21109	1870091	4279908	1945536	2651019	95667	2231
23/12/22	500	1037858	10309	28339	1870184	4283328	1948458	2651822	96054	2312
24/12/22	500	1050106	11315	23954	1870277	4286748	1951380	2652625	96441	2243
25/12/22	500	1062354	10282	27693	1870370	4290168	1954302	2653428	96828	1987
26/12/22	500	1074602	10987	15334	1870463	4293588	1957224	2654231	97215	3421
27/12/22	500	1086850	11907	20412	1870556	4297008	1960146	2655034	97602	3008
28/12/22	500	1099098	10646	26928	1870649	4300428	1963068	2655837	97989	4231
29/12/22	500	1111346	10977	12612	1870742	4303848	1965990	2656640	98376	5432
30/12/22	500	1123284	12692	8496	1870835	4307268	1968912	2657443	98763	1989
31/12/22	500	1124296	12608	9509	1870913	4310673	1971833	2658253	99164	2451
	Total	**355,894 kg**			**2775 kg**	**102585kg**	**87659 kg**	**24097 kg**	**11624 kg**	**99354 cylinders**

Then the capacity for both compressors to produce a CO_2 gas in a month is 500*2*23*30=690,000

The observed capacity or the actual output for a month is 356553 kg so the capacity utilization for the compressor 1 and 2 is.

$$\boldsymbol{CU = 355{,}894 / 720000 = 0.4943}$$

Which is 49.43% of the capacity is utilized?

The total cylinder filled per month is 99354 from this 35% of 10kg, 25% of 15kg, 25% of 20kg and 15% of 25kg cylinders.

Which are

- 34.773.9 of 10kg cylinders
- 24,838.5 of 15kg cylinders
- 24,838.5 of 20kg cylinders
- 14,903.1 of 25kg cylinders

347,739+372,577.5+496,770+372,577.5= **1,589,664 kg**

The total Co2 gas used per month is.

$$\mathbf{2775\ kg + 102585 kg + 87659\ kg + 24097\ kg + 11624 kg\ + 1,589,664\ kg}$$
$$\mathbf{= \ 1,818,404\ kg}$$

Date	Capacity of each compressor (kg/h)	Co2 generation after two compressors	Storage tank 1,20 ton	Storage 2,30 ton	Bottling	New Kegging	Filtration	Wastewater treatment	Brew house	Total cylinder filled
Month/year		Index	Index	Index	Index	Index	Index	Index	Index	
01/01/23	500	1124296	10403	22990	1870913	4310673	1971833	2658253	99164	3975
02/01/23	500	1136062	17980	24112	1871016	4314066	1974980	2659230	99620	4326
03/01/23	500	1147828	8075	17143	1871119	4317459	1978127	2660207	100076	3785
04/01/23	500	1159594	11274	27878	1871222	4320852	1981274	2661184	100532	3256
05/01/23	500	1171360	9927	24217	1871325	4324245	1984421	2662161	100988	2453
06/01/23	500	1183126	13996	20514	1871428	4327638	1987568	2663138	101444	3097

07/01/23	500	1194892	18485	16988	1871531	4331031	1990715	2664115	101900	2413
08/01/23	500	1206658	17321	20178	1871634	4334424	1993862	2665092	102356	4567
09/01/23	500	1218424	13098	27783	1871737	4337817	1997009	2666069	102812	4767
10/01/23	500	1230190	15097	18538	1871840	4341210	2000156	2667046	103268	3421
11/01/23	500	1241956	12360	18626	1871943	4344603	2003303	2668023	103724	4533
12/01/23	500	1253722	17608	16505	1872046	4347996	2006450	2669000	104180	3566
13/01/23	500	1265488	16611	11295	1872149	4351389	2009597	2669977	104636	4421
14/01/23	500	1277254	15794	15255	1872252	4354782	2012744	2670954	105092	2231
15/01/23	500	1289020	10880	19197	1872355	4358175	2015891	2671931	105548	3466
16/01/23	500	1300786	14364	9578	1872458	4361568	2019038	2672908	106004	3427
17/01/23	500	1312552	12721	16349	1872561	4364961	2022185	2673885	106460	4376
18/01/23	500	1324318	9517	13013	1872664	4368354	2025332	2674862	106916	3243
19/01/23	500	1336084	11901	26033	1872767	4371747	2028479	2675839	107372	2143
20/01/23	500	1347850	16370	24728	1872870	4375140	2031626	2676816	107828	1990
21/01/23	500	1359616	18615	14311	1872973	4378533	2034773	2677793	108284	1754
22/01/23	500	1371382	14468	25981	1873076	4381926	2037920	2678770	108740	2331
23/01/2	500	1383148	17088	16289	1873179	4385319	2041067	2679747	109196	2755

3										
24/01/23	500	1394914	13641	23433	1873282	4388712	2044214	2680724	109652	2997
25/01/23	500	1406680	8909	23423	1873385	4392105	2047361	2681701	110108	2337
26/01/23	500	1418446	10370	16097	1873488	4395498	2050508	2682678	110564	4307
27/01/23	500	1430212	16665	19134	1873591	4398891	2053655	2683655	111020	2442
28/01/23	500	1441978	13047	8905	1873694	4402284	2056802	2684632	111476	3988
29/01/23	500	1453744	15587	28269	1873797	4405677	2059949	2685609	111932	2445
30/01/23	500	1477264	17915	14572	1874008	4409539	2063181	2686546	112306	2013
	Total	**352,968 kg**			**3095 kg**	**98863kg**	**91348kg**	**28293 kg**	**13142kg**	**96825cylinders**

Then the capacity for both compressors to produce a Co2 gas in a month is 500*2*23*30=690,000

The observed capacity or the actual output for a month is 356553 kg so the capacity utilization for the compressor 1 and 2 is.

$$\boldsymbol{CU = 352,968 / 720000 = 0.4902}$$

Which is 49.02% of the capacity is utilized?

The total cylinder filled per month is 96825 from this 35% of 10kg, 25% of 15kg, 25% of 20kg and 15% of 25kg cylinders.

