IMPROVEMENT IN CONDENSATE RECOVERY FOR ENERGY CONSERVATION USING SIX SIGMA METHODOLOGY IN A TEXTILE INDUSTRY

By

Abdul Qadeer Hussain Shah

(Registration No: 00000327238)

Department of Design and Manufacturing Engineering

School of Mechanical and Manufacturing Engineering

National University of Sciences & Technology (NUST)

Islamabad, Pakistan

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Supervisor: Dr. Shahid Ikramullah Butt

Co-Supervisor: Dr. Hussain Imran

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Signature:

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Date: 08 - Mar - 2024

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Examination Committee Members

1.	Name: Syed Hussain Imran Jaffery	Signature:
2.	Name: Muhammad Salman Khan	Signature:
3.	Name: Waqas Khalid	Signature:

Supervisor: Shahid Ikram Ullah Butt   Signature:

Date: 08 - Mar - 2024

Head of Department   08 - Mar - 2024

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Student Name: Abdul Qadeer Hussain Shah   Signature: ________________

Examination Committee:

Name: Dr. Hussain Imran   Signature: ________________

Name: Dr. Muhammad Salman Khan   Signature: ________________

Name: Dr. Waqas Khalid   Signature: ________________

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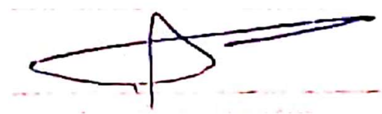

Student Signature: ____________________________

Name: Abdul Qadeer Hussain Shah

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Abdul Qadeer Hussain Shah

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LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

JIT	Just-in-Time Manufacturing
TPS	Toyota Production System
ILD	Indentation Load Deflection
RCFA	Root Cause Failure Analysis
DMAIC	Define Measure Analyze Improve and Control
DMADV	Define Measure Analyze Design Verify
TV PCB	Television Printed Circuit Boards
SPC	Statistical Process Control
DPMO	Defects per million opportunities

ABSTRACT

The hot byproduct of steam, called condensate, still retains 25% of the energy from the original steam. Rather than draining it, it makes more sense to return it to the boiler. In today's world, energy is a precious resource and we are facing an energy crisis. Pakistan is currently experiencing one of the worst energy crises in its history. As a result, the textile industry is struggling due to high production costs compared to other global markets. However, condensate has now become a valuable resource that can significantly reduce operating costs.

Every day, approximately 840 m3 of water is fed into the coal-fired steam boiler, which generates 820 tons of steam. 300 tons of steam are supplied to Processing Div. II, with 80 tons used directly on machines and the remaining steam used indirectly through heat exchangers. This leaves about 154 m3 of condensate at 80-90 ℃ that can either be wasted or returned to the system for reuse.

This report serves as an optimized tool for conducting a cost-benefit analysis of condensate recovery systems. Advanced techniques were used to identify the root causes of condensate wastage. A detailed audit of the Processing Div. II was conducted, data was collected and analyzed, and potential improvements were identified. Some repair and maintenance activities were completed and others are currently in progress. Ultimately, a model will be designed to find potential savings by upgrading the current condensate recovery system. This report promotes a zero-drain approach in the textile industry, contributing to a sustainable environment and reducing fabric costs.

Keywords: Lean and Six Sigma, DMAIC, Defects per million opportunities, Statistical Process Control, Root Cause Analysis

CHAPTER 1: INTRODUCTION

This portion of the report describes the background of the topics and articles that we needed to discuss before starting the project. Lean manufacturing was the most common topic we needed to understand. DMAIC Methodology and the necessary details of the relevant industry were required to initiate our project. The case studies related to lean manufacturing and value stream mapping have also been discussed.

1.1 Lean Manufacturing

Lean Manufacturing is one of the most widely used manufacturing techniques that is used throughout the industries of the world to get better efficiency and make the manufacturing process more efficient resulting in a wide increase in the productivity of the industries and the production rate. It includes the reduction in the defects and decreasing the cost of implementation that are causing the process to either slow down or reduce the output of the manufacturing process. This can be achieved in the form of fewer workers, less equipment and machinery required, minimum investment, and less inventory. The basic principles and techniques of lean manufacturing must be identified and understood. The basic approach includes: (1)

- The identification of wastes in the industry
- Standardizing the equipment and processes
- Maintaining the quality of products.

H.R. Budiman contemplated the impacts of actualizing lean manufacturing in a shoe organization. The waste assessment model was utilized to lessen the waste of the business. He recognized defects in the crude materials as a significant waste of the organization. For the necessary reason, a waste assessment survey was readied and the data from various sources was assembled. After the distinguishing proof of significant wastes, lean manufacturing was executed to decrease the defects and holding up time. The waste assessment model was effectively used to actualize the lean framework which eventually limited the waste and improved productivity.

Gokul Raju R. investigated the strategies to diminish the lead time and increase the creation pace of the creation line of a high-weight gate valve. Worth stream planning was utilized to execute lean manufacturing. The present status guide of the creation line was made and reproductions were raced to distinguish the likely territories of progress. The lead time determined was very on the high side. Because of the ill-advised parity of the assembly line, the creation was additionally low. Correspondingly, he recognized different issues and after adjustments, the future state guide of the assembly line was drawn. In the future state map, the hardware was improved and the format was additionally changed to make the progression of material and individuals smooth. Alongside esteem stream planning, different strategies like the 5S method were additionally utilized. It additionally increased the effectiveness of the assembly line while keeping the expense and space practically the same. (2)

Mohamed Abdelkhak examined the working of the assembly line of a Television Printed Circuit Board (TV PCB) in the Middle East industry. The significant information concerning the business was assembled and the simulations were performed to explore the territories of concern. The significant issue recognized was the ill-advised format and underutilization of the workers. In addition, the unevenness in the workstations was likewise watched. The discrete reproduction approach was utilized for the necessary reason. Various techniques were utilized to actualize the lean framework in the business to diminish the lead time and idle time of the laborers. The outcomes demonstrated that the lean framework adjusted the workstations by adjusting the workload on workers. It diminished the lead time of the assembly line up to 9% through the usage of workers and the assets were expanded by about 10%. The decrease in waste at last expanded the efficiency by 52% and the salary of the organization was expanded by around 17900 USD in just around a half year. (3)

1.1.1 Types of wastes

The lean manufacturing framework was first actualized by the Japanese organization. As per the Toyota Production System (TPS), seven significant wastes of any industry should be recognized and expelled to increase profitability. In TPS, these wastes are otherwise called "Muda". (2)

- The principal waste is defects in the parts been created. Any deformity in the parts is not just an outcome of wastage of vitality and time however it additionally increases the expense and impacts the notoriety of the organization.
- The subsequent waste is the creation of a bigger number of parts than required or requested by the clients.
- The third waste or Muda is the stock of the organization. The capacity cost is commonly increased because of stock and it can likewise bring about defects in the parts created.
- Another primary waste in the industry is the transportation of material or items starting with one spot and then onto the next. It doesn't enhance the item and increases the cost factor by and large. Most organizations center around limiting this sort of waste.
- The fifth Muda of the industry is the over-processing of any part. For the most part, it isn't distinguished as waste since it can upgrade the quality. In any case, preparing any part more than the client's interest is viewed as a waste by the created nations.
- The sixth waste as indicated by TPS is the movement of workers in the organization. The over-the-top and un-important development of workers brings about the waste of time and a decline underway.
- The seventh waste that each organization around is pausing. It additionally causes a waste of time and cash without expanding profitability. (4)

1.1.2 Techniques of Lean Manufacturing

The lean manufacturing framework essentially takes a shot at the methodology of constant improvement in the business. Nothing is impeccable in the business and it must be improved ceaselessly to adapt to the necessities of the modern age society. Japan is the pioneer in acquiring lean strategy with the world. Its standards were set by the Japanese manufacturing ventures which are:

- First of all, the basic requirements of the customer are taken into consideration to provide customer satisfaction by carefully analyzing the customer's area of interest in the product.
- The second part is to determine the values that can be profitable to the process taking place in the industry. There are some non-profitable values also present in the process of manufacturing. These values are also to be determined.
- In the next step, after determining the profitable and non-profitable values, the non-profitable values present in the process are to be removed to increase the productivity of the process.
- In the final step, all the steps performed above are repeated to make sure that all processes are done to the maximum efficiency to increase the production rate of the process. (5)

There are different tools used for applying the lean methodology in the industrial sector. Some of the important tools are listed below:

1.1.2.1 Kaizen 5S

The best technique that can be used for waste elimination from the process to increase the efficiency of the project and make the process more efficient is the Kaizen 5S tool. Kaizen 5S is very helpful in identifying the wastes and then removing the wastes present in the process. The process of this technique is demonstrated in Figure 1-1. The 5S of this tool includes

- Sort (Saiton): The basic function of the sort is to arrange the tools that are useful for the process and this arrangement is done to make the tools and products easy to use thus removing the chances of waste production.

- Straighten (Seiri): The basic function of straightening is to make a separation between useful tools for the process and non-useful tools for the process and then remove the non-useful processes.

- Shine (Seiketsu): The basic purpose of shine is to keep the quality of the product high by using different cleaning techniques. Both the sort and straighten processes are made sure to be conducted daily for the production to run smoothly and eliminate waste.

- Standardize (Seiso): The basic purpose of standardizing is to maintain the standard of the products and it can be maintained by increasing the quality of the product and reducing the time of production of the products. For the efficiency of the process to be enhanced some certain standards are to be achieved.

- Sustain (Shitsuke): In Sustain all the above four standards are made sure to be working efficiently so that the quality of the product is in good condition and continuous improvement in the process is taking place so that the standard of the product can be achieved for the customer. (6)

Figure 1-1 Kaizen 5S

1.1.2.2 Poka-Yoke

Poka-Yoke is a Japanese expression that signifies "Error Proofing" in English. Poka-Yoke is a technique that foretells the defects in the process before happening and then those defects can be taken care of even before they can have substantial damage to the manufacturing process. This makes this technique a very useful one in the manufacturing of products. It depends on the recognition of the problems and then the best way to stop the problems before they can have a dreadful effect on the process. It also includes the possibility of human error and operator fatigue when the process is taking place. Along these lines, the requirement for Quality Control after the procedure is essentially not required.

The objective of using Poka-Yoke:

The main objective of a Poka-Yoke is to remove the possibility of the error happening at any time in the future even before the process has committed the defect. The fundamental purpose of the Poka-Yoke technique is to remove the waste products that might happen in the process at any time thus removing the chances of defective production and a great deal of enhancement in the quality of the product.

Another Six Sigma Technique that is similar to that of Poka-Yoke is the Jab Yoke Technique. This type of technique takes the possibility of defects due to some human errors or fatigue and some errors due to the mechanical deficiency of the process. So, the basic use of this technique is limited to that of the Manufacturing or Administration Industry. (7)

Types of Poka-Yoke:

To detect the defects in the process and remove those defects to increase the efficiency of the process, there are three basic types of Poka-Yoke

- Visual Aids: Visual Aids are the type of Poka-Yoke that contains pictures or signs that are helpful in the detection of work procedures and the instructions that are required to ensure the correct working methods.

- Visual Control: Visual Control is the type of Poka-Yoke that uses the method of displaying the warning signals or signs if the process is having any type of possibility of deviation from the original process thus making the worker acknowledge the possibility of waste of production.

- Fail-Safe: Fail-Safe is a type of Poka-Yoke to ensure the safety of the process with the help of signals. If signals show the ensured waste production the worker is forced to take action otherwise there is no need to take action ensured by the signals (7)

Steps to Implement Poka-Yoke:

The following steps need to be taken to implement Poka-Yoke in an organization,

Define: This is the first step of the implementation of Poka-Yoke. In this step, all the possibilities which can cause defects in the process are observed and the major cause of the defect is to be defined in this step. In this step, only the major defects are identified and no further action is taken.

Measure: In the second step of the implementation of Poka-Yoke the basic defects values are measured and process capability is measured along with the control charts and other tools to measure the defects that are causing the downfall of the productivity of the process.

Analyze: The next step is the Analyze step which is used to find the basic cause due to which the defects are emerging in the process. In this process, thorough analysis of the process is done to make sure that all the causes can become clear which can lead to the implementation of the Poka-Yoke to remove the causes of defects and defects to enhance the quality of the process.

Improve: The next step is the Improve step in which a basic solution is suggested based on the Poka-Yoke techniques and tools and these techniques are applied to the root cause of the problem that was identified in the analysis phase.

Control: The last phase is the control phase. In this step, the Poka-Yoke has already been applied to improve the process, and testing of the implementation takes place in this step. The testing is done by comparing the processes before and after the implementation of a Poka-Yoke device. If the process capability is enhanced then it means that the process has increased its efficiency. There is another thing that is known as Zero Quality Control and it can only be achieved if the implementation of the Poka-Yoke device exactly fits the solution of the defect and the possibility of the error production becoming zero at any time in the future. (8)

1.2. Six Sigma Approach

Six Sigma Methodologies are one of the most common approaches in the manufacturing industries to remove the production waste from the process and as a result, provide an unusual increase in the production process and the most stable outcomes to the process. By using this approach, the possibility of the process making an error is minimized as much as possible to increase the quality of the process. It takes the process to a place where there are 3.4 defects in 1 million items. There are different methodologies, techniques, and tools involved in the Six Sigma Approach to solve the problems occurring in the process and increase the production rate of the process. (9)

1.2.1. Methodologies of Six Sigma

There are two methodologies which are discussed below

1.2.1.1. DMAIC

The existing operation processes are improved by using this methodology. DMAIC methodology is described in Figure 1-2 stands for,

Define: The basic purpose is to define the problem and the goal of the project.

