IMPROVEMENT OF OVERALL EQUIPMENT EFFICIENCY (OEE) BY TOTAL PRODUCTIVE MAINTENANCE (TPM) - A CASE STUDY

by

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CERTIFICATE OF APPROVAL

The thesis titled "IMPROVEMENT OF OVERALL EQUIPMENT EFFICIENCY (OEE) BY TOTAL PRODUCTIVE MAINTENANCE (TPM) - A CASE STUDY" submitted by Md. Shoreful Islam, Student No. 100708104 F, and Session - October 2007 has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Master of Engineering in Advanced Engineering Management on April 30, 2011.

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ABSTRACT

There are a great number of public and private chemical plants inside the country. But this sector is running with many problems essentially the production loss due to downtime, process instability, and low product quality. TPM can solve this problem by improving OEE with little or no investment required. The most common goal of TPM is to maximize Overall Equipment Efficiency (OEE) by loss minimization and at the same time, increasing employee morale and job satisfaction. TPM reduces production losses by improving process instability, equipment availability and product quality. TPM makes it easier for the organization to improve OEE ratio by providing a formula to quantify losses, and by giving priority to the most important ones using its tools and techniques.

This thesis describes the application of Total Productive Maintenance (TPM) tools and techniques to identify the losses and to reduce them on priority basis to maximize the Overall Equipment Efficiency (OEE). This work was done in Hydrogen Peroxide Plant of Samuda Chemical Complex Ltd, one of the largest private chemical manufacturing and processing companies of Bangladesh. Based on production capacity real data on losses and their corresponding causes were accumulated with a view to improve OEE. These losses were then classified into six major losses and the target was set to eliminate the most significant losses. WWBLA, a tool of TPM was used to reach at the root of the problem to eliminate them. Management was convinced and they performed the improvement work the study suggested. Ultimately the better OEE was found and there was also a positive impact of TPM on the organization at the end.

The purpose of this study was to eliminate root causes of the losses by using TPM tools to improve OEE. It appears that the causes of losses are related mainly to process instability rather than equipment failure and also the performance rate and quality rate can be improved sooner rather than availability. A real understanding of this study may leads to improve present situation of chemical plants, which are facing the problem of lower OEE within the shortest possible time with little or no investment.

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1.1 Introduction

Nowadays world market is too much competitive and customer satisfaction is the most critical factor to sustain in business. Cost & quality play the vital role to satisfy customer. Cost and quality can be controlled to a certain extent by maximizing Overall Equipment Efficiency. The goal of TPM is to maximize Overall Equipment Efficiency (OEE) and to reduce unplanned equipment downtime to zero while improving quality and production capacity, at the same time, increasing employee morale and job satisfaction. TPM reduces equipment losses by investing in people who can then improve equipment availability, improve product quality, and reduce labor costs [1].

This study shows the impact of TPM on OEE in chemical processing plant considering our culture and business environment. This study also describes the difficulties involved to manage top management, factory management and field operator and what approach was taken to overcome those difficulties during implementing a single pillar of TPM the third pillar KUBETSU KAIZEN (continuous improvement). This pillar is aimed at reducing losses in the workplace that affect our efficiencies. By using a detailed and thorough procedure we eliminate losses in a systematic method using various Kaizen tools.

1.2 Objectives of this Study

The specific objectives of this study are:

a) Identification of critical section and major losses by analyzing materials movement and impact of equipment failure on output.
b) Reduction of losses through identification and elimination of root causes with TPM Tools and Analytical Techniques.
c) Evaluation of the effectiveness of the previous steps taken, by analyzing Overall Equipment Efficiency (OEE).

1.3 Importance of this Study

Bangladesh has enormous prospects to utilize its natural resources properly in chemical processing and manufacturing industries for the development of its economic strength. There are a great number of public and private chemical processing and manufacturing plants inside the country. Such as fertilizer, sugar, cement, ceramics, food & beverages, petroleum oil refinery, gas & oil production company and other chemical industries.

But all are facing problems of downtime, process instability, and lower quality products, which result lower overall equipment effectiveness (OEE) and finally little or no profit margin. Government always has to give financial assistance for this type of industries. But the development of this sector can save a lot of foreign currency as well as we can earn the same by exporting its products to abroad. For this we need to eliminate the unplanned downtime and process instability and also have to improve product quality. In chemical processing plants, there are a lot of hazardous materials and their environmental impact is very dangerous. So the safety issue of the plant and its people are also very important.