Which are

- 33,888.75 of 10kg cylinders
- 24,206.25 of 15kg cylinders

- 24,206.25 of 20kg cylinders
- 14,523.75 of 25kg cylinders

338,887.5+363,093.75+484,125+363,093.75= **1,549,200 kg**

The total Co2 gas used per month is

$$\mathbf{3095\ kg + 98863kg + 91348\ kg + 28293\ kg + 13142kg\ + 1,549,200\ kg} \\ \mathbf{= \ 1,783,941\ kg}$$

Date	Capacity of each compressor (kg/h)	Co2 generation after two compressors	Storage tank 1,20 ton	Storage 2,30 ton	Bottling	New Kegging	Filtration	Wastewater treatment	Brew house	Total cylinder filled
Month/year		Index	Index	Index	Index	Index	Index	Index	Index	
01/02/23	500	1,477,268	18,633	25,785	1,874,008	4,409,536	2063181	2686546	112306	3465
02/02/23	500	1,490,010	19,723	12,007	1,874,131	4,413,041	2066397	2687620	112827	3327
03/02/23	500	1,502,752	9,178	12,400	1,874,254	4,416,546	2069613	2688694	113348	2756
04/02/23	500	1,515,494	14,301	24,561	1,874,377	4,420,051	2072829	2689768	113869	2156
05/02/23	500	1,528,236	16,874	26,289	1,874,500	4,423,556	2076045	2690842	114390	2653
06/02/23	500	1,540,978	10,626	16,273	1,874,623	4,427,061	2079261	2691916	114911	4002
07/02/23	500	1,553,720	13,315	9,235	1,874,746	4,430,566	2082477	2692990	115432	3484
08/02/23	500	1,566,462	9,109	12,158	1,874,869	4,434,071	2085693	2694064	115953	3563
09/02/23	500	1,579,204	12,655	27,651	1,874,992	4,437,576	2088909	2695138	116474	3764
10/02/23	500	1591946	12,774	22,728	1,875,115	4,441,081	2092125	2696212	116995	3529
11/02/23	500	1,604,688	16,391	17,888	1,875,23	4,444,58	2095341	2697286	11751	3733

					8	6			6	
12/02/23	500	1617430	16,022	14,290	1,875,361	4,448,091	2098557	2698360	118037	3526
13/02/23	500	1,630,172	14,758	14,993	1875484	4,451,596	2101773	2699434	118558	3441
14/02/23	500	1642914	9,377	8,631	1,875,607	4,455,101	2104989	2700508	119079	3241
15/02/23	500	1,655,656	11,132	20,926	1875730	4,458,606	2108205	2701582	119600	2496
16/02/23	500	1668398	17,351	27,227	1,875,853	4,462,111	2111421	2702656	120121	3248
17/02/23	500	1,681,140	16,681	25,185	1875976	4,465,616	2114637	2703730	120642	3374
18/02/23	500	1693882	16,626	17,527	1,876,099	4,469,121	2117853	2704804	121163	3415
19/02/23	500	1,706,624	10,753	21,551	1876222	4,472,626	2121069	2705878	121684	4222
20/02/23	500	1719366	18,193	10,261	1,876,345	4,476,131	2124285	2706952	122205	2445
21/02/23	500	1,732,108	11,772	16,246	1876468	4,479,636	2127501	2708026	122726	3421
22/02/23	500	1744850	10,305	17,642	1,876,591	4,483,141	2130717	2709100	123247	2767
23/02/23	500	1,757,592	8,326	28,712	1876714	4,486,646	2133933	2710174	123768	2453
24/02/23	500	1770334	13,203	13,558	1,876,837	4,490,151	2137149	2711248	124289	3011
25/02/23	500	1,783,076	15,283	21,025	1876960	4,493,656	2140365	2712322	124810	3190
26/02/23	500	1795818	14,408	16,666	1,877,083	4,497,161	2143581	2713396	125331	3357
27/02/23	500	1,808,560	13,500	20,379	1877206	4,500,666	2146797	2714470	125852	2976
28/02/23	500	1821302	15,499	22,159	1,877,329	4,504,171	2150013	2715544	126373	3013

	Total	**381,946kg**			**3682 kg**	**101566kg**	**94501kg**	**30536 kg**	**15614 kg**	**95892cylinders**

Then the capacity for both compressors to produce a Co2 gas in a month is 500*2*23*30=690,000

The observed capacity or the actual output for a month is 356553 kg so the capacity utilization for the compressor 1 and 2 is.

$$\boldsymbol{CU = 381,946kg\ /720000 = 0.5304}$$

Which is 53.04% of the capacity is utilized?

The total cylinder filled per month is 95892 from this 35% of 10kg, 25% of 15kg, 25% of 20kg and 15% of 25kg cylinders.

Which are

- 33,562.2 of 10kg cylinders
- 23,973 of 15kg cylinders
- 23,973 of 20kg cylinders
- 14,383.8 of 25kg cylinders

335,622+359,595+479,460+359,595= **1,534,272 kg**

The total Co2 gas used per month is

$$\boldsymbol{3682\ kg + 101566kg + 94501kg + 30536\ kg + 15614kg\ + 1,534,272\ kg = 1,780,171\ kg}$$

Date	Capacity of each compressor (kg/h)	Co2 generation after two compressors	Storage tank 1,20 ton	Storage 2,30 ton	Bottling	New Kegging	Filtration	Waste water treatment	Brew house	Total cylinder filled
Month/year		Index	Index	Index	Index	Index	Index	Index	Index	

01/03/23	500	1859218	12716	15899	1877690	4511102	2157682	2717082	127920	3703
02/03/23	500	1871939	12639	20005	1877802	4514552	2160838	2718199	128371	2324
03/03/23	500	1884660	11852	18301	1877914	4518002	2163994	2719316	128822	2453
04/03/23	500	1897381	13137	22895	1878026	4521452	2167150	2720433	129273	2951
05/03/23	500	1910102	12394	8665	1878138	4524902	2170306	2721550	129724	2954
06/03/23	500	1922823	11760	13959	1878250	4528352	2173462	2722667	130175	3715
07/03/23	500	1935544	9157	17805	1878362	4531802	2176618	2723784	130626	3184
08/03/23	500	1948265	12618	11427	1878474	4535252	2179774	2724901	131077	2561
09/03/23	500	1960986	11434	23011	1878586	4538702	2182930	2726018	131528	2793
10/03/23	500	1973707	7841	23435	1878698	4542152	2186086	2727135	131979	3427
11/03/23	500	1986428	10492	9668	1878810	4545602	2189242	2728252	132430	2743
12/03/23	500	1999149	10841	17815	1878922	4549052	2192398	2729369	132881	3221
13/03/23	500	2011870	9623	16377	1879034	4552502	2195554	2730486	133332	2448
14/03/23	500	2024591	8639	10672	1879146	4555952	2198710	2731603	133783	3247
15/03/23	500	2037312	12259	11197	1879258	4559402	2201866	2732720	134234	3491
16/03/23	500	2050033	8178	17375	1879370	4562852	2205022	2733837	134685	2247
17/03/23	500	2062754	12752	9555	1879482	4566302	2208178	2734954	135136	3776
18/03/23	500	2075475	12187	17315	1879594	4569752	2211334	2736071	135587	2495