Measure: The basic principle is to measure the severity of the problem in the current process.

Analyze: The basic process is to analyze the obtained data to find the possible root cause of the problem.

Improve: The basic principle is to improve the process by applying a solution to the problem.

Control: The main objective is to control the running of the process in the future. (10)

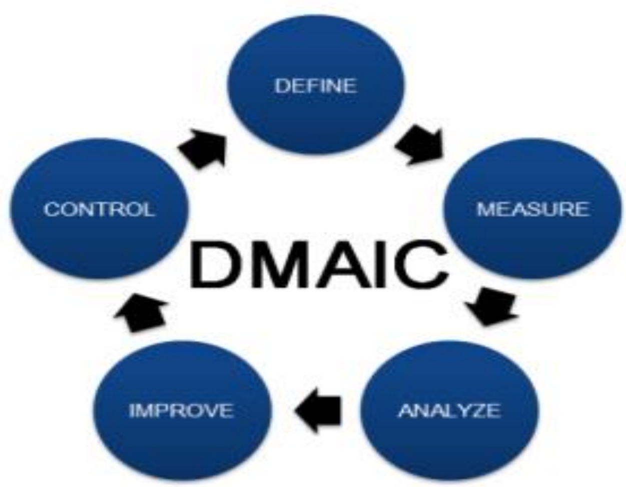


Figure 1-2 DMAIC Methodology

1.2.1.2. <u>DMADV</u>

The creation of new processes or products and services is done by using this methodology. DMADV is shown in Figure 1-3 stands for,

Define: The basic purpose is to define the goals of the project.

Measure: The basic principle is to measure the product capabilities and the critical components of the process.

Analyze: The most common objective is to analyze the obtained data to develop the best design for the process.

Design: The basic phenomenon is to design the selected process and test its details.

Verify: The basic function is to verify the design by running simulations before giving it to the customer. (11)

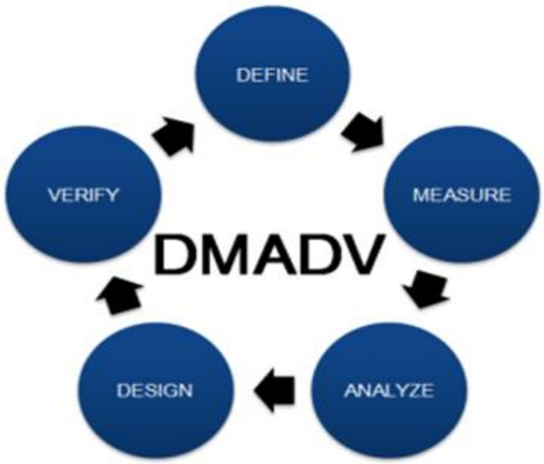


Figure 1-3 DMADV Methodology

1.2.2. Management Tools Used Within Six Sigma

1.2.2.1. Five Why's

The management tools are important when we are dealing with the Six Sigma methodology. Why means to question the reason behind the defect to reach the root cause of the problem. The five why's mean we have to consider five reasons of the question for the defect in the process. The questioning is very important as it helps us reach the root cause of the defect. In five why's all the questions are interrelated and the answer to one question relates to the other question until the root cause of the problems is determined. This type of tool is very helpful in getting to the root cause, that is causing the defects and as a result, preventing the process from repeating the same defects by applying the Six Sigma Methodology. (12)

1.2.2.2. <u>CTQ Tree</u>

Critical to Quality Tree is very helpful as it can break down the process based on the needs and requirements of the customer. As a result, the quality of the product manufacturing process is enhanced. The products and services are included in the process based on the eye of the customer. Thus, increasing the satisfaction level of the customers for your products and as a result of this enhancement, the productivity of the process increases as the customer satisfaction is increased by using the CTQ Tree which is one of the basic purposes of the Six Sigma Methodology. (13)

1.2.2.3. <u>Root Cause Analysis</u>

This is somewhat similar to the Five Why's tool as it also helps us find the root cause of the defect in the process. The difference is that in root cause analysis we remove the root cause itself completely rather than removing the symptoms caused by the defect. To find the root cause of the process the analysis is based on these steps;

- First of all, it has to be determined what has happened
- Secondly, determine the reason why the defects happened
- Lastly, we have to determine what we have to do to stop the defects from happening again and again.

After doing these steps you most probably have achieved the problem and have applied the Six Sigma Methodology to increase the productivity of a process. (14)

1.2.3. Software used for Statistical Process Control (SPC)

Statistical process control (SPC) is a quality control strategy that utilizes statistical techniques for monitoring and controlling a process. It further virtually guarantees the process is running effectively, creating more specification-compliant goods with fewer non-conformities. Some of the major SPC tools include run charts, control charts, proactive approach, and designing the process. The assembly lines are an illustration of a method where SPC is implemented.

In the current era, several soft wares are available which can aid in process control. While the graphs required to check the process control can be generated using pencil & paper the operation is time-consuming and hectic. Hence, for easy proceedings and high statistical accuracy, we use computerized software. A few are named as follows:

- Minitab
- QI Macros SPC Software Excel
- Mattec
- SPC for Excel

There are several other software wares available to perform SPC analysis, but we utilized "QI-macros" due to their easy accessibility and available Free-trial version.

1.2.4. Tools of Six Sigma:

There are many different tools used in this technique to successfully implement it. Some of them are explained below:

1.2.4.1. Pareto Chart

A Pareto Chart is a tool that is used to explain the analytical values using the Six Sigma methodology. It is an analytical tool that is used to describe the frequency and cumulative frequencies using bars and lines and give the analytical results of the data the analysis is to be made. A Pareto chart can also be used to find the major defect in any of the processes.

A Pareto Chart consists of 2 components. One is the bar chart and the other is the line chart.

The first one is the bar graph and the bars in it represent the defects that are observed during the process and the height of the bars is responsible for the percentage of effect that defect has on the process. The second one is the line graph and in the Pareto Chart line is the representation of the cumulative percentage that the defects have on the process.

One of the main processes of the Pareto Chart is the 80/20 rule. According to this rule, 20% of the causes produce an effect that is nearly equal to 80% or more. So, this process is very helpful in the determination of the major defect in the process and thus can be solved accordingly using Six Sigma techniques. (15)

1.2.4.2. Process Capability Histogram

A histogram is the representation of observed data in the form of bars that are from the different ranges set of the data. It shows the shape in which the data ranges are placed. One type of histogram is the process capability histogram. Process capability histogram shows the data ranges as well as the limits and some values like C_p and C_{pk}. The basic value that it gives is the percentage of defects that are present in the data set ranges.

The histogram can also give the highest value as well as the lowest value from the data set with the highest bar and the lowest bar. It is helpful in the determination of the data set capability. The process capability histogram shows a lot of data set values and we have to determine which factors we have to take into account depending on our observation of the problem statement.

The process capability histogram is a very helpful tool for a six-sigma process as it gives the range of our data set as well as the maximum and minimum values from our data set and also provides us with the percentage of defects that are present in our data set. (16)

1.2.4.3. Defects Per Million Opportunities (DPMO)

Defects Per Million Opportunities (DPMO) is a very helpful term in the Six Sigma Methodology. DPMO is a ratio of the defects number to the opportunities of the defects to be created multiplied by 1 million. The basic function of DPMO is to give the defects that can be generated in a process due to some certain nonconformity.

DPMO = (No. of Defects)/ (of Units ×No. of defects opportunities per unit) ×1 million

The calculation of DPMO is very helpful as it gives the accurate accuracy of the process. The lesser the DPMO present in the process, the better the process productivity is. In Six Sigma the approach is to reduce the defects and increase productivity. In this way, DPMO becomes a helpful tool in increasing productivity by reducing the value of DPMO in a process using techniques of Six Sigma. (17)

1.2.4.4. Sigma Level

Sigma Level is also an important term in the Methodology of Six Sigma. The greater sigma level is to be attained to increase the productivity of the process. The sigma level is the standard deviation present in the process. The lower the value of sigma is of the process, the more the process deviates from the standard thus producing more defects. There are two types of sigma levels

Sigma Level Short-Term is the most common of the sigma level. The Sigma level of a process is an equivalent unilateral figure of merit. The merit here takes into consideration the efficiency and effectiveness of the process. So, based on these merits the sigma level is almost always considered to be a short-term process capability.

The other one is the Sigma Level Long-Term. This level of sigma is mostly not considered but it is taken into account when the sigma level short-term doesn't give the complete efficiency and effectiveness of the process. In this type, the sigma level of a process is to be adjusted by the 1.5 Sigma level that is present. Let's say if the sigma level is 6 then the value of Sigma Level Long-Term will be 4.5 as it is always 1.5 less than the sigma level. (18)

1.2.4.5. X-Bar Chart:

The x-bar Chart is a control chart that gives the average value from the data set and upper and lower control limits. These charts are the basic tools of the Six Sigma methodology to find the control limit from the data set of measurements. If the values exceed the UCL and LCL then our product is in the defective range and the closer the values are to the average line the more stable our measurements are and our product is good.

To plot the X-bar chart, we must have the data set values with the variations. The larger the variations, the less our product manufactured is stable. So, we take a variety of values from the data set plot them on the X-bar control chart, and observe the pattern. UCL and LCL are the limits set by the manufacturer as he determines the defects must not exceed certain limits and these limits are UCL and LCL. If the values exceed these limits then there is some defect present in the process. This defect must be removed or dealt with before doing further work. (19)

1.2.4.6. R Chart:

Another type of control chart is the R Chart which is used to show the range of the data subgroup values in the form of a graph. The range of the groups means the monitoring of the process variability by dividing the readings into small subgroups which are present at regular intervals from each other. The LCL of R Charts is always taken 0 but the UCL depends on the process data capability. The center line of the R chart shows the range statistic. The closer the values are to the center line of the chart, the more accurate the data range is. For the process to keep working smoothly the data set should be in the range, which means it should not exceed the LCL and UCL of the range of the R Chart. Otherwise, the process will go out of control. So, for the process to stay in control, the data set must lie within the allowed range of the R Chart of the process. (20)

1.2.4.7. Ishikawa Diagram

Ishikawa Diagram also known as the "Cause and Effect Diagram" shows the causes of the possible failures in any of the processes and the effects those causes would have on the process. This type of tool is mostly used where the manufacturing of products is taking place to find the causes of delay and defects in the manufacturing of any certain product and gives the effects that they have on the total manufacturing of the product like delay in the time of manufacturing or reduced quality of the product.

In Ishikawa Diagram we determine all the defects that are present in the process by observing the process. Then based on our observations of the process we determine which of the factors are responsible for the major defects in the manufacturing of the product. After determining the major defect, the area where that defect is present is determined along with the effect of that defect/cause. Then the tools and techniques of Six Sigma are applied to that process to remove that defect/cause and make our manufacturing process smooth and our product profitable. (21)

CHAPTER 2: DEFINE PHASE

2.1 Introduction:

Processing Div. II of our Textile Industry is a 100% export-oriented, knitwear fabric dyeing, and finishing unit. Knitted fabric is received as Grieg fabric, which is the input to the dyeing process. The Grieg fabric is dyed, reduced, washed, and finished. Fabric is dyed with reactive and dispersed dyes. The finishing process involves applying finishes on the fabric and drying. The layout of the machines is shown in Figure 2-1.

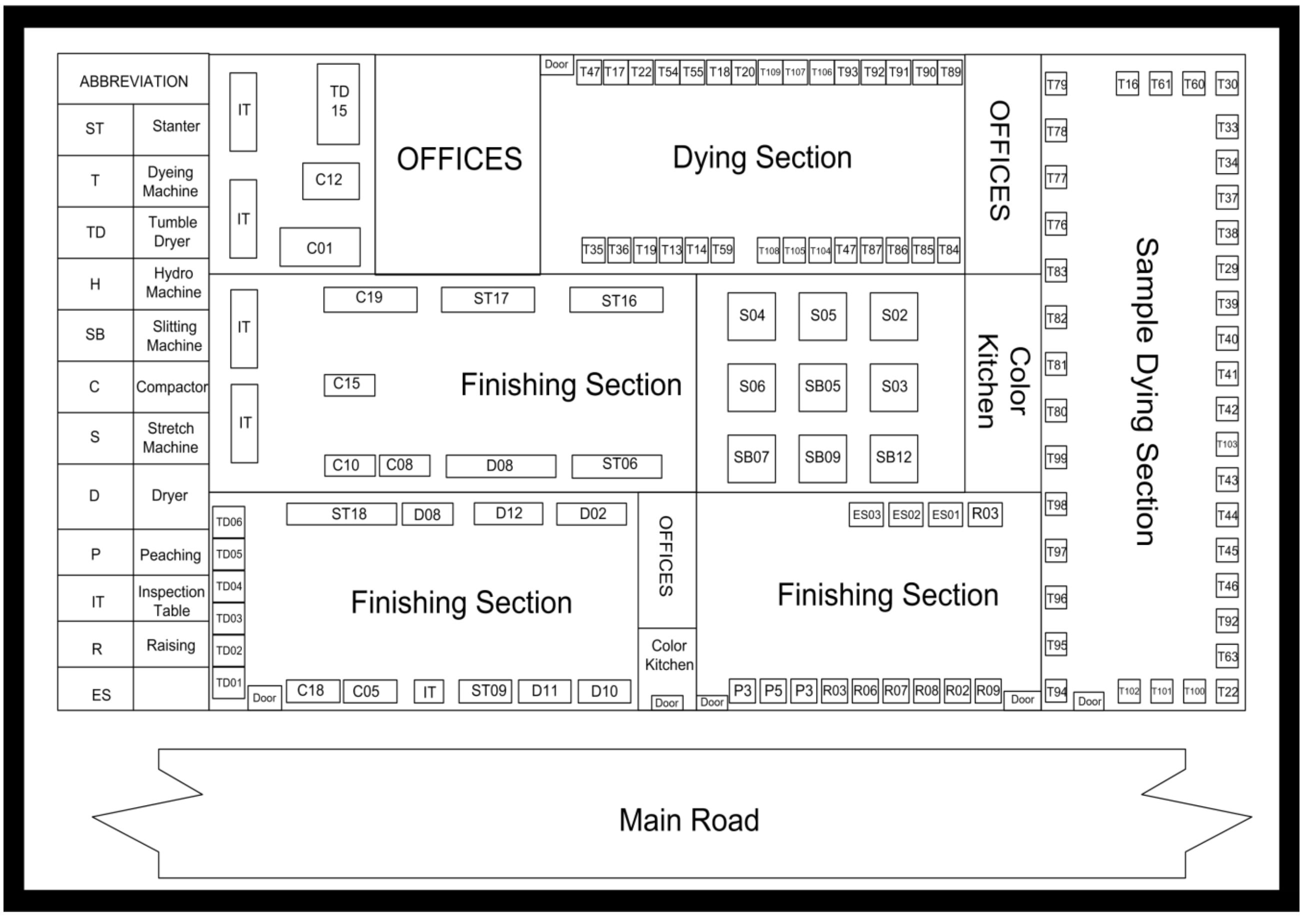


Figure 2-1 Layout Processing Division II

2.1.1 Machine's Detail

Details of the machines installed are shown in Table 2-1.