To bring dynamism in this sector some realistic steps are required to undertake. Such steps can be categorized as reducing unplanned downtime, increasing process stability, improving quality, improving productivity knowledge of the workers, strengthening marketing and promotion ability, improving management skills and techniques, increasing overall equipment efficiency, safety etc. There is a great opportunity to increase overall equipment efficiency of fertilizer, sugar, cement, petroleum oil refinery, and natural gas processing plant and other chemical industries by implementing TPM, which is very much essential for the existence of this sector in the competitive world. This study will encourage implementing TPM to increase productivity, equipment efficiency and product quality in these sectors.

Chapter 2

Total Productive Maintenance:

A Literature Review

2.1 Introduction

TPM is a systematic approach to understand the equipment's function, the equipment's relationship to product quality, and the likely cause and frequency of failure of the critical equipment components (Nakajima, 1988) [2]. To maximize equipment effectiveness TPM establishes a thorough system of maintenance for the equipment's entire life span. This TPM system requires all employees working in autonomous small groups to work together to eliminate equipment breakdowns. Everyone is involved since every component of the manufacturing system—including operations, product and process design, and management— impacts equipment maintenance [3].

In the manufacturing industry, the utilization of installed capacity is rather low for various reasons. The implementation of total productive maintenance (TPM) has shown considerable results in different industries. It has not been unusual to increase the level of overall utilization from 60 to 90 percent according to Nakajima [3], which indicates a major increase of production. TPM is based on three major concepts:

(1) Maximizing equipment effectiveness

(2) Autonomous maintenance by operators and

(3) Small group activities.

TPM was introduced to achieve the following objectives:

- Avoid wastage in a quickly changing economic environment
- Producing goods without reducing product quality
- Reduce cost
- Produce a low batch quantity at the earliest possible time
- Goods send to the customers must be non-defective.

TPM was developed in a capital-intensive manufacturing environment. But the principles of TPM can be applied to all environments. Robinson and Ginder [4] stated that in Japan TPM is being used in a wide variety of service functions such as secretarial pools and administrative offices. To accomplish this, the TPM concept of reliability was expanded from equipment reliability to organizational reliability.

2.2 History of TPM

TPM is an innovative Japanese concept. The origin of TPM can be traced back to 1951 when preventive maintenance was introduced in Japan. However the concept of preventive maintenance was taken from USA. Nippon Denso was the first company to introduce plant wide preventive maintenance in 1960. Preventive maintenance is the concept wherein, operators produced goods using machines and the maintenance group was dedicated with work of maintaining those machines, however with the automation of Nippon Denso, maintenance became a problem, as more maintenance personnel were required. So the management decided that the operators would carry out the routine maintenance of equipment. This is Autonomous maintenance, one of the features of TPM. Maintenance group took up only essential maintenance works [8].

Thus Nippon Denso, which already followed preventive maintenance, also added Autonomous maintenance done by production operators. The maintenance crew went in the equipment modification for improving reliability. The modifications were made or incorporated in new equipment. This led them to maintenance prevention. Thus preventive maintenance along with maintenance prevention and maintainability improvement gave birth to Productive maintenance. The aim of productive maintenance was to maximize plant and equipment effectiveness to achieve optimum life cycle cost of production equipment.

By then Nippon Denso had made quality circles, involving the employee's participation. Thus all employees took part in implementing Productive maintenance in 1969. Based on these developments Nippon Denso was awarded the ―Distinguished Plant Prize" for developing and implementing TPM, by the Japanese Institute of Plant Engineers (JIPE) in 1971 [3]. Thus Nippon Denso of the Toyota group became the first company to obtain the TPM certification. To eliminate waste, Toyota became one of the first companies to implement TPM [3].

In the year 1995 there were are about 800 companies or company units using the TPM in Japan (Johansson, 1996). Also the European companies have started to apply TPM; one of the very first has been the Swedish car manufacturer Volvo in the Gent factory in Belgium. In Sweden especially the IVF (Institut För Verkstadsteknisk Forskning) has made big efforts to implement TPM in the Swedish companies, also in the small - and medium – Sized enterprises.

2.3 TQM & TPM: The Similarities & the Differences

TQM takes every process in an organization and strives to improve it by using simple quality improvement techniques. TPM is able to define performance conditions to realize equipment quality and to maintain it so that product quality can be accomplished by equipment. TPM is a very important subset of TQM. The TPM process increases equipment reliability, makes the process more repeatable, and reduces waste. The key ingredient to the success of a TPM and TQM process is the involvement of the worker. The true power in both TPM and TQM is using the knowledge and experience of all the workers to generate ideas and contribute to the goals and objectives of the company. The goal of TPM is waste reduction and process repeatability. This ties conveniently to the process improvement goals characterized by TQM. Both the TPM and TQM are aiming to prevent the problems and to eliminate the waste and collective responsibility for the development work. The final goal is to deliver a product, which is filling all the quality requirements of the customer, and that all the costs can be predicted.