19/03/23	500	2088196	11512	14545	1879706	4573202	2214490	2737188	136038	3272
20/03/23	500	2100917	8003	15370	1879818	4576652	2217646	2738305	136489	2348
21/03/23	500	2113638	9093	27240	1879930	4580102	2220802	2739422	136940	2426
22/03/23	500	2126359	12035	23180	1880042	4583552	2223958	2740539	137391	2822
23/03/23	500	2139080	8487	20919	1880154	4587002	2227114	2741656	137842	2421
24/03/23	500	2151801	12066	19346	1880266	4590452	2230270	2742773	138293	1988
25/03/23	500	2164522	10226	17543	1880378	4593902	2233426	2743890	138744	2675
26/03/23	500	2177243	10884	9062	1880490	4597352	2236582	2744007	139195	3032
27/03/23	500	2189964	10215	17906	1880602	4600802	2239738	2744124	139646	2762
28/03/23	500	2202685	11472	29174	1880714	4604252	2242894	2745241	140097	2543
29/03/23	500	2215406	12185	23150	1880826	4607702	2246050	2745358	140548	1987
30/03/23	500	2228127	8082	20104	1880938	4600986	2247875	2746124	140999	2187
31/03/23	500	2236900	9984	15957	1881045	4610945	2248474	2746687	141445	2215
	Total	**377,682kg**			**3355 kg**	**99843kg**	**90792kg**	**29605 kg**	**13525kg**	**82984 cylinders**

Then the capacity for both compressors to produce a Co2 gas in a month is 500*2*23*30=690,000

The observed capacity or the actual output for a month is 356553 kg so the capacity utilization for the compressor 1 and 2 is.

$$CU = 377,682kg / 720000 = 0.5245$$

Which is 52.45% of the capacity is utilized?

The total cylinder filled per month is 82984 from this 35% of 10kg, 25% of 15kg, 25% of 20kg and 15% of 25kg cylinders.

Which are

- 29,044.4 of 10kg cylinders
- 20,746 of 15kg cylinders
- 20,746 of 20kg cylinders
- 12,447.6 of 25kg cylinders

290,444+311,190+414,920+311,190= **1,327,744 kg**

The total Co2 gas used per month is

3355 kg+99843kg+90792 kg+29605 kg+13525kg +1,327,744 kg= 1,564,864 kg

Date	Capacity of each compressor (kg/h)	Co2 generation after two compressors	Storage tank 1,20 ton	Storage 2,30 ton	Bottling	New Kegging	Filtration	Wastewater treatment	Brew house	Total cylinder filled
Month/year		Index	Index	Index	Index	Index	Index	Index	Index	
01/04/23	500	2236906	8406	10211	1881045	4610945	2248474	2746687	141445	2975
02/04/23	500	2248420	13856	4156	1881155	4614566	2251396	2747820	141950	2363
03/04/23	500	2259934	12782	24619	1881265	4618187	2254318	2748953	142455	2753
04/04/23	500	2271448	9717	14697	1881375	4621808	2257240	2750086	142960	2921
05/04/23	500	2282962	11779	14568	1881485	4625429	2260162	2751219	143465	3254
06/04/23	500	2294476	13190	19194	1881595	4629050	2263084	2752352	143970	2717
07/04/23	500	2305990	1307	17666	1881705	4632671	2266006	2753485	144475	2189

			0							
08/04/23	500	2317504	8501	15640	1881815	4636292	2268928	2754618	144980	2868
09/04/23	500	2329018	8120	6718	1881925	4639913	2271850	2755751	145485	3140
10/04/23	500	2340532	8728	9980	1882035	4643534	2274772	2756884	145990	2467
11/04/23	500	2352046	13233	12113	1882145	4647155	2277694	2758017	146495	3003
12/04/23	500	2363560	13046	6974	1882255	4650776	2280616	2759150	147000	2276
13/04/23	500	2375074	9679	15430	1882365	4654397	2283538	2760283	147505	1980
14/04/23	500	2386588	15594	13495	1882475	4658018	2286460	2761416	148010	2105
15/04/23	500	2398102	12125	6818	1882585	4661639	2289382	2762549	148515	2491
16/04/23	500	2409616	8989	5969	1882695	4665260	2292304	2763682	149020	3247
17/04/23	500	2421130	10799	11396	1882805	4668881	2295226	2764815	149525	2776
18/04/23	500	2432644	11409	24310	1882915	4672502	2298148	2765948	150030	2991
19/04/23	500	2444158	9958	28559	1883025	4676123	2301070	2767081	150535	2292
20/04/23	500	2455672	11091	27779	1883135	4679744	2303992	2768214	151040	3307
21/04/23	500	2467186	13790	18768	1883245	4683365	2306914	2769347	151545	1426
22/04/23	500	2478700	13453	10149	1883355	4686986	2309836	2770480	152050	0
23/04/23	500	2490214	8675	22684	1883465	4690607	2312758	2771613	152555	0
24/04/23	500	2524756	9561	20917	1883575	4694228	2315680	2772746	153060	1872
25/042/23	500	2536270	11819	8224	1883685	4697849	2318602	2773879	153565	1935
26/04/23	500	2547784	9409	11853	1883795	4701470	2321524	2775012	154070	2047
27/04/23	500	2559298	12340	11232	1883905	4705091	2324446	2776145	154575	2921
28/04/23	500	2578892	1041	6693	1884389	4711167	2333123	2780369	156509	2053

			9							
29/04/23	500	2444158	9958	28559	1883025	4676123	2301070	2767081	150535	2292
30/04/23	500	2490214	8675	22684	1883465	4690607	2312758	2771613	152555	0
	Total	**341,986kg**			**3304 kg**	**100,220kg**	**87649kg**	**33,682 kg**	**15,064kg**	**66369cylinders**

Then the capacity for both compressors to produce a Co2 gas in a month is 500*2*23*30=690,000

The observed capacity or the actual output for a month is 356553 kg so the capacity utilization for the compressor 1 and 2 is.