Table 2-1 Processing Division II Machine's Detail

Sr. No.	Machine Detail	Quantity [No.]
1	Dyeing – Production	29
2	Dyeing – Sampling	38
3	Finishing - Slitting & Stretch	9
4	Finishing – Stenter	6
5	Finishing – Dryer	6
6	Finishing – Compactor	8
7	Finishing - Raising & Peaching	4
8	Finishing – Others	11
9	Total	111

2.1.2 Production and Steam Consumption of Processing Div. II:

About 820 tons/day of steam is produced. Division of Production from different sources is shown in Figure 2-2. This steam is divided into different departments shown in Figure 2-3. Steam consumption in Processing Division II is shown in Figure 2-4.

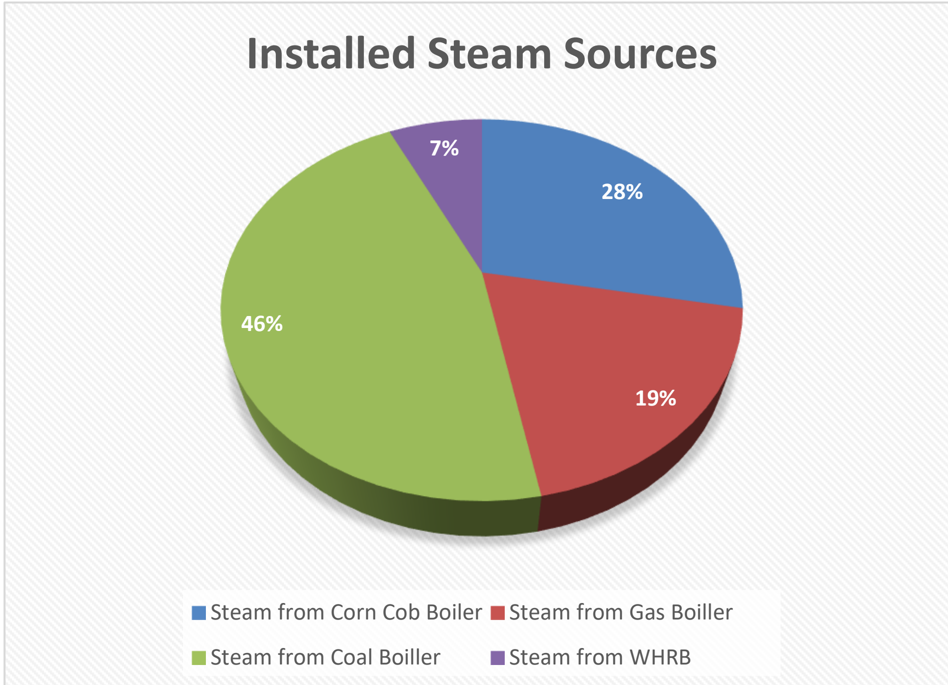


Figure 2-2 Steam Sources of Industry

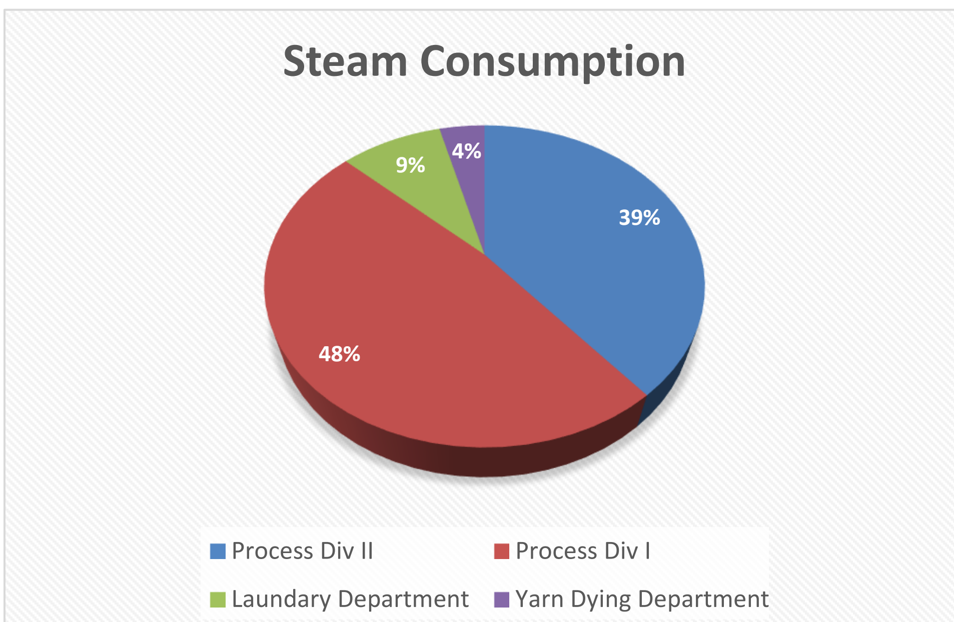


Figure 2-3 Steam Consumption of Industry

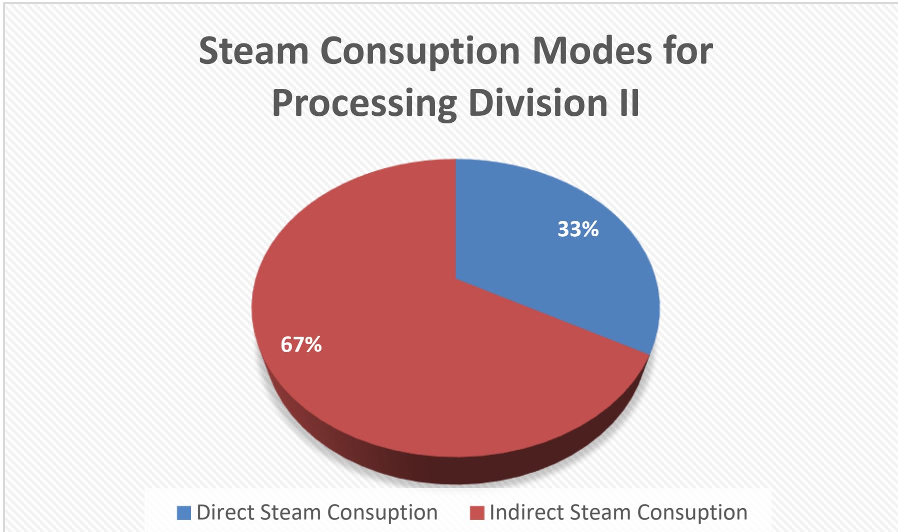


Figure 2-4 Steam Consumption of Processing Division II

Production of processing Div. II is approximately 35617 Kg/Day and 1769 Kg/Day is reprocessed because of different kinds of defects in the fabric. Production data from November 2020 to October 2021 is shown in Table 2-2.

Table 2-2 Production of Processing Division II

Month-Year	**Wash**	**Bleach**	**Production [kg]**	**Cotton**	**Polyester**	**Total**	**Reprocess**
			Cotton	**+PC**			
20-Nov	67,048	209,578	245,917	77,208	76,760	676,511	41,926
20-Dec	174,225	200,241	244,888	110,198	50,303	779,855	-
20-Jan	107,428	202,261	161,421	137,051	22,215	630,376	37,640
21-Feb	137,977	340,407	214,990	145,186	10,378	848,938	80,805
21-Mar	206,361	286,036	277,026	102,114	25,196	896,371	61,555
21-Apr	266,999	278,330	331,786	64,460	37,209	978,782	38,043
21-May	221,410	276,703	350,028	61,360	30,432	939,933	59,347
21-Jun	169,692	235,430	311,308	133,221	6,361	856,012	69,248
21-Jul	196,292	168,264	416,407	118,296	31,658	930,917	-
21-Aug	209,267	312,987	432,738	114,601	11,587	1,081,180	78,276
21-Sep	169,657	299,330	319,262	187,482	1,442	977,163	64,001
21-Oct	156,260	297,230	387,266	211,573	36,410	1,088,739	-
Total	2,082,616	3,106,797	3,693,025	1,462,750	339,994	10,685,137	530,841

2.1.3 Process Flow of Dyeing and Finishing Section:

The block diagram for the dyeing section is shown in Figure 2-5

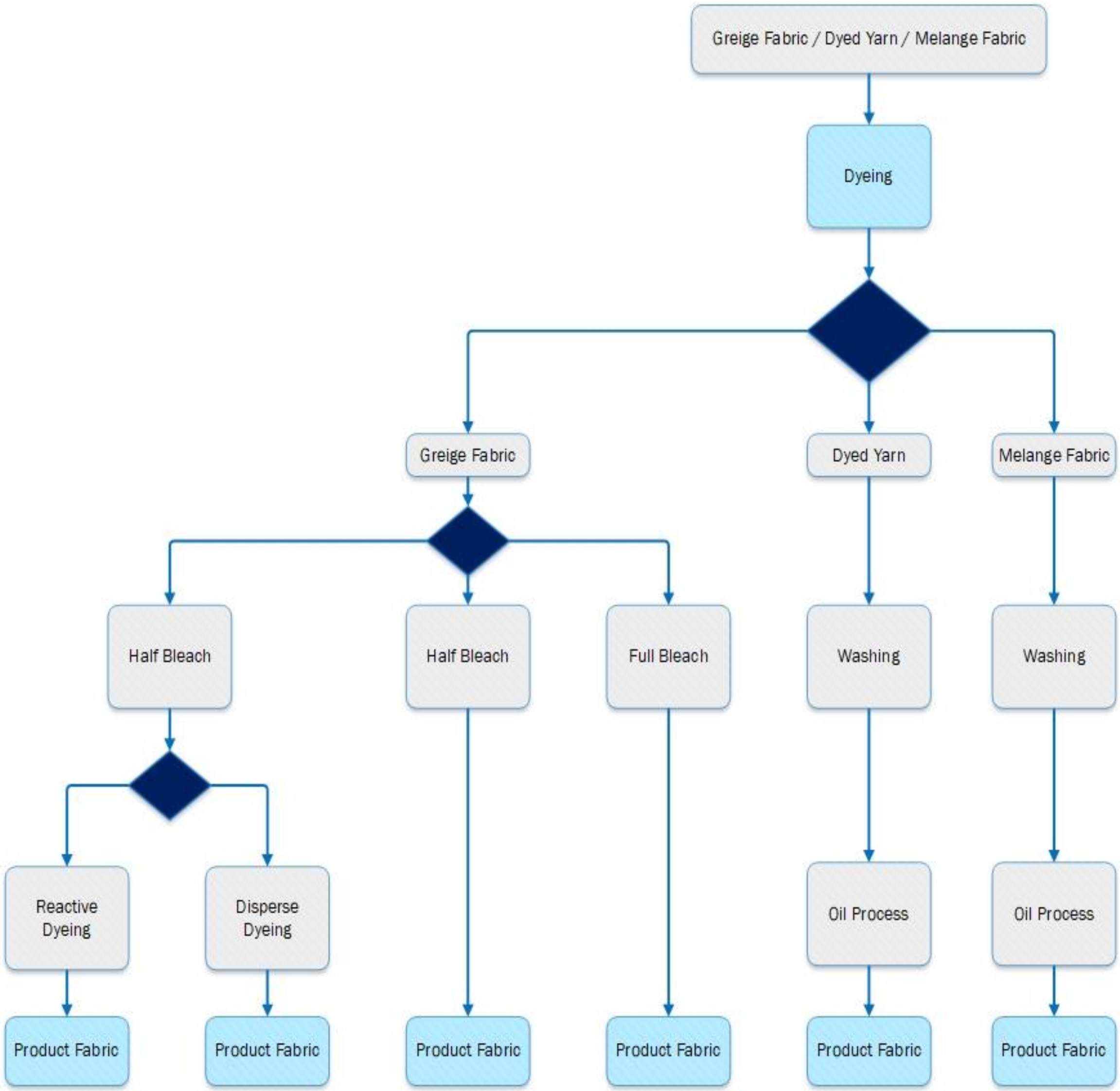


Figure 2-5 Dyeing Section - Block Diagram

The block diagram for the finishing section is shown in Figure 2-6.