2.3.1 The Similarities between TQM and TPM

The TPM program closely resembles the popular Total Quality Management (TQM) program. Many of the tools such as check sheet, pareto chart, flowchart, cause effect diagram, histogram, scatter diagram, control chart, employee empowerment, benchmarking, documentation etc. used in TQM are used to implement and optimize TPM.

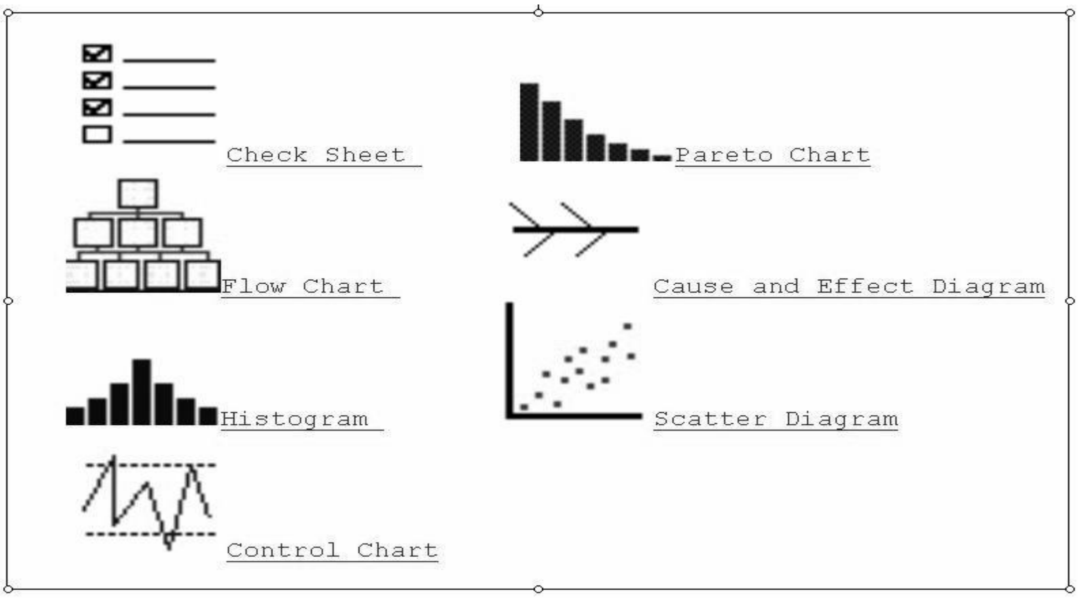


Figure 2.1: Tools used in both TPM & TQM

Total commitment to the program by upper level management is required in both programmes. Employees must be empowered to initiate corrective action, and a long-range outlook must be accepted as TPM may take a year or more to implement and both TQM and TPM are continuous process.

2.3.2 The Differences Between TQM and TPM

Table 2.1: Differences between TQM and TPM

Category	TQM	TPM
Object	Quality (Output and effects)	Equipment (Input and cause)
Means of attaining goal	Systematize the management. It is software oriented	Employees participation and it is hardware oriented
Target	Quality of product	Elimination of losses and wastes.

2.4 Different Types of Maintenance

1. Breakdown Maintenance

It means that people waits until equipment fails and repair it. Such a thing could be used when the equipment failure does not significantly affect the operation or production or generate any significant loss other than repair cost.

2. Preventive Maintenance (1951)

It is a daily maintenance (cleaning, inspection, oiling and re-tightening), design to retain the healthy condition of equipment and prevent failure through the prevention of deterioration, periodic inspection or equipment condition diagnosis, to measure deterioration. It is further divided into periodic maintenance and predictive maintenance. Just like human life is extended by preventive medicine, doing preventive maintenance can prolong the equipment service life.

2a. Periodic Maintenance (Time Based Maintenance - TBM)

Time based maintenance consists of periodically inspecting, servicing and cleaning equipment and replacing parts to prevent sudden failure and process problems.

2b. Predictive Maintenance (Condition-Based Maintenance- CBM)

This is a method in which the service life of important part is predicted based on inspection or diagnosis, in order to use the parts to the limit of their service life. Compared to periodic maintenance, predictive maintenance is condition-based maintenance. It manages trend values, by measuring and analyzing data about deterioration and employs a surveillance system, designed to monitor conditions through an online system.