CU=341,986/720000=0.4749

Which is 47.49% of the capacity is utilized?

The total cylinder filled per month is 66369 from this 35% of 10kg, 25% of 15kg, 25% of 20kg and 15% of 25kg cylinders.

Which are

- 23,229.19 of 10kg cylinders
- 16,592.25 of 15kg cylinders
- 16,592.25 of 20kg cylinders
- 9,955.35 of 25kg cylinders

232,291.5+248,883.75+331,845+248,883.75= **1,061,904 kg**

The total Co2 gas used per month is.

$$\mathbf{3304\ kg + 100,220kg\ kg + 87649\ kg\ + 33,682\ kg + \ 15,064\ kg + 1,061,904kg = \ 1,301,823\ kg}$$

Date	Capacity of each compressor	Co2 generation after two compres	Storage tank 1,20 ton	Storage 2,30 ton	Bottling	New Kegging	Filtration	Wastewater treatment	Brew house	Total cylinder filled

	(kg/h)	sors								
Month/ year		Index	Index	Index	Index	Index	Index	Index	Index	
01/05/23	500	2578892	13126	9641	1884349	4711167	2336123	2780369	156509	1898
02/05/23	500	2589998	7714	25295	1884430	4714500	2339100	2781290	156801	0
03/05/23	500	2601104	14059	19226	1884511	4717833	2342077	2782211	157093	2289
04/05/23	500	2612210	15257	27688	1884592	4721166	2345054	2783132	157385	3045
05/05/23	500	2623316	7819	17874	1884673	4724499	2348031	2784053	157677	3113
06/05/23	500	2634422	8171	26105	1884754	4727832	2351008	2784974	157969	2290
07/05/23	500	2645528	14146	12016	1884835	4731165	2353985	2785895	158261	1810
08/05/23	500	2656634	10917	9214	1884916	4734498	2356962	2786816	158553	2134
09/05/23	500	2667740	12403	10459	1884997	4737831	2359939	2787737	158845	0
10/05/23	500	2678846	10563	20187	1885078	4741164	2362916	2788658	159137	3422
11/05/23	500	2689952	9720	9317	1885159	4744497	2365893	2789579	159429	3132
12/05/23	500	2701058	14351	26513	1885240	4747830	2368870	2790500	159721	1864
13/05/23	500	2712164	8938	28849	1885321	4751163	2371847	2791421	160013	2098
14/05/23	500	2723270	15200	20734	1885402	4754496	2374824	2792342	160305	2143
15/05/23	500	2734376	9807	11373	1885483	4757829	2377801	2793263	160597	3121
16/05/23	500	2745482	15447	23614	1885564	4761162	2380778	2794184	160889	2908

17/05/23	500	2756588	10170	28235	1885645	4764495	2383755	2795105	161181	3200
18/05/23	500	2767694	16236	19211	1885726	4767828	2386732	2796026	161473	2897
19/05/23	500	2778800	11982	24724	1885807	4771161	2389709	2796947	161765	1875
20/05/23	500	2789906	8359	17701	1885888	4774494	2392686	2797868	162057	1678
21/05/23	500	2801012	8871	19562	1885969	4777827	2395663	2798789	162349	2284
22/05/23	500	2812118	11048	13187	1886050	4781160	2398640	2799710	162641	1737
23/05/23	500	2823224	8823	22232	1886131	4784493	2401617	2800631	162933	3424
24/05/23	500	2834330	16258	10595	1886212	4787826	2404594	2801552	163225	2323
25/05/23	500	2845436	14300	27839	1886293	4791159	2407571	2802473	163517	2131
26/05/23	500	2856542	16435	8548	1886374	4794492	2410548	2803394	163809	1221
27/05/23	500	2867648	16262	14615	1886455	4797825	2413525	2804315	164101	3321
28/05/23	500	2878754	9451	19667	1886536	4801158	2416502	2805236	164393	2121
29/05/23		2889860	8391	28956	1886617	4804491	2419479	2806157	164685	2332
30/05/23		2900966	16369	8192	1886698	4807824	2422456	2807078	164977	3441
31/05/23		2908534	10234	19290	1886760	4812440	2427713	2808703	165589	2312
	Total	**329,642 kg**			**2411 kg**	**101,273kg**	**91590kg**	**28334 kg**	**9080kg**	**71564cylinders**

Then the capacity for both compressors to produce a Co2 gas in a month is 500*2*23*30=690,000

The observed capacity or the actual output for a month is 356553 kg so the capacity utilization for the compressor 1 and 2 is.

$$\boldsymbol{CU = 329,642\ /720000 = 0.4578}$$

Which is 45.78% of the capacity is utilized?

The total cylinder filled per month is 71564 from this 35% of 10kg, 25% of 15kg, 25% of 20kg and 15% of 25kg cylinders.

Which are

- 25,047.4 of 10kg cylinders
- 17,891 of 15kg cylinders
- 17,891 of 20kg cylinders
- 10,734.6 of 25kg cylinders

250,474+268,365+357,820+268,365= **1,145,024 kg**

The total Co2 gas used per month is.

$$\boldsymbol{2411\ kg + 101,273kg\ kg + 91590\ kg\ + 28334\ kg + \ 9080\ kg + 1,145,024\ kg = \ 1,377,712\ kg}$$

Date	Capacity of each compressor (kg/h)	Co2 generation after two compressors	Daily production in kg	Storage tank 1,20 ton	Storage 2,30 ton	Bottling	New Kegging	Filtration	Wastewater treatment	Brew house	Total cylinder filled
Month /year		Index	Index	Index	Index	Index	Index	Index	Index	Index	
01/06/ 23	500	2908534	9284	11500	14950	1886760	4812442	2427720	2808703	165597	4242
02/06/ 23	500	2917325	8791	14570	10350	1886820	4813274	2429997	2809460	165904	5715
03/06/ 23	500	2927323	9998	15310	6610	1886880	4816629	2432274	2810220	166316	5982
04/06/	500	2939050	11727	15610	6950	1886940	4818925	2434551	2810982	166731	3223