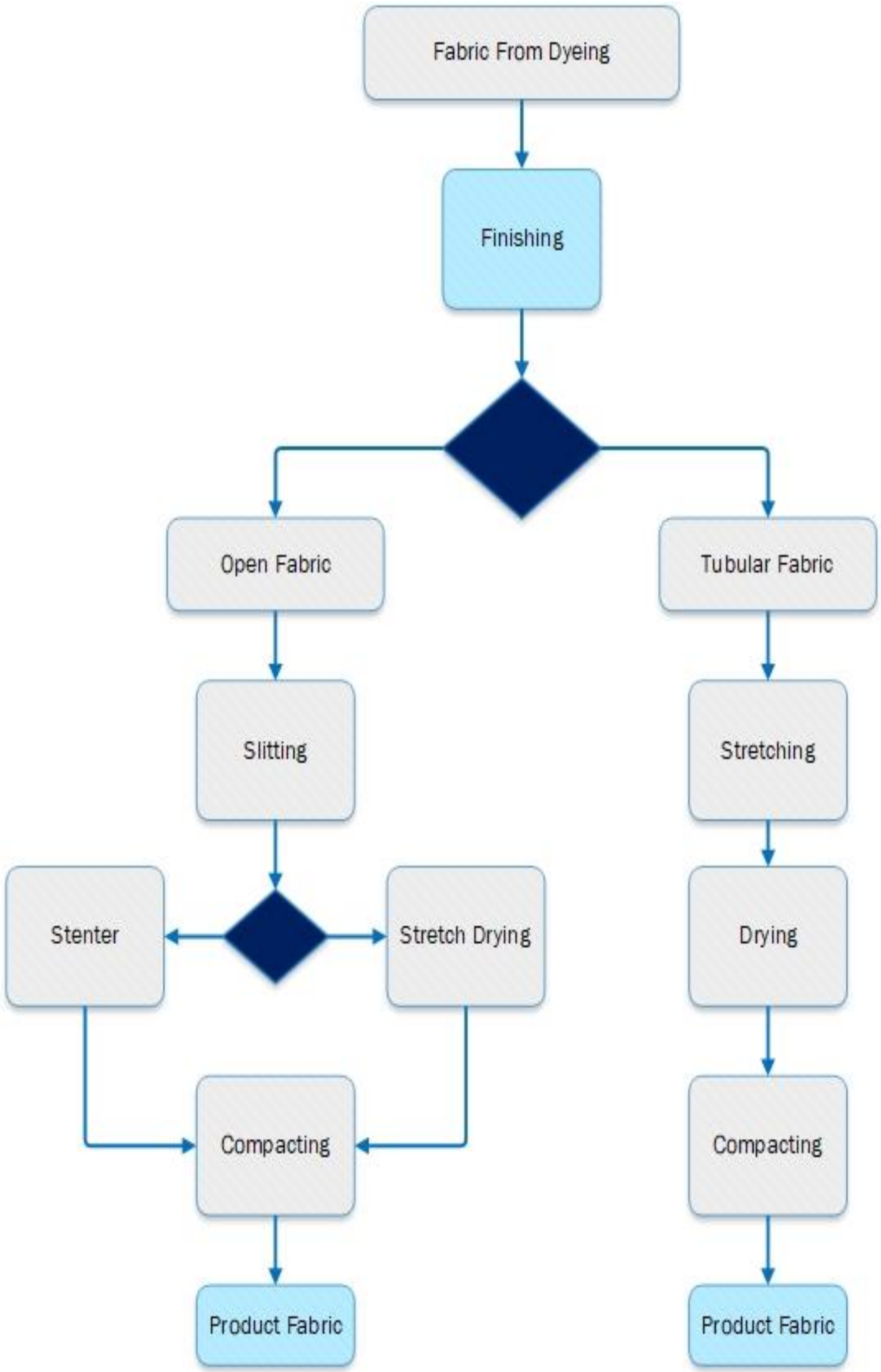


Figure 2-6 Finishing Section - Block Diagram

2.2 Problem Statement:

Condensate Recovery from Dying Machines is negligible, Causing High Draining Rate, High Financial Loss, and Low Energy Conservation.

Business Unit Description (Process Div. II): Steam at 170^{o}C and 9 Bar Pressure received from the Boiler and Supplied to Heat Exchangers of Dying Machines. Which converts to condensate at 90^{o}C. Daily Steam Consumption is approximately 190 Tons/Day and 120 Tons/Day condensate is readily available to return to the Feedwater Tank of the Boiler for reuse.

2.3 Scope of Work:

The scope of our study is to implement the DMAIC 6σ methodology to reduce the condensate wastage and increase the condensate recovery by 40%. This will decrease a significant amount of fuel and water consumption and add quality to the process.

2.4 Objective of Study:

One of the main objectives of our research is to implement the DMAIC 6σ methodology to increase the condensate recovery of the system. The key achievable will be the following

- Increase condensate recovery using statistical tools.
- Find critical factors affecting the condensate recovery.
- Process mapping and study the current condensate recovery process.
- Stakeholder analysis of the complete process.
- Data collection Plan and Pareto Analysis.
- Fishbone Diagram using brainstorming.
- Use the Casuse and Effect Matrix to classify the root causes.
- Implementation of the proposed solutions using the 5W2H tool.

- Comparison of before and after data.
- Giving a control plan for continuous tracking and improvement of process.

2.5 Research Benefits

In addition to solving the problem, quality improvement, and process optimization of the facility there are several other anticipated benefits:

- To Reduce Water Consumption
- To Reduce Boiler Chemical Consumption
- To Reduce Boiler Fuel Consumption
- To Reduce Effluent Treatment Charges
- To Eliminate Colour from Condensate

2.6 Process Flow Diagram:

The process flow diagram for the process of condensate is shown in Figure 2-7 The process starts by extracting water from the well and then moves to the R.O. plant for treatment. Treated water is then moved towards the feed water tank of the boiler. Here, steam is applied along with chemical dosing. Steam is generated by the boiler and distributed to departments. Steam is converted into condensate after releasing its heat energy. In heat exchangers if condensate is contaminated with color liquor, then it is drained otherwise it is returned to the boiler.