23											
05/06/23	500	2951175	12125	16530	7380	1887000	4821922	2436828	2811728	166849	3280
06/06/23	500	2964625	13450	18120	23510	1887060	4824564	2439105	2812484	166850	3251
07/06/23	500	2975107	10482	17720	25420	1887120	4826628	2441382	2813242	167136	3860
08/06/23	500	2983072	7965	16890	22650	1887180	4829390	2443659	2813999	167507	5035
09/06/23	500	2992014	8942	13390	22470	1887240	4833141	2445936	2814743	167656	3548
10/06/23	500	2999269	7255	16850	14920	1887300	4835415	2448213	2815493	167951	3020
11/06/23	500	3004763	5494	16430	11290	1887360	4838200	2450490	2816259	168325	2002
12/06/23	500	3013538	8775	14290	11270	1887420	4841059	2452767	2817001	168568	3004
13/06/23	500	3022224	8686	13140	11120	1887480	4844198	2455044	2817759	168871	3046
14/06/23	500	3031641	9417	12710	11070	1887540	4846197	2457321	2818487	169061	3076
15/06/23	500	3040777	9136	12860	10930	1887600	4848283	2459598	2819235	169151	2006
16/06/23	500	3048489	7712	9690	10780	1887660	4851384	2461875	2819993	169616	3020
17/06/23	500	3056393	7904	9330	10740	1887720	4853625	2464152	2820748	169892	1976
18/06/23	500	3065888	9495	7980	10590	1887780	4857218	2468706	2821500	170117	2010
19/06/23	500	3073198	7310	5180	10520	1887840	4860452	2470983	2822248	170658	2000
20/06/23	500	3082037	8839	9840	4100	1887900	4864122	2473260	2822950	171256	0
21/06/23	500	3093787	11750	17270	22200	1887960	4867386	2475537	2823674	171522	1130

22/06/23	500	3106194	12407	16800	22810	1888020	4870964	2477814	2824445	172075	4009
23/06/23	500	3118221	12027	15860	22680	1888080	4874770	2480091	2825180	172409	4064
24/06/23	500	3132047	13826	18020	23190	1888140	4878724	2482368	2825929	173026	3049
25/06/23	500	3145416	13369	18880	26330	1888200	4881700	2484645	2826676	173600	4018
26/06/23	500	3159019	13603	19530	26130	1888260	4885530	2486922	2827412	173825	5160
27/06/23	500	3169496	10477	17340	26130	1888320	4887280	2489199	2828147	174074	5346
28/06/23	500	3181649	12148	17950	28650	1888380	4890295	2491476	2828892	174511	4004
29/06/23	500	3199346	12702	19720	29890	1888440	4892348	2493753	2829634	174817	3206
30/06/23	500	3265087	10741	20076	29670	1888500	4895545	2497981	2830374	175053	1937
	Total	**356553 kg**				**1,872kg**	**83,103kg**	**70,261kg**	**21,671kg**	**9,456kg**	**99,219**

Then the capacity for both compressors to produce a Co2 gas in a month is 500*2*23*30=690,000

The observed capacity or the actual output for a month is 356553 kg so the capacity utilization for the compressor 1 and 2 is.

$$CU = 356553/720000 = 0.4952$$

Which is 49.52% of the capacity is utilized?

The total cylinder filled per month is 99219from this 35% of 10kg, 25% of 15kg, 25% of 20kg and 15% of 25kg cylinders.

Which are

- 34,726.65 of 10kg cylinders
- 24,804.75 of 15kg cylinders

- 24,804.75 of 20kg cylinders
- 14,882.85 of 25kg cylinders

347,266.5+372,071.25+496,095+372,071.25= **1,587,504 kg**

The total Co2 gas used per month is.

$$\mathbf{1,872\,kg + 83,103\,kg + 70,261\,kg + 21,671\,kg + 9,456\,kg + 1,587,504\,kg = 1,773,867\,kg}$$

Date	Capacity of each compressor (kg/h)	Co2 generation after two compressors	Storage tank 1,20ton	Storage 2,30 ton	Bottling	New Kegging	Filtration	Wastewater treatment	Brew house
Month/ year		Index	Index	Index	Index	Index	Index	Index	Index
01/07/23	500	3265087	14572	7436	1888632	4895545	2497981	2830374	175053
02/07/23	500	3274850	14168	26275	1888696	4898335	2500450	2831125	175445
03/07/23	500	3284613	13291	14516	1888760	4901125	2502919	2831876	175837
04/07/23	500	3294376	16131	26053	1888824	4903915	2505388	2832627	176229
05/07/23	500	3304139	11546	15811	1888888	4906705	2507857	2833378	176621
06/07/23	500	3313902	8969	12459	1888952	4909495	2510326	2834129	177013
07/07/23	500	3323665	16703	24661	1889016	4912285	2512795	2834880	177405
08/07/23	500	3333428	12340	20997	1889080	4915075	2515264	2835631	177797
09/07/23	500	3343191	5696	25338	1889144	4917865	2517733	2836382	178189
10/07/2	500	3352954	13457	12628	1889	4920655	2520202	2837133	178581

3					208				
11/07/23	500	3362717	10989	20321	1889272	4923445	2522671	2837884	178973
12/07/23	500	3372480	6067	14596	1889336	4926235	2525140	2838635	179365
13/07/23	500	3382243	10472	11252	1889400	4929025	2527609	2839386	179757
14/07/23	500	3392006	5515	12271	1889464	4931815	2530078	2840137	180149
15/07/23	500	3401769	14200	16143	1889528	4934605	2532547	2840888	180541
16/07/23	500	3411532	13903	24022	1889592	4937395	2535016	2841639	180933
17/07/23	500	3421295	7166	13330	1889656	4940185	2537485	2842390	181325
18/07/23	500	3431058	14977	21630	1889720	4942975	2539954	2843141	181717
19/07/23	500	3440821	10380	14652	1889784	4945765	2542423	2843892	182109
20/07/23	500	3450584	14200	26139	1889848	4948555	2544892	2844643	182501
21/07/23	500	3460347	13902	10361	1889912	4951345	2547361	2845394	182893
22/07/23	500	3470110	9203	15850	1889976	4954135	2549830	2846145	183285
23/07/23	500	3479873	8221	9243	1890040	4956925	2552299	2846896	183677
24/07/23	500	3489636	15320	26184	1890104	4959715	2554768	2847647	184069
25/07/23	500	3499399	6294	19248	1890168	4962505	2557237	2848398	184461
26/07/23	500	3509162	14123	7626	1890232	4965295	2559706	2849149	184853

27/07/23	500	3518925	14895	17356	1890296	4968085	2562175	2849900	185245
28/07/23	500	3528688	10496	19169	1890360	4970875	2564644	2850651	185637
29/07/23	500	3538451	11621	24978	1890424	4973665	2567113	2851402	186029
30/07/23	500	3548214	14870	7391	1890488	4976455	2569582	2852153	186421
31/07/23	500	3567744	12158	17453	1890613	4981591	2574418	2853477	187140
	Total	**302,657 kg**			**1981 kg**	**86046kg**	**76437kg**	**23103 kg**	**12087kg**

Then the capacity for both compressors to produce a Co2 gas in a month is 500*2*23*30=690,000

The observed capacity or the actual output for a month is 356553 kg so the capacity utilization for the compressor 1 and 2 is.

$$\boldsymbol{CU = 302,657\ /720000 = 0.4203}$$

Which is 42.03% of the capacity is utilized?