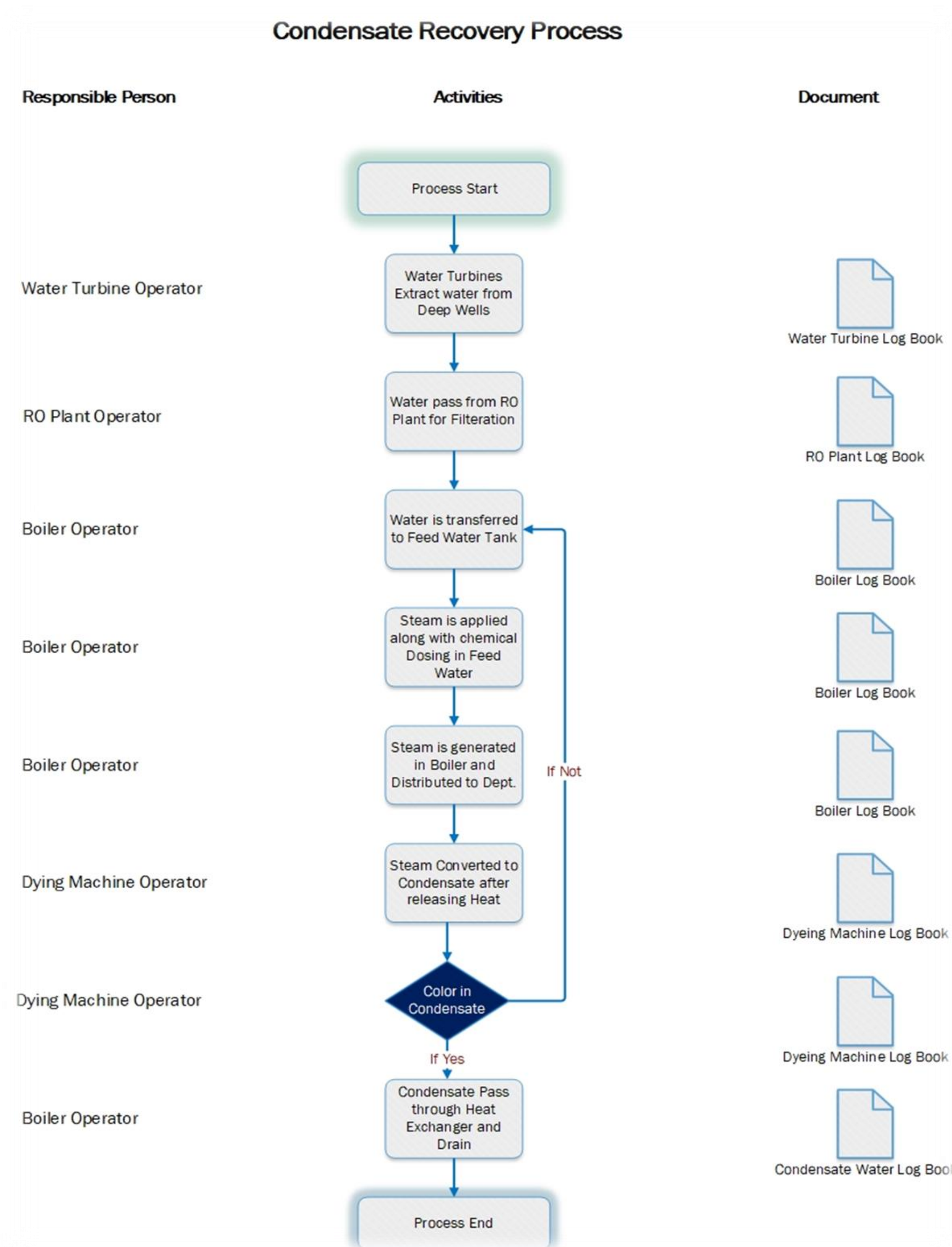


Figure 2-7 Process Flow Diagram - Condensate Recovery Process

2.7 SIPOC Diagram

The SIPOC diagram of the process is given below in Figure 2-8

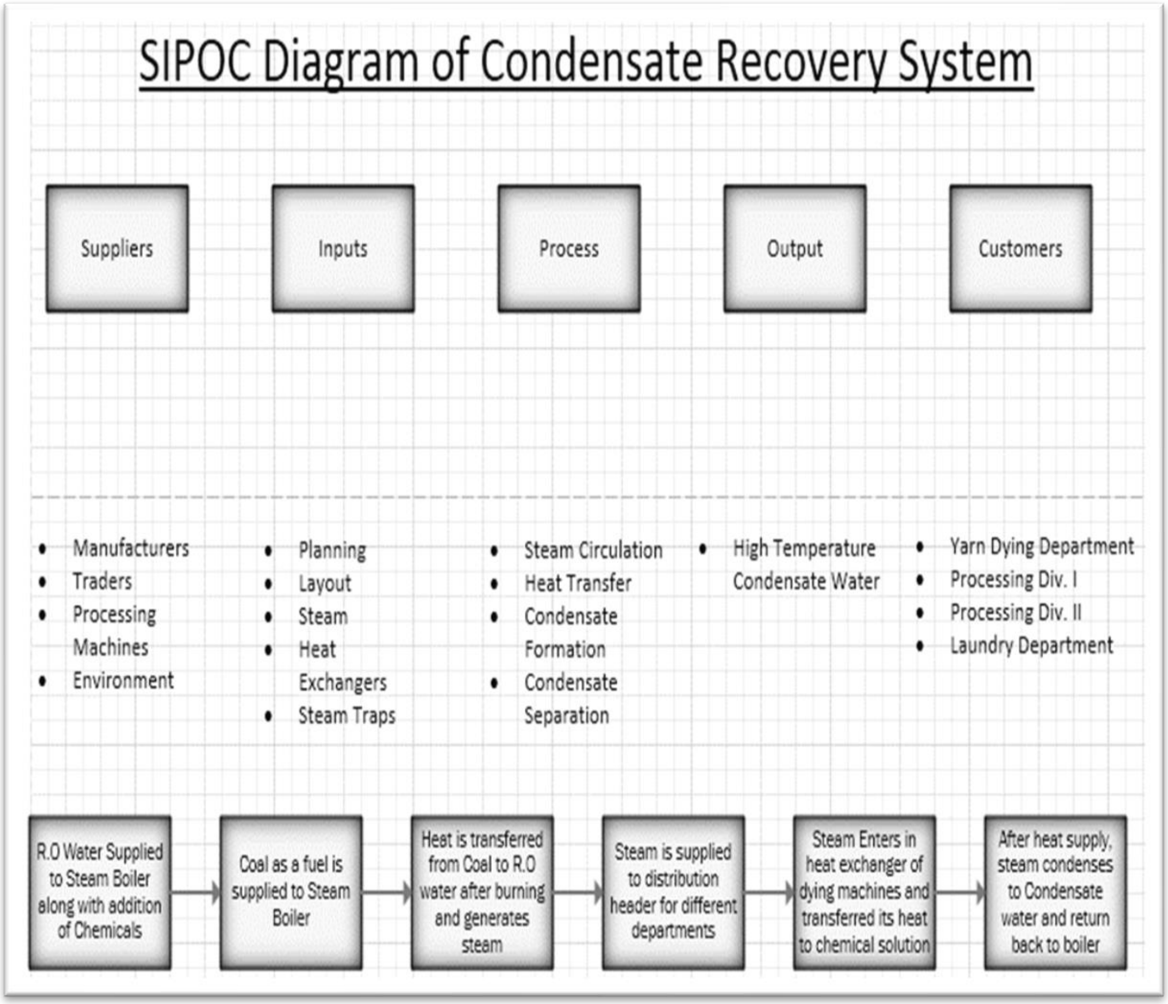
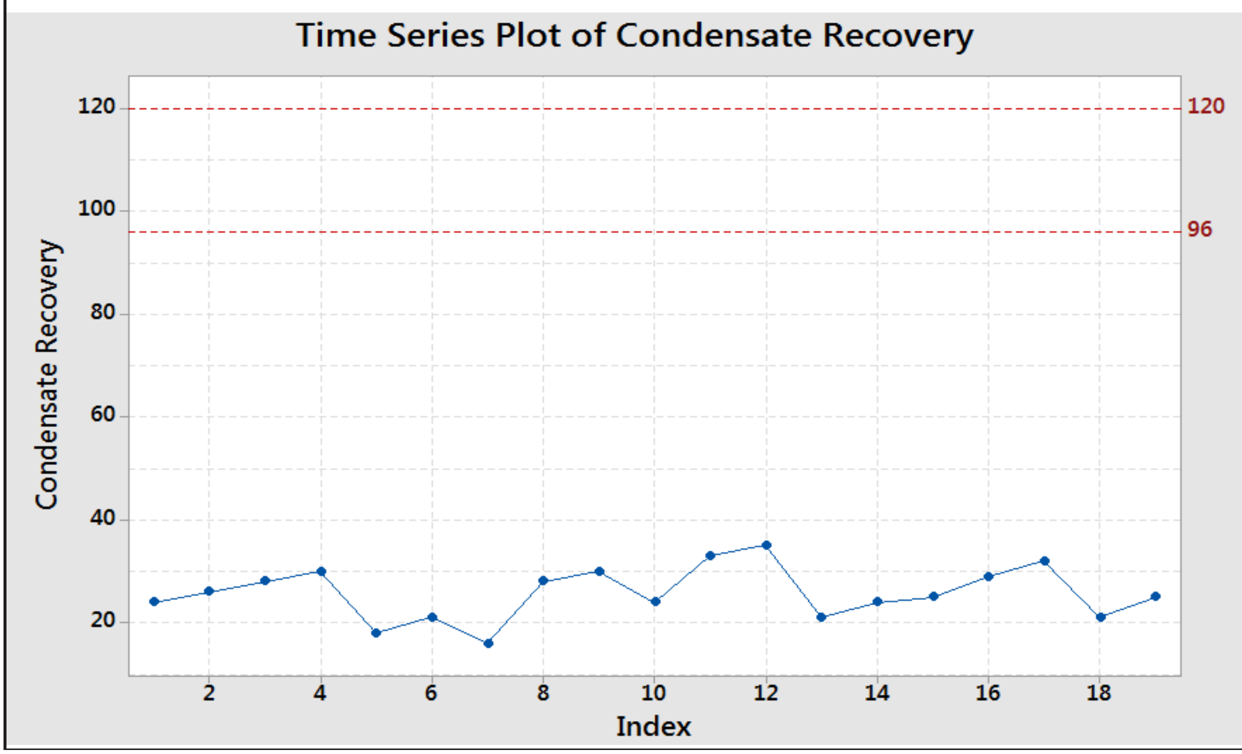


Figure 2-8 SIPOC Diagram - Condensate Recovery Process

2.8 Project Charter:

Project Charter	
Project Title: Improvement in Condensate Recovery	**Business Unit:** Dying Processing Division II
Project Leader: Mouaavia Zeeshan Sharif **Team Members & Responsibilities:** Mr. Riaz Ahmad (Sr. Manager Maintenance) Mr. Abdul Qadeer (University Researcher)	**Business Unit Description:** Steam at 170 °C and 9 Bar Pressure is received from the Boiler and Supplied to Heat Exchangers of Dying Machines. Which converts to condensate at 90 °C. Daily Steam Consumption is approximately 190 Tons/Day and 120 Tons/Day of condensate is readily available to return to the Feedwater Tank of the Boiler for reuse **Unit Sr. Manager:** Mr. Wali Muhammad
Problem Statement: Condensate Recovery from Dying Machines is negligible, Causing a High Draining Rate, High Financial Loss, and Low Energy Conservation.	



Project Primary Objective: To increase condensate recovery from the Dying Section of processing Division II.

Primary metrics: Increment in Condensate Recovery

Condensate Recovery %age = (Recovered Condensate / Total Provision for Condensate Recovery) *100

Project Secondary Objectives: To Reduce Water Consumption

To Reduce Boiler Chemical Consumption

To Reduce Boiler Fuel Consumption

To Reduce Effluent Treatment Charges

To Eliminate Color from Condensate

Business Case/Financial Impact: To improve condensate recovery from 25% to 80% in the dying section of Processing Division II in 6 months, which represents 14.88 million of cost impact per annum under the supervision of G.M Maintenance Mr. Israr Zaidi.

Project Scope is: Maintenance of Steam Traps, New installation of Faulty Steam Traps, Maintenance of Heat Exchangers, and Leakage Detection of Heat Exchangers.

Deliverables:

- Customer satisfaction through Cheaper Products.
- Reduces Effluent Charges
- Reduce Water Consumption
- Reduce Boiler Chemical Consumption
- Baseline Measurement is 80%
- Reduce Defects on fabric because of colored condensate

Support Required: Production Manager, Machine Operators, Maintenance Department, Procurement and Finance Department.

Schedule: (key milestones and dates) Project Start	Target	Target	Status
• D—Define: Confirm scope and purpose statements. Document findings from site visits and Data Collection.	Jan-2021	Jan-2021	Complete
• M—Measure: Determine appropriate measurements for condensate Recovery. Calculate baseline and performance goals.	Feb-2021	Feb-2021	Complete
• A—Analyze: Perform process analysis and identify drivers of baseline performance. Document analysis of opportunity areas. Highlight control parameters, and highlight key factors.	July-2021	July-2021	Complete
• Innovative improvement: Improve and implement new hybrid flexible and more stable processes.	Aug – 2021	Aug- 2021	Complete
• C—Control: Verify that performance goals were met. Standardize the process and list future improvement opportunities.	Aug - 2021	Aug- 2021	Complete
Realized Financial Impact: 14.8 million PKR Per Annum			
Prepared by: Abdul Qadeer	**Date:**		

CHAPTER 3 MEASURE PHASE

3.1 Data Collection Plan:

Collecting data is costly, time-consuming, and resource-draining. Often project teams who do not plan for data collection spend too much time during the measure phase, going in circles searching for data and measuring everything in sight. Perhaps it will be useful to ask questions regarding its purpose.

Why do we collect data?

To obtain the information and answers to questions that we want answers we have developed the data collection plan shown in Table 3-1.

Table 3-1 Data Collection Plan

Measure Title	Data Type	Operational Definition	Stratification factors (by who/what/where/when)	Sampling Notes (Time Frame etc.)	Who and How (Person responsible and method)
Water Consumption	Continuous	Amount of water extracted from Deep Well by water turbines.	By Water Turbines By Water Turbines Operator	Sample after every 24 hours for the next 20 days	By water turbine operator with the help of Water flow meter
Boiler Chemical Consumption	Continuous	Amount of chemical consumption in the boiler to maintain PH, reduce scaling and rusting, to control TDS and hardness of the water.	By Boilers By Boilers Operators	Sample after every 12 hours for the next 20 days	By the boiler operator with the help of a recipe given to him by the Chemical Engineer after checking TDS, PH, etc.
Boiler Fuel Consumption	Continuous	Amount of fuel consumption in the boiler to form steam	By Boilers By Boilers Operators	Sample after every 24 hours for the next 20 days	By boiler operator with the help of weighting the coal
Effluent Treatment Charges	Continuous	Amount of effluent released daily in a cubic meter	By Wastewater treatment operator	Sample after every 24 hours for the next 20 days	Wastewater treatment plant operator by v-notch

Color from condensate	Continuous	Amount of color-contaminated water measured in a cubic meter	By Mechanical Engineer	Sample after every 24 hours for the next 20 days	A mechanical engineer by physical observation
Treatment Charges in R.O plant	Continuous	Amount of water treated in R.O plant	By R.O Operator	Sample after every 24 hours for the next 20 days	R.O operator by the flow meter

3.2 Current Baseline Measurements:

Current Baseline performance measurements are shown in Table 3-2 and chemical consumption in Table 3-3.

Table 3-2 Current Baseline Performance

Sr. #	Days	Water Consumption	Boiler's fuel consumption	Effluent treatment charges		R.O plant treatment charges	Color of condensate
		Tons / Day	Tons/Day	Tons/Day	PKR	PKR	
1	1	150	21	142	4970	7500	Color
2	2	152	22	143	5005	7600	Color
3	3	152	21	141	4935	7600	Color
4	4	153	21	141	4935	7650	Color
5	5	149	22	139	4865	7450	Color
6	6	148	23	141	4935	7400	Color
7	7	151	21	141	4935	7550	Color
8	8	152	24	142	4970	7600	Color
9	9	153	19	143	5005	7650	Color
10	10	149	20	144	5040	7450	Color
11	11	150	21	139	4865	7500	Color
12	12	152	22	140	4900	7600	Color
13	13	151	23	141	4935	7550	Color
14	14	149	21	142	4970	7450	Color
15	15	150	21	140	4900	7500	Color
16	16	152	23	139	4865	7600	Color
17	17	151	21	139	4865	7550	Color
18	18	152	19	140	4900	7600	Color
19	19	150	22	141	4935	7500	Color
20	20	149	21	141	4935	7450	Color

Table 3-3 Boiler's Chemical Consumption

Sr.	Day	Sodium Sulphide	Tri polyphosphate	Caustic Soda	Hydrazine	Tannin	Sodium Hexa-meta phosphate	Ammonia
		Kg/Day	Kg/Day	Lt/Day	Lt/Day	Kg/Day	Kg/Day	Lt/Day
1	1	2.6	1	6	0.4	0.4	2.4	7
2	2	2.6	1	6	0.4	0.4	2.4	7
3	3	2.6	1	6	0.4	0.4	2.4	7
4	4	2.6	1	6	0.4	0.4	2.4	7
5	5	2.6	1	6	0.4	0.4	2.4	7
6	6	2.6	1	6	0.4	0.4	2.4	7
7	7	2.6	1	6	0.4	0.4	2.4	7
8	8	2.6	1	6	0.4	0.4	2.4	7
9	9	2.6	1	6	0.4	0.4	2.4	7
10	10	2.6	1	6	0.4	0.4	2.4	7
11	11	2.6	1	6	0.4	0.4	2.4	7
12	12	2.6	1	6	0.4	0.4	2.4	7
13	13	2.6	1	6	0.4	0.4	2.4	7
14	14	2.6	1	6	0.4	0.4	2.4	7
15	15	2.6	1	6	0.4	0.4	2.4	7
16	16	2.6	1	6	0.4	0.4	2.4	7
17	17	2.6	1	6	0.4	0.4	2.4	7
18	18	2.6	1	6	0.4	0.4	2.4	7
19	19	2.6	1	6	0.4	0.4	2.4	7
20	20	2.6	1	6	0.4	0.4	2.4	7

3.3 Identified Potential Causes:

A total of seven major causes were identified

i. No pipeline
ii. Leakage in Heat Exchanger pipelines
iii. Leakage in Heat Exchanger Endplates
iv. Faulty Steam Trap
v. Pneumatic Valve malfunctioning
vi. Back Pressure Problem
vii. Operator bypass

The following data collection plan was formed to collect data for causes shown in Table 3-4

Table 3-4 Data Collection Plan for Causes

Measure Title	Data Type	Operational Definition	Stratification factors (by who/what/where/when)	Sampling Notes (Time Frame etc.)	Who and How (Person responsible and method)
No - pipeline	discrete	No. of machines with no pipeline for return back of condensate	By machine units	Only once	A mechanical engineer by using his skill
Leakage in tubes of heat exchanger	discrete	No machines having leakages in tubes of heat exchanger	By machine units	Check after every month	A mechanical engineer takes the sample from the suction side of the machine
Leakage in end plates of heat exchanger	discrete	No of the machines have leakages in the end plates of the heat exchanger	By machine units	Check after every month	Mechanical engineer by taking the sample from the suction side of the machine
Faulty steam trap	discrete	No of the machines has a faulty steam trap	By machine units	Check after every month	Mechanical engineer by taking the sample from the suction side of the machine
Back pressure	discrete	No of the machines facing the problem of back pressure	By machine units	Check after every month	Mechanical engineer by taking the sample from the suction side of the machine
Operator fault	discrete	No of the machines facing the problem of bypass by the operator	By machine units	Check after every month	Mechanical engineer by taking the sample from the suction side of the machine
Faulty Pneumatic valve	discrete	No of the machines has a faulty pneumatic valve	By machine units	Check after every month	Mechanical engineer by taking the sample from the suction side of the machine

Data was collected according to this data collection plan and is shown in Table 3-5

Table 3-5 Current Condensate Wastage

Sr. #	Defects	No. of Machines	Code of Machines	Condensate Wastage
1	No Condensate Pipeline attached	17	T16,T22,T28,T29,T37,T39,T40,T41,T42, T43,T44,T45,T46,T60,T61,T63,T97,T103	30
2	Leakage in Tubes of Heat Exchanger	8	T13,T14,T17,T36,T54,T59,T79,T98	47
3	Leakage in End Plates of Heat Exchanger	3	T35,T55,T94	14
4	Steam Trap Malfunctioning	7	T19,T20,T21,T33,T77,T81,T97,	25
5	Pneumatic Valve Malfunctioning	1	T18	8
6	Condensate Back Pressure Problem	2	T30	5
7	Operation By Pass Fault	2	T85	2
8	**Total Machines**	**40**	**Total Condensate Lost (Tons/Day)**	**131**

3.4 DPMO calculation:

Opportunities: seven opportunities per machine

- No Pipeline
- Leakage in Heat Exchanger pipelines
- Leakage in Heat Exchanger Endplates
- Faulty Steam Trap
- Pneumatic Valve malfunctioning
- Back Pressure Problem
- Operator bypass

Total defects = 131000 litters/day

Total opportunities = 154000 liters/day

Defects per unit (machine) = total defects / total unit = 131000 / 154000 = 0.850649

Defects per opportunity = total defects / (units * no of opportunities)

= 131000 / (154000*1) = 0.850649

Defects per million opportunities (DPMO) = 850649

Sigma level = 0.46

Yield = 15% %

There are 850649 defects per million opportunities and the sigma level is 0.46 in our process. Here are the calculations done on MS Excel given below in Table 3-6

Table 3-6 Current DPMO Calculation

No. of Units	Total Defects	Defect Opportunities	DPU	DPO	DPMO	Sigma Level	Yield	Bad Quality
154000	131000	1	0.850649	0.850649	850649	0.46	15%	85%

CHAPTER 4 ANALYZE PHASE

4.1 Hypothesis testing:

Hypothesis testing is necessary to determine when there is a significant difference between two sample populations and to determine whether there is a significant difference between a sample population and a target value.

Q 1: Is there a significant difference between the condensed wastage of two sections: Dyeing and Sampling?

Following are the sampling data collected from 2 sections: Dyeing and Sampling. 12 data points are collected. Data shown in Table 4-1 have total condensate wastage each day in tons.

Table 4-1 Condensate Wastage for Dyeing and Finishing Section

Sampling Section	Condensate Wastage of Sampling (Tons per day)	Dyeing Section	Condensate Wastage of dyeing (Tons per day)
Sampling	42	Dyeing	88
Sampling	43	Dyeing	89
Sampling	41	Dyeing	89
Sampling	50	Dyeing	81
Sampling	48	Dyeing	82
Sampling	46	Dyeing	86
Sampling	38	Dyeing	84
Sampling	44	Dyeing	89
Sampling	45	Dyeing	92
Sampling	47	Dyeing	92
Sampling	46	Dyeing	91
Sampling	41	Dyeing	97

Let's test the assumption that the condensate wastage of the dying section is not significantly different from the sampling section.

We test our assumption statistically.

Test Assumption-1

Null Hypothesis, H_0: Condensate wastage of both sections is not significantly different.

Alternative Hypothesis, H_A: Condensate wastage of both sections has a significant difference.

Significance Level, α = 0.05

Using Minitab 18 we test the assumption and the box plot is shown in Figure 4-1

Appropriate Test: 2 Sample t-test

We'll compare the average mean of sampling of the data from both sections.

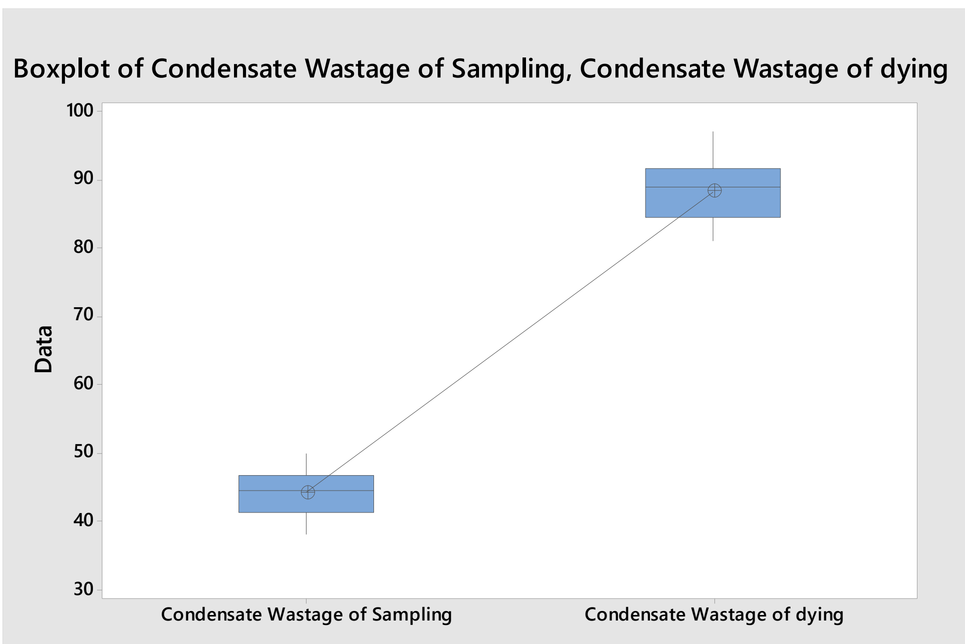


Figure 4-1 Boxplot - Condensate Wastage of Dyeing and Sampling Section

Two-Sample T-Test and CI: Condensate Wastage of Sampling and condensate wastage of dying

Method:

μ_1: mean of Condensate Wastage of Sampling

μ_2: mean of Condensate Wastage of dying

Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	St_{Dev}	SE Mean
Condensate Wastage of Sampling	12	44.25	3.41	0.99
Condensate Wastage of dying	12	88.33	4.56	1.3

Estimation for Difference:

Difference: -44.08 95% CI for Difference (-47.51, -40.65)

Test

Null hypothesis H_0: $\mu_1 - \mu_2 = 0$

Alternative hypothesis H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
-26.81	20	0.000

Conclusion:

The p-value is 0.000 which suggests accepting the alternative hypothesis, that condensate wastage of both sections has a significant difference.

Q 2: How far is our current condensate recovery from our target?

Following are the sampling data collected for the current amount of condensate recovery shown in Table 4-2. 18 sample data are collected. Data shows the total condensate recovery each day in tons.

Table 4-2 Current Condensate Recovery

Target Condensate Recovery Tons/day	Current Condensate Recovery Tons/day
120	25
120	26
120	24
120	18
120	22
120	33
120	28
120	30
120	31
120	24
120	23
120	25
120	29
120	28
120	24
120	26
120	25
120	23
120	24
120	25

Let's test the assumption that the condensate recovery is equal to our target

Test Assumption-2

Null Hypothesis, H0: The condensate recovery is equal to our target

Alternative Hypothesis, HA: The condensate recovery is far from our target

Significance Level, $\alpha = 0.05$

Using Minitab 18 we test the assumption and the box plot is shown in Figure 4-2

Appropriate Test: 1 Sample t-test

We'll compare the current condensate recovery data with the target.

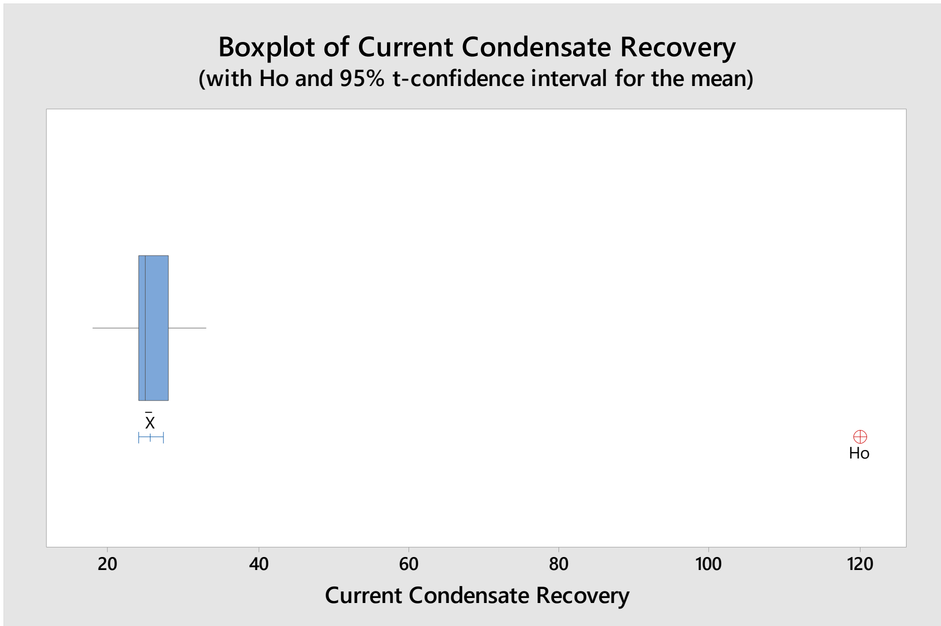


Figure 4-2 Boxplot - Current Condensate Recovery

One-Sample T: Current Condensate Recovery

N	Mean	StDev	SE Mean	95% CI for μ
20	25.650	3.422	0.765	(24.048, 27.252)

Test:

Null hypothesis H_0: $\mu = 120$

Alternative hypothesis H_1: $\mu \neq 120$

T-Value	P-Value
-123.29	0.000

Conclusion:

P value is 0.000 which suggests accepting the alternative hypothesis, that our condensate recovery is far from our target.

Q 3: Is there a significant difference between the condensed wastage of two types of machines: Auto and Manual?

Following are the sampling data shown in Table 4-3 collected from 2 two types of machines: Auto and Manual. 10 sample data are collected. Data shows the total condensate wastage each day in tons.

Table 4-3 Condensate Wastage for Auto and Manual Machine

Auto Machines Condensate Waste Tons/day	Manual Machines Condensate Waste Tons/day
55	81
54	76
53	82
56	85
58	84
51	88
59	86
53	85
58	79
57	80

Let’s test the assumption that there is no significant difference between condensate wastage of auto and manual machines.

Test Assumption-3

Null Hypothesis, H0: No significant difference between condensate wastage of auto and manual machines.

Alternative Hypothesis, HA: Significant difference between condensate wastage of auto and manual machines.

Significance Level, α = 0.05

Using Minitab 18 we test the assumption and a box plot is shown in Figure 4-3

Appropriate Test: 2 Sample t-test

We'll compare the average mean of sampling of the data from both types of machines: auto and manual machines.

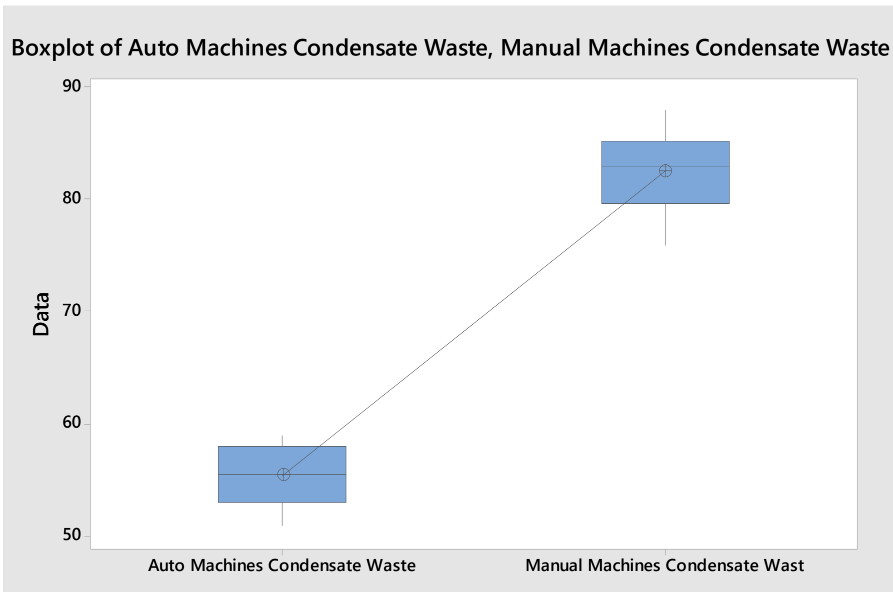


Figure 4-3 Boxplot - Condensate Wastage for Auto and Manual Machine

Two-Sample T-Test and CI: Auto Machines Condensate ... ensate Waste

Method:

μ_1: mean of Auto Machines Condensate Waste

μ_2: mean of Manual Machines Condensate Waste

Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics:

Sample	N	Mean	St_{Dev}	SE Mean
Auto Machines Condensate Waste	10	55.40	2.63	0.83
Manual Machines Condensate Waste	10	82.60	3.66	1.2

Estimation for Difference:

Difference	95% CI for Difference
-27.20	(-30.22, -24.18)

Test:

Null hypothesis H_0: $\mu_1 - \mu_2 = 0$

Alternative hypothesis H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
-19.09	16	0.000

Conclusion:

P value is 0.000 which suggests accepting the alternative hypothesis, that there is a significant difference between condensate wastage of auto and manual machines.

Q 4: Is there a significant difference between the condensed wastage of two components of heat exchangers: Tubes and End Plates?

Following are the sampling data collected in Table 4-4 for the condensed wastage of two components of heat exchangers: Tubes and End Plates. 10 sample data are collected. Data shows the total condensate recovery each day in tons.