The total cylinder filled per month is 69025 from this 35% of 10kg, 25% of 15kg, 25% of 20kg and 15% of 25kg cylinders.

Which are

- 24,158.75 of 10kg cylinders
- 17,256.25 of 15kg cylinders
- 17,256.25 of 20kg cylinders
- 10,353.75 of 25kg cylinders

241,587.5+258,843.75+345,125+258,843.75= **1,104,400 kg**

The total Co2 gas used per month is

$$1981kg + 86046kg + 76437\ kg + 23103\ kg + 12087\ kg + 1,104,400\ kg$$
$$= 1,304,054\ kg$$

Annex-II
Air plant data

Date	Ingorsol SM90	Capacity (m3/hr)	Ingorsol SM150	Capacity (m3/hr)	Ingorsol SL150	Capacity (m3/hr)
	Running hour		Running hour		Running hour	
01/07/23	77743	816	58781	1500	15901	1560
02/07/23	77754	816	58789	1500	15917	1560
03/07/23	77765	816	58797	1500	15933	1560
04/07/23	77776	816	58805	1500	15949	1560
05/07/23	77787	816	58813	1500	15965	1560
06/07/23	77798	816	58821	1500	15981	1560
07/07/23	77809	816	58829	1500	15997	1560
08/07/23	77820	816	58837	1500	16013	1560
09/07/23	77831	816	58845	1500	16029	1560
10/07/23	77842	816	58853	1500	16045	1560
11/07/23	77853	816	58861	1500	16061	1560
12/07/23	77864	816	58869	1500	16077	1560
13/07/23	77875	816	58877	1500	16093	1560
14/07/23	77886	816	58885	1500	16109	1560
15/07/23	77897	816	58893	1500	16125	1560
16/07/23	77908	816	58901	1500	16141	1560
17/07/23	77919	816	58909	1500	16157	1560
18/07/23	77930	816	58917	1500	16173	1560
19/07/23	77941	816	58925	1500	16189	1560
20/07/23	77952	816	58933	1500	16205	1560

21/07/23	77963	816	58941	1500	16221	1560
22/07/23	77974	816	58949	1500	16237	1560
23/07/23	77985	816	58957	1500	16253	1560
24/07/23	77996	816	58965	1500	16269	1560
25/07/23	78007	816	58973	1500	16285	1560
26/07/23	78018	816	58981	1500	16301	1560
27/07/23	78029	816	58989	1500	16317	1560
28/07/23	78040	816	58997	1500	16333	1560
29/07/23	78051	816	59005	1500	16349	1560
30/07/23	78062	816	59013	1500	16365	1560
31/07/23	78073	816	59021	1500	16381	1560
Total monthly running hour	330		240		480	

Date	Ingorsol SM90	Capacity (m3/hr)	Ingorsol SM150	Capacity (m3/hr)	Ingorsol SL150	Capacity (m3/hr)
	Running hour		Running hour		Running hour	
01/06/23	77442	816	58457	1500	15461	1560
02/06/23	77452	816	58468	1500	15475	1560
03/06/23	77462	816	58479	1500	15489	1560
04/06/23	77472	816	58490	1500	15503	1560
05/06/23	77482	816	58501	1500	15517	1560
06/06/23	77492	816	58512	1500	15531	1560
07/06/23	77502	816	58523	1500	15545	1560
08/06/23	77512	816	58534	1500	15559	1560
09/06/23	77522	816	58545	1500	15573	1560

10/06/23	77532	816	58556	1500	15587	1560
11/06/23	77542	816	58567	1500	15601	1560
12/06/23	77552	816	58578	1500	15615	1560
13/06/23	77562	816	58589	1500	15629	1560
14/06/23	77572	816	58600	1500	15643	1560
15/06/23	77582	816	58611	1500	15657	1560
16/06/23	77592	816	58622	1500	15671	1560
17/06/23	77602	816	58633	1500	15685	1560
18/06/23	77612	816	58644	1500	15699	1560
19/06/23	77622	816	58655	1500	15713	1560
20/06/23	77632	816	58666	1500	15727	1560
21/06/23	77642	816	58677	1500	15741	1560
22/06/23	77652	816	58688	1500	15755	1560
23/06/23	77662	816	58699	1500	15769	1560
24/06/23	77672	816	58710	1500	15783	1560
25/06/23	77682	816	58721	1500	15797	1560
26/06/23	77692	816	58732	1500	15811	1560
27/06/23	77702	816	58743	1500	15825	1560
28/06/23	77712	816	58754	1500	15839	1560
29/06/23	77722	816	58765	1500	15853	1560
30/06/23	77739	816	58788	1500	15897	1560
Total monthly running hour	297		321		436	

Date	Ingorsol SM90	Capacity (m3/hr)	Ingorsol SM150	Capacity (m3/hr)	Ingorsol SL150	Capacity (m3/hr)

	Running hour		Running hour		Running hour	
01/05/23	77096	816	58103	1500	15037	1560
02/05/23	77108	816	58115	1500	15052	1560
03/05/23	77120	816	58127	1500	15067	1560
04/05/23	77132	816	58139	1500	15082	1560
05/05/23	77144	816	58151	1500	15097	1560
06/05/23	77156	816	58163	1500	15112	1560
07/05/23	77168	816	58175	1500	15127	1560
08/05/23	77180	816	58187	1500	15142	1560
09/05/23	77192	816	58199	1500	15157	1560
10/05/23	77204	816	58211	1500	15172	1560
11/05/23	77216	816	58223	1500	15187	1560
12/05/23	77228	816	58235	1500	15202	1560
13/05/23	77240	816	58247	1500	15217	1560
14/05/23	77252	816	58259	1500	15232	1560
15/05/23	77264	816	58271	1500	15247	1560
16/05/23	77276	816	58283	1500	15262	1560
17/05/23	77288	816	58295	1500	15277	1560
18/05/23	77300	816	58307	1500	15292	1560
19/05/23	77312	816	58319	1500	15307	1560
20/05/23	77324	816	58331	1500	15322	1560
21/05/23	77336	816	58343	1500	15337	1560
22/05/23	77348	816	58355	1500	15352	1560
23/05/23	77360	816	58367	1500	15367	1560
24/05/23	77372	816	58379	1500	15382	1560
25/05/23	77384	816	58391	1500	15397	1560
26/05/23	77396	816	58403	1500	15412	1560

27/05/23	77408	816	58415	1500	15427	1560
28/05/23	77420	816	58427	1500	15442	1560
29/05/23	77432	816	58439	1500	15453	1560
30/05/23	77438	816	58451	1500	15458	1560
Total monthly running hour	346		354		408	

Date	Ingorsol SM90	Capacity (m3/hr)	Ingorsol SM150	Capacity (m3/hr)	Ingorsol SL150	Capacity (m3/hr)
	Running hour		Running hour		Running hour	
01/04/23	77227	816	58046	1500	15139	1560
02/04/23	77235	816	58061	1500	15151	1560
03/04/23	77243	816	58076	1500	15163	1560
04/04/23	77251	816	58091	1500	15175	1560
05/04/23	77259	816	58106	1500	15187	1560
06/04/23	77267	816	58121	1500	15199	1560
07/04/23	77275	816	58136	1500	15211	1560
08/04/23	77283	816	58151	1500	15223	1560
09/04/23	77291	816	58166	1500	15235	1560
10/04/23	77299	816	58181	1500	15247	1560
11/04/23	77307	816	58196	1500	15259	1560
12/04/23	77315	816	58211	1500	15271	1560
13/04/23	77323	816	58226	1500	15283	1560
14/04/23	77331	816	58241	1500	15295	1560
15/04/23	77339	816	58256	1500	15307	1560
16/04/23	77347	816	58271	1500	15319	1560

17/04/23	77355	816	58286	1500	15331	1560
18/04/23	77363	816	58301	1500	15343	1560
19/04/23	77371	816	58316	1500	15355	1560
20/04/23	77379	816	58331	1500	15367	1560
21/04/23	77387	816	58346	1500	15379	1560
22/04/23	77395	816	58361	1500	15391	1560
23/04/23	77403	816	58376	1500	15403	1560
24/04/23	77411	816	58391	1500	15415	1560
25/04/23	77419	816	58406	1500	15427	1560
26/04/23	77427	816	58421	1500	15439	1560
27/04/23	77435	816	58436	1500	15451	1560
28/04/23	77442	816	58457	1500	15461	1560
29/04/23	77379	816	58331	1500	15367	1560
30/04/23	77427	816	58421	1500	15439	1560
Total monthly running hour	215		411		322	

Date	Ingorsol SM90	Capacity (m3/hr)	Ingorsol SM150	Capacity (m3/hr)	Ingorsol SL150	Capacity (m3/hr)
	Running hour		Running hour		Running hour	
01/03/23	76430	816	57186	1500	14041	1560
02/03/23	76441	816	57200	1500	14057	1560
03/03/23	76452	816	57214	1500	14073	1560
04/03/23	76463	816	57228	1500	14089	1560
05/03/23	76474	816	57242	1500	14105	1560
06/03/23	76485	816	57256	1500	14121	1560

07/03/23	76496	816	57270	1500	14137	1560
08/03/23	76507	816	57284	1500	14153	1560
09/03/23	76518	816	57298	1500	14169	1560
10/03/23	76529	816	57312	1500	14185	1560
11/03/23	76540	816	57326	1500	14201	1560
12/03/23	76551	816	57340	1500	14217	1560
13/03/23	76562	816	57354	1500	14233	1560
14/03/23	76573	816	57368	1500	14249	1560
15/03/23	76584	816	57382	1500	14265	1560
16/03/23	76595	816	57396	1500	14281	1560
17/03/23	76606	816	57410	1500	14297	1560
18/03/23	76617	816	57424	1500	14313	1560
19/03/23	76628	816	57438	1500	14329	1560
20/03/23	76639	816	57452	1500	14345	1560
21/03/23	76650	816	57466	1500	14361	1560
22/03/23	76661	816	57480	1500	14377	1560
23/03/23	76672	816	57494	1500	14393	1560
24/03/23	76683	816	57508	1500	14409	1560
25/03/23	76694	816	57522	1500	14425	1560
26/03/23	76705	816	57536	1500	14441	1560
27/03/23	76716	816	57550	1500	14457	1560
28/03/23	76727	816	57564	1500	14473	1560
29/03/23	76738	816	57578	1500	14489	1560
30/03/23	76741	816	57592	1500	14505	1560
31/03/23	76748	816	57614	1500	14529	1560
Total monthly running	318		428		488	

hour						

Date	Ingorsol SM90	Capacity (m3/hr)	Ingorsol SM150	Capacity (m3/hr)	Ingorsol SL150	Capacity (m3/hr)
	Running hour		Running hour		Running hour	
01/02/23	76748	816	57614	1500	14529	1560
02/02/23	76759	816	57631	1500	14545	1560
03/02/23	76770	816	57648	1500	14561	1560
04/02/23	76781	816	57665	1500	14577	1560
05/02/23	76792	816	57682	1500	14593	1560
06/02/23	76803	816	57699	1500	14609	1560
07/02/23	76814	816	57716	1500	14625	1560
08/02/23	76825	816	57733	1500	14641	1560
09/02/23	76836	816	57750	1500	14657	1560
10/02/23	76847	816	57767	1500	14673	1560
11/02/23	76858	816	57784	1500	14689	1560
12/02/23	76869	816	57801	1500	14705	1560
13/02/23	76880	816	57818	1500	14721	1560
14/02/23	76891	816	57835	1500	14737	1560
15/02/23	76902	816	57852	1500	14753	1560
16/02/23	76913	816	57869	1500	14769	1560
17/02/23	76924	816	57886	1500	14785	1560
18/02/23	76935	816	57903	1500	14801	1560
19/02/23	76946	816	57920	1500	14817	1560
20/02/23	76957	816	57937	1500	14833	1560
21/02/23	76968	816	57954	1500	14849	1560
22/02/23	76979	816	57971	1500	14865	1560