Table 4-4 Condensate Wastage for Both Components of Heat Exchangers

Heat Exchanger Tubes Leakage Tons/day	Heat Exchanger End Plate Leakage Tons/day
46	14
48	15
45	16
47	14
50	12
44	13
43	18
46	19
48	14
44	16

Let's test the assumption that there is no significant difference between condensate wastage of tubes and end plates of heat exchangers.

Test Assumption-4

Null Hypothesis, H0: No significant difference between condensate wastage of tubes and end plates of heat exchangers.

Alternative Hypothesis, HA: Significant difference between condensate wastage of tubes and end plates of heat exchangers.

Significance Level, $\alpha = 0.05$

Using Minitab 18 we test the assumption and a box plot is shown in Figure 4-4

Appropriate Test: 2 Sample t-test

We'll compare the average mean of sampling of the data from both components of heat exchangers

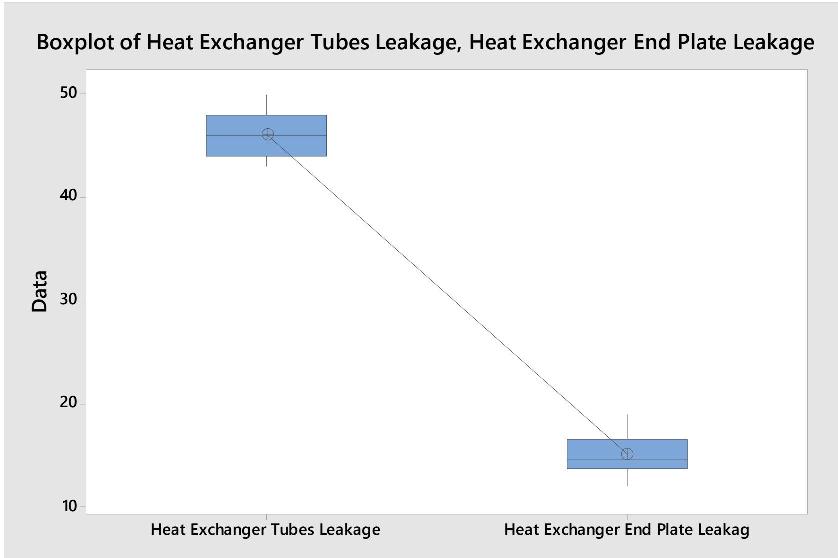


Figure 4-4 Boxplot - Condensate Wastage for Both Component of Heat Exchangers

Two-Sample T-Test and CI: Heat Exchanger Tubes ... End Plate Leakage

Method:

μ_1: mean of Heat Exchanger tube leakage

μ_2: mean of Heat Exchanger End Plate Leakage

Difference: $\mu_1 - \mu_2$

Descriptive Statistics:

Sample	N	Mean	St_{Dev}	SE Mean
Heat Exchanger Tubes Leakage	10	46.10	2.18	0.69
Heat Exchanger End Plate Leakage	10	15.10	2.18	0.69

Estimation for Difference:

Difference	95% CI for Difference
31.000	(28.949, 33.051)

Test:

Null hypothesis H_0: $\mu_1 - \mu_2 = 0$

Alternative hypothesis H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
31.75	18	0.000

Conclusion:

P value is 0.000 which suggests accepting the alternative hypothesis, that there is a significant difference between condensate wastage of tubes and end plates of heat exchangers.

4.2 Cause and Effect Diagram:

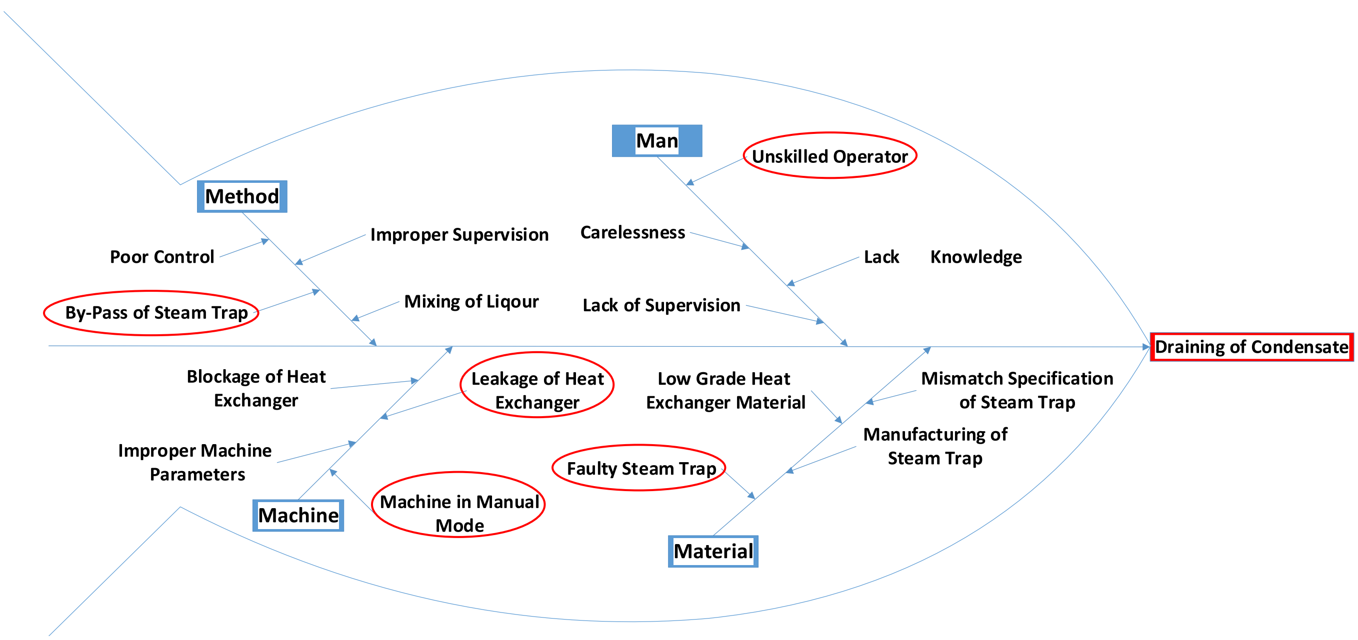


Figure 4-5 Cause and Effect Diagram

The following cause and effect diagram shown in Figure 4-5 has made with some genral causes and some major causes which we have verified using hypothesis testing highlighted in red.

4.3 Cause and Effect Matrix

After making the cause-and-effect diagram, we shall make a cause-and-effect matrix (X-Y matrix) shown in Table 4-5 to prioritize the significant factors (independent variables). Xs are our independent variables and Ys are the dependent variables. The causes of condensate wastage are the independent variables and the defects are the dependent variable

Table 4-5 Cause and Effect Matrix

Cause and Effect Matrix							
Output Variables	**Reduce Water Consumption**	**Reduce Boiler Chemical Consumption**	**Reduce Boiler Fuel Consumption**	**Reduce Effluent Treatment Charges**	**Eliminate Color from Condensate**	**Reduce Treatment Charges in R.O. Plant**	**Total**
Weighted	7	6	8	5	10	9	
No Pipeline	10 / 70	7 / 42	8 / 64	8 / 40	2 / 20	8 / 72	308
Leakage in tubes of Heat Exchanger	6 / 42	7 / 42	8 / 64	8 / 40	10 / 100	8 / 72	360
Leakage in End Plate of Heat Exch.	6 / 42	7 / 42	8 / 64	8 / 40	10 / 100	8 / 72	360
Faulty Steam Trap	8 / 56	6 / 36	6 / 48	5 / 25	5 / 50	5 / 45	211
Pneumatic Valve Malfunctioning	4 / 28	8 / 48	5 / 40	5 / 25	3 / 30	4 / 36	207
Back Pressure Problem	3 / 21	3 / 18	4 / 32	3 / 15	3 / 30	4 / 36	152
Operator By-Pass	8 / 56	3 / 18	6 / 48	7 / 35	3 / 30	8 / 72	259

Using the above matrix, we have categorized the causes of the defects according to their importance. I have concluded that the first four variables are causing more than 80% of problems. Leakages in the tubes of the heat exchanger and leakages in the end plate of the heat exchanger are at the top of the list. Leakages in the tubes of the heat exchanger and end plate should be considered first in the analysis. Similarly, no pipeline for return back of condensate, faulty steam trap, and operator bypass are very significant affecting variables.

4.4 Pareto Analysis:

Table 4-6 Data Table for Pareto Analysis

Sr. no	Defects	No. of Machines	Code of Machines	Condensate Wastage	Cum.
1	No Condensate Pipeline attached	17	T16,T22,T28,T29,T37,T39, T40,T41,T42,T43,T44,T45, T46,T60,T61,T63,T97,T103	30	30
2	Leakage in Tubes of HE	8	T13,T14,T17,T36,T54,T59, T79,T98	47	77
3	Leakage in End Plates of HE	3	T35,T55,T94	14	91
4	Steam Trap Malfunctioning	7	T19,T20,T21,T33,T77,T81, T97,	25	116
5	Pneumatic Valve Malfunctioning	1	T18	8	124
6	Condensate Back Pressure Problem	2	T30	5	129
7	Operation By Pass Fault	2	T85	2	131

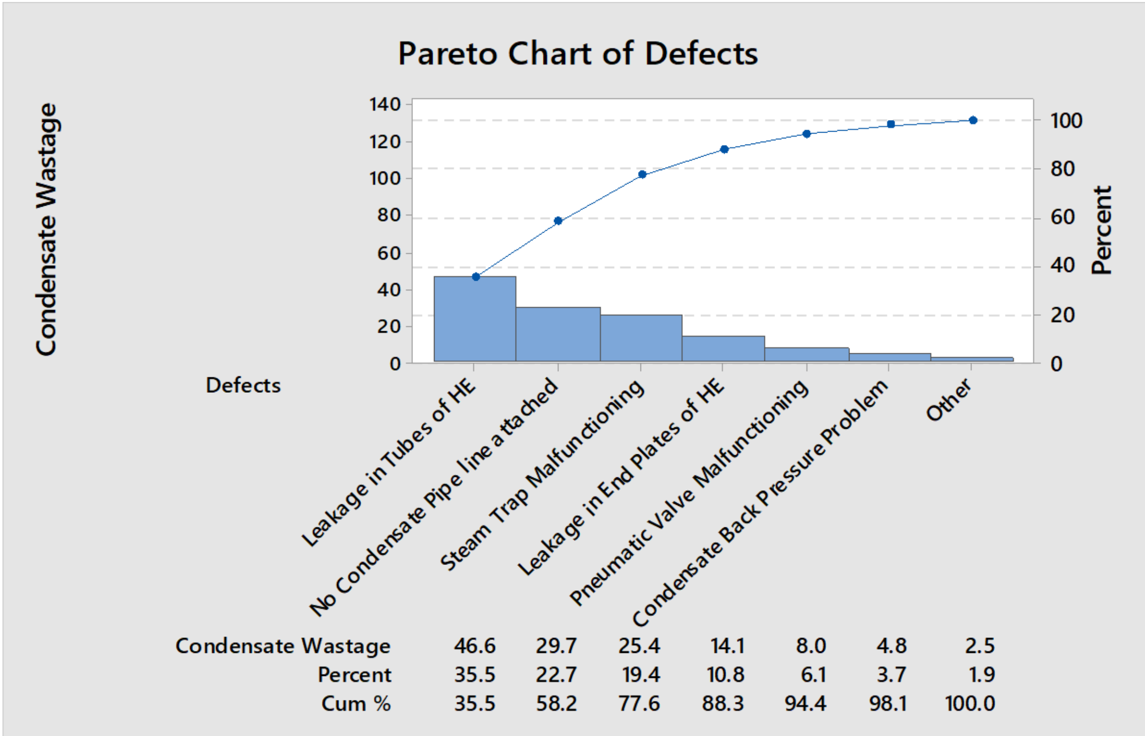


Figure 4-6 Pareto Chart

Pareto analysis shows that 80% of the condensate wastage problem is due to 4 key factors:

i. Leakage in Tubes of HE
ii. No Condensate Pipeline attached
iii. Steam Trap Malfunctioning
iv. Leakage in End Plates of HE

CHAPTER 5 IMPROVE PHASE

5.1 List of potential solution

X's	Potential Solutions
No Pipeline	Installation of pipelines of Heat Exchanger By Maintenance Department
Leakage in tubes of Heat Exchanger	Replacement of tubes
	Blind of tubes
Leakage in End Plates of Heat Exchanger	Welding of Leaked Endplates
	Replacement of endplates
Faulty Steam Trap	Steam traps will be repaired
	New steam Traps will be demanded and will be replaced
Pneumatic Valve Malfunctioning	The faulty pneumatic valve will be replaced
Bypass by operator	Training sessions will be conducted to the improvement of the skill level of the operator
Back Pressure problem	A booster pump will be installed in condensate pipelines

5.2 Selection of key solutions

Defects	Solutions	Reason
No Pipeline	Installation of pipelines of Heat Exchanger By Maintenance Department	By installing pipelines, we can recover all the condensate reached.
Leakage in HE Tubes	Replacement of tubes	Due to blinding the tubes, the flow rate will be reduced. The heat transfer rate will also be reduced. Blind is only 15-18% possible, so we'll replace tubes.
Leakage in HE Endplate	Welding of Leaked Endplates, Replacement of endplates	Both are preferable according to the requirement (thickness of end plate).
Faulty steam trap	Steam traps will be repaired	The new steam strap is costly compared to the repair cost.