23/02/23	76990	816	57988	1500	14881	1560
24/02/23	77001	816	58005	1500	14897	1560
25/02/23	77012	816	58022	1500	14913	1560
26/02/23	77023	816	58039	1500	14929	1560
27/02/23	77034	816	58056	1500	14945	1560
28/02/23	77045	816	58073	1500	14961	1560
Total monthly running hour	346		489		508	

Date	Ingorsol SM90	Capacity (m3/hr)	Ingorsol SM150	Capacity (m3/hr)	Ingorsol SL150	Capacity (m3/hr)
	Running hour		Running hour		Running hour	
01/01/23	77139	816	58069	1500	15004	1560
02/01/23	77149	816	58082	1500	15019	1560
03/01/23	77159	816	58095	1500	15034	1560
04/01/23	77169	816	58108	1500	15049	1560
05/01/23	77179	816	58121	1500	15064	1560
06/01/23	77189	816	58134	1500	15079	1560
07/01/23	77199	816	58147	1500	15094	1560
08/01/23	77209	816	58160	1500	15109	1560
09/01/23	77219	816	58173	1500	15124	1560
10/01/23	77229	816	58186	1500	15139	1560
11/01/23	77239	816	58199	1500	15154	1560
12/01/23	77249	816	58212	1500	15169	1560
13/01/23	77259	816	58225	1500	15184	1560
14/01/23	77269	816	58238	1500	15199	1560

15/01/23	77279	816	58251	1500	15214	1560
16/01/23	77289	816	58264	1500	15229	1560
17/01/23	77299	816	58277	1500	15244	1560
18/01/23	77309	816	58290	1500	15259	1560
19/01/23	77319	816	58303	1500	15274	1560
20/01/23	77329	816	58316	1500	15289	1560
21/01/23	77339	816	58329	1500	15304	1560
22/01/23	77349	816	58342	1500	15319	1560
23/01/23	77357	816	58355	1500	15334	1560
24/01/23	77369	816	58368	1500	15349	1560
25/01/23	77379	816	58381	1500	15364	1560
26/01/23	77389	816	58394	1500	15379	1560
27/01/23	77398	816	58407	1500	15394	1560
28/01/23	77409	816	58420	1500	15409	1560
29/01/23	77429	816	58433	1500	15424	1560
30/01/23	77442	816	58457	1500	15461	1560
Total monthly running hour	303		388		457	

Date	Ingorsol SM90	Capacity (m3/hr)	Ingorsol SM150	Capacity (m3/hr)	Ingorsol SL150	Capacity (m3/hr)
	Running hour		Running hour		Running hour	
01/12/22	76767	816	57605	1500	14588	1560
02/12/22	76779	816	57620	1500	14601	1560
03/12/22	76791	816	57635	1500	14614	1560
04/12/22	76803	816	57650	1500	14627	1560

05/12/22	76815	816	57665	1500	14640	1560
06/12/22	76827	816	57680	1500	14653	1560
07/12/22	76839	816	57695	1500	14666	1560
08/12/22	76851	816	57710	1500	14679	1560
09/12/22	76863	816	57725	1500	14692	1560
10/12/22	76875	816	57740	1500	14705	1560
11/12/22	76887	816	57755	1500	14718	1560
12/12/22	76899	816	57770	1500	14731	1560
13/12/22	76911	816	57785	1500	14744	1560
14/12/22	76923	816	57800	1500	14757	1560
15/12/22	76935	816	57815	1500	14770	1560
16/12/22	76947	816	57830	1500	14783	1560
17/12/22	76959	816	57845	1500	14796	1560
18/12/22	76971	816	57860	1500	14809	1560
19/12/22	76983	816	57875	1500	14822	1560
20/12/22	76995	816	57890	1500	14835	1560
21/12/22	77007	816	57905	1500	14848	1560
22/12/22	77019	816	57920	1500	14861	1560
23/12/22	77031	816	57935	1500	14874	1560
24/12/22	77043	816	57950	1500	14887	1560
25/12/22	77055	816	57965	1500	14900	1560
26/12/22	77067	816	57980	1500	14913	1560
27/12/22	77079	816	57995	1500	14926	1560
28/12/22	77091	816	58010	1500	14939	1560
29/12/22	77103	816	58025	1500	14952	1560
30/12/22	77115	816	58040	1500	14965	1560
31/12/22	77137	816	58069	1500	15001	1560

Total monthly running hour	370		464		413	

Date	Ingorsol SM90	Capacity (m3/hr)	Ingorsol SM150	Capacity (m3/hr)	Ingorsol SL150	Capacity (m3/hr)
	Running hour		Running hour		Running hour	
01/11/22	76390	816	57194	1500	14085	1560
02/11/22	76403	816	57208	1500	14102	1560
03/11/22	76416	816	57222	1500	14119	1560
04/11/22	76429	816	57236	1500	14136	1560
05/11/22	76442	816	57250	1500	14153	1560
06/11/22	76455	816	57264	1500	14170	1560
07/11/22	76468	816	57278	1500	14187	1560
08/11/22	76481	816	57292	1500	14204	1560
09/11/22	76494	816	57306	1500	14221	1560
10/11/22	76507	816	57320	1500	14238	1560
11/11/22	76520	816	57334	1500	14255	1560
12/11/22	76533	816	57348	1500	14272	1560
13/11/22	76546	816	57362	1500	14289	1560
14/11/22	76559	816	57376	1500	14306	1560
15/11/22	76572	816	57390	1500	14323	1560
16/11/22	76585	816	57404	1500	14340	1560
17/11/22	76598	816	57418	1500	14357	1560
18/11/22	76611	816	57432	1500	14374	1560
19/11/22	76624	816	57446	1500	14391	1560
20/11/22	76637	816	57460	1500	14408	1560

21/11/22	76650	816	57474	1500	14425	1560
22/11/22	76663	816	57488	1500	14442	1560
23/11/22	76676	816	57502	1500	14459	1560
24/11/22	76689	816	57516	1500	14476	1560
25/11/22	76702	816	57530	1500	14493	1560
26/11/22	76715	816	57544	1500	14510	1560
27/11/22	76728	816	57558	1500	14527	1560
28/11/22	76741	816	57572	1500	14544	1560
29/11/22	76754	816	57586	1500	14561	1560
30/11/22	76767	816	57605	1500	14588	1560
Total monthly running hour	377		411		503	