Back Pressure Problem	A booster pump will be installed in condensate pipelines	Drain flow will be increased so will the heat transfer rate.
Operator Fault	Training sessions will be conducted to the improvement of the skill level of the operator	Training will help the operator to control the parameters.
Pneumatic valve malfunctioning	The faulty pneumatic valve will be replaced	Fresh water will not mix with condensate.

5.3 Condensate recovery after improvement

Data for Condensate Recovery after Improvement is shown in Table 5-1

Table 5-1 Data for Condensate Recovery - After Improvement

Sr. #	Defects	No. of Machines	Code of Machines	Conden. Wastage	No. of Machines	Code of Machines	Condensate Recovered
1	No Condensate Pipeline attached	11	T29,T37, T42,T43, T44,T45, T46,T60, T63, T97,T103	18	7	T16,T22,T28, T39,T40, T41,T61	11
2	Leakage in Tubes of Heat Exchanger	5	T14,T17,T54, T59,T79	26	3	T13,T36,T98	21
3	Leakage in End Plates of Heat Exchanger	2	T55,T94	6	1	T35	8
4	Steam Trap Malfunctioning	7	T19,T20,T21, T33,T77,T81, T97,	25	0	Nil	0
5	Pneumatic Valve Malfunctioning	0	Nil	0	1	T18	8
6	Condensate Back Pressure Problem	0	T30	5	1	Nil	0
7	Operation By Pass Fault	0	Nil	0	1	T85	3
	Total	**25**		**80**	**14**		**51**

5.4 DPMO Calculation – After Improvement:

Total defects = 80000 litters/day

Total opportunities = 154000 litters/day

Defects per unit (machine) = total defects / total unit = 80000 / 154000 = 0.514805

Defects per opportunity = total defects / (units * no of opportunities)

= 80000 / (154000*1) = 0.514805

Defects per million opportunities (DPMO) = 514805

Sigma level = 1.46

Yield = 48.5%

There are 514805 defects per million opportunities and the sigma level is 1.46 in our process. Here are the calculations done on MS Excel given below in Table 5-2

Table 5-2 DMPO Calculation - After Improvement

Sr. No.	No. of Units	Total Defects	DPU	DPO	DPMO	Sigma Level	Yield	Bad Quality
1	154000	80000	0.514805	0.514805	514805	1.46	48.5%	51.5

5.5 Comparison of Data Before and After Improvements:

A comparison is drawn on the time series plot shown in Figure 5-1 which shows we have increased our condensate recovery by a significant amount but to reach our target range we have to some more improvements in the process.

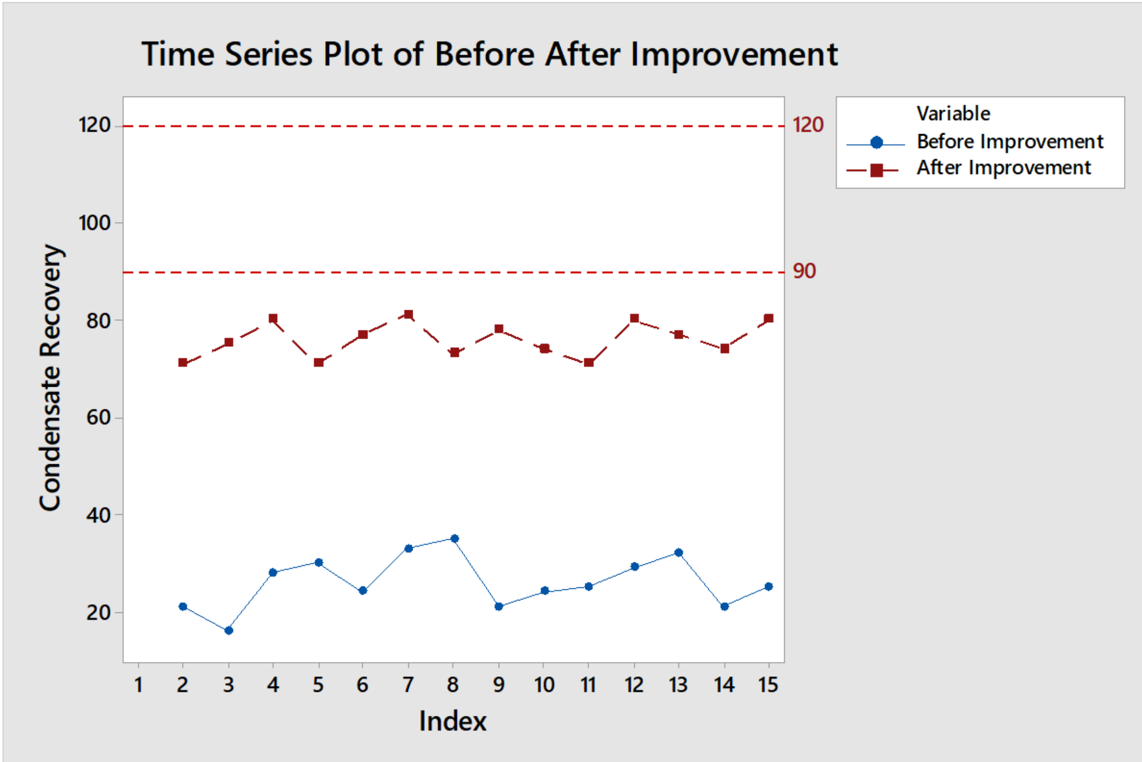


Figure 5-1 Time Series Plot for Condensate Recovery

There were 850649 defects per million opportunities and the sigma level is 0.46 in our process. After the implementation of a proportion of solutions, there are 514805 defects per million opportunities now and the sigma level becomes 1.46 in our process. The yield has increased by 33% and the increase in sigma level is 1σ.

CHAPTER 6 CONTROL PHASE

6.1 Control Plan:

The factors that need to be controlled in condensate water are

i. PH
ii. DS (mg/L)
iii. Conductivity (ohm-meter)
iv. Color

The specification, targets, or desired range is shown in Table 6-1

Table 6-1 Condensate Water Control Factors Range

Controlling factors	Specification, Targets, or Desired Range
PH	8 -10
TDS	0 -60
Conductivity	0 -60
Color	Transparent

How feedback on actual performance is provided?

We will inspect the sample from the main condensate return line fill the following Performa daily and compare the data with specifications or targets of variables.

When to take action and what action to take?

i. When our sample measurements do not meet the above-stated criteria, we'll take the following actions:

ii. Put the condensate on the drain (not allowing the condensate to return to the boiler and RO plant.)

iii. We'll collect the sample from each dyeing machine and inspect the stated properties to see which specific machines are creating the problem.

iv. After finding out the faulty machines, the condensate of these machines will be drained.

v. Maintenance dept. will inspect which problem is causing that specific problem.

Who is responsible and authorized?

Maintenance department.

CHAPTER 7 CONCLUSION

Condensate recovery was only 23 Tons/day before the implementation of the 6σ DMAIC Methodology. After the successful implementation of the process, we not only have saved another 51 Tons/day of steam but also

- ✓ 3000 Ton/year of Fuel.
- ✓ About 52 million Liters of Water every year.
- ✓ About 6.5 Lack Rs. /Year of Effluent Treatment Charges.
- ✓ About 1 million Rs. /Year of R.O. Plant Treatment Charges.
- ✓ And a large quantity of chemicals used for the treatment of water.

7.1 Future Recommendation:

Here are the key points for future work in your project involving Lean and Six Sigma:

- Resolve Other Identified Problems: Addressing additional issues will enhance Condensate Recovery.
- Sigma Level Enhancement: Even though we've reached a 1.46 Sigma Level, keep improving. Aim to reach a 6 Sigma level for top quality.
- Real-Time Monitoring System: Establish a system for continuous monitoring and prompt corrective actions.
- Staff Training: Train employees in Lean and Six Sigma principles to foster a culture of quality and encourage excellence.

Remember, quality improvement is a journey, and each step counts!

REFERENCES

1. *Application of Six Sigma Using DMAIC Methodology in the Process of Product Quality Control in Metallurgical Operation.* Lenka GIRMANOVÁ*, Marek ŠOLC, Juraj KLIMENT, Adriana DIVOKOVÁ, Vojtech MIKLOŠ. 2017, Application of Six Sigma Using DMAIC Methodologyyy in the Process, pp. 104–109.

2. *The implementation of a Lean Six Sigma framework to enhance operational performance in an MRO facility.* J Hill, Andrew Thomas, Rachel mason-jones, Sherien N. Elkateb. s.l. : Production & Manufacturing Research, 2018, Vol. 06.

3. *Six Sigma DMAIC phases application in Y company: a case study.* Husam Kaid, Mohammed A., NomanEmad Abouel Nasr, Mohammed Alkahtani. s.l. : International Journal of Collaborative Enterprise, 2016.

4. II THOMAS. [Online] Thomas Publishing Company. [Cited: 11 11, 2023.] https://www.thomasnet.com/insights/8-lean-wastes/..

5. MASTER OF PROJECT ACADEMY. [Online] [Cited: 11 15, 2023.] https://blog.masterofproject.com/8-lean-techniques/.

6. 5S TODAY. [Online] 5SToday, 11 15, 2023. https://www.5stoday.com/what-is-5s/.

7. BUSINESSMAP. [Online] BUSINESSMAP, 11 25, 2023. https://businessmap.io/lean-management/improvement/what-is-poka-yoke?_gl=1*ygcxre*_up*MQ..*_ga*MjA0NTk1NTU4NS4xNzEwNzAwNDU1*_ga_E8GMFKPCV6*MTcxMDcwMDQ1NS4xLjAuMTcxMDcwMDQ1NS4wLjAuMA...

8. SHMULA. [Online] 11 25, 2023. https://www.shmula.com/5-steps-to-effective-poka-yoke-mistake-proofing/24878/.

9. *Using the Six Sigma DMAIC Methodology to Improve an Internal Logistic Process.* Luís Miguel D. F. Ferreira, Cristovão Silva Carolina Mesquita. Porto, Portugal : 23rd International Conference on Flexible Automation & intelligent Manufacturing, 2013.

10. ASQ. [Online] American Society for Quality. [Cited: 11 27, 2023.] https://asq.org/quality-resources/dmaic#:~:text=Define%2C%20measure%2C%20analyze%2C%20improve%2C%20and%20control%20(DMAIC,strategy%20used%20to%20improve%20processes.&text=It%20is%20an%20integral%20part,improvement%20initiatives%20such%20as%20lean.

11. SIX SIGMA DAILY. [Online] [Cited: 12 02, 2023.] https://www.sixsigmadaily.com/what-is-

dmadv/#:~:text=DMADV%20is%20a%20Six%20Sigma,improving%20a%20previously%20existing%20one..

12. Learn Lean Sigma. [Online] Learn Lean Sigma. [Cited: 12 12, 2023.] https://www.learnleansigma.com/guides/5-whys/.

13. Master of Project Academy. [Online] Master of Project Academy. [Cited: 12 12, 2023.] https://blog.masterofproject.com/ctq-tree/.

14. *QUALITY CONTROL ANALYSIS, SIX SIGMA, DMAIC, AND ROOT CAUSE ANALYSIS OF RING CVT (CASE STUDY AT PT. DENAPELLA LESTARI).* Ignacia Claresta, Jennifer Juyanto, Lina Gozali, Ahad Ali. Istanbul, Turkey : e International Conference on Industrial Engineering and Operations Management, 2022.

15. TULIP. [Online] TULIP. [Cited: 12 02, 2023.] https://tulip.co/blog/what-is-a-pareto-chart-definition-examples/?.

16. *Using Process Capability Indices to Develop the Execution Models of DMAIC Process.* Kuen-Suan Chen, Chin-Chia Liu, Chi-Han Chen, Chun-Min Yu. s.l. : International Journal of Reliability Quality and Safety Engineering, 2022.

17. MASTER OF PROJECT. [Online] Master of Project Academy. [Cited: 12 03, 2023.] https://blog.masterofproject.com/dpmo-six-sigma/#:~:text=What%20Does%20DPMO%20Mean%20in,opportunities%20multiplied%20by%201%20million.

18. SIX SIGMA ONLINE. [Online] EDUCATE 360. [Cited: 12 02, 2023.] https://www.sixsigmaonline.org/defects-per-million-opportunities-dpmo-six-sigma/.

19. SIX SIGMA DAILY. [Online] [Cited: 12 10, 2023.] https://www.sixsigmadaily.com/x-bar-and-r-chart-example/.

20. Six Sigma Study Guide. [Online] [Cited: 12 10, 2023.] https://sixsigmastudyguide.com/x-bar-r-control-charts/.

21. *Application of Six Sigma at cell site construction: a case study.* Hakeem Ur Rehman, Muhammad Asif, Muhammad Aamir Saeed, Muhammad Asim Akbar, Muhammad Usman Awan. s.l. : Asian Journal on Quality, 2012, Vol. 13.

22. NIST. [Online] NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY. [Cited: 12 02, 2023.] https://www.itl.nist.gov/div898/handbook/ppc/section4/ppc46.htm#:~:text=Process%20capability%20analysis%20entails%20comparing,a%20process%20against%20its%20specifications.&text=Graphically%2C%20we%20assess%20process%20capability,then%20the%20process%20is%.

23. Investopedia. [Online] Investopedia. [Cited: 12 12, 2023.] https://www.investopedia.com/terms/i/ishikawa-diagram.asp#:~:text=An%20Ishikawa%20diagram%20is%20a,are%20required%20at%20specific%20times.

24. LEARN ABOUT QUALITY. [Online] American Society for Quality. [Cited: 12 12, 2023.] https://asq.org/quality-resources/root-cause-analysis.