3. Corrective Maintenance (1957)

It improves equipment and its components so that preventive maintenance can be carried out reliably. Equipment with design weakness must be redesigned to improve reliability or improving maintainability.

4. Maintenance Prevention (1960)

It indicates the design of new equipment. Weaknesses of current machines are sufficiently studied (on site information leading to failure prevention, easier maintenance and prevents of defects, safety and ease of manufacturing) and are incorporated before commissioning new equipment.

5. Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) is a practice that combines preventive maintenance with total quality management and total employee involvement. Operations and maintenance teams' work together to identify areas in equipment maintenance, which operators with existing skills or with, minor training can handle. In a TPM implementation operators take ownership of their equipment for better maintenance and improved productivity [9-10].

2.5 Different Features of TPM

Motives of TPM: The motives of TPM are to adopt the life cycle approach for improving the overall performance of production process and equipment, improving productivity by highly motivated workers, which is achieved by job enlargement and finally the use of voluntary small group activities for identifying the cause of failure, possible process and equipment modifications.

Uniqueness of TPM: The major difference between TPM and other concepts is that the operators are also made to involve in the maintenance process. The concept of "I (Production operators) Operate, You (Maintenance department) fix" is not followed.

Goals of TPM: The Major five goals of TPM are-

1. Maximize equipment effectiveness (improve overall efficiency).
2. Develop a system of productive maintenance for the life of the equipment.
3. Involve all departments that plan, design, use, or maintain equipment in implementing TPM (engineering and design, productive, and maintenance).
4. Actively involve all the employees-from top management to shop floor workers.
5. Promote TPM through motivation management: autonomous small group activities.

Direct benefits of TPM: The direct benefits of TPM are-

1. Increase in productivity and OEE (Overall Equipment Efficiency)
2. Reduction in customer complaints.
3. Reduction in the manufacturing cost by 30%.
4. Satisfying the customers needs by 100 % (Delivering the right quantity at the right time, in the required quality.)
5. Reduced accidents.

Indirect benefits of TPM: The indirect benefits of TPM are-

1. Higher confidence level among the employees.
2. A clean, neat and attractive work place.
3. Favorable change in the attitude of the operators.
4. Achieve goals by working as team.
5. Horizontal deployment of a new concept in all areas of the organization.
6. Enables Knowledge Sharing and expertise.
7. The worker develops a sense of ownership of the machine he operates.

2.6 OEE (Overall Equipment Efficiency)

The basic measure associated with Total Productive Maintenance (TPM) is the OEE. This OEE highlights the actual "Hidden capacity" in an organization. OEE is not an exclusive measure of how well the maintenance department works. The design and installation of equipment as well as how it is operated and maintained affect the OEE. It measures both efficiency (doing things right) and effectiveness (doing the right things) with the equipment based on a given production plan.

Toyota measures six categories of equipment losses throughout its production system. These are: (a) equipment failures, (b) setup and adjustment, (c) idling and minor stoppages, (d) reduced speed, (e) defects in the process, and (f) reduced yield [1]. These six losses are combined into one measure of overall equipment Efficiency (OEE). OEE incorporates three basic indicators of equipment performance and reliability [5-7]:

1. Equipment Availability: Availability is the proportion of time machine is actually available out of time it should be available.

Equipment Availability = (Loading time – Downtime) / Loading time............................(a)

Gross available time or Working Time for production include 365 days per year, 24 hours per day, 7 days per week. However, this is an ideal condition. Planned downtime includes vacation, holidays, not enough loads and scheduled maintenance. Availability losses include equipment failures and setup & adjustment/ changeovers indicating situations when the line is not running although it is expected to run. Loading time is the total time available for operation minus planned or necessary downtime such as breaks in production schedule, precautionary resting times and daily shop floor meetings.

2. Performance Efficiency: The second category of OEE is performance. The formula can be expressed in this way:

Performance Efficiency = (Theoretical cycle time X Processed amount) / Operating time ....(b)

Operating time is the time during which the products are actually produced i.e. the loading time minus the time the machine is down due to breakdowns, set up and adjustments, retooling and other stoppages. Speed losses i.e. idling and minor stoppages and reduced speed in the line indicate that the line is running, but it is not providing the quantity it should.

3. Rate of Quality Products: Rate of Quality Product is percentage of good parts out of total produced. Sometimes it is called ―yield". Quality losses refer to the situation when the line is producing, but there are quality losses due to defects in the process and reduced yield i.e. in-progress production and warm up rejects. We can express a formula for quality like this:

Rate of Quality Products = (Processed amount - Defect amount) / Processed amount ....(c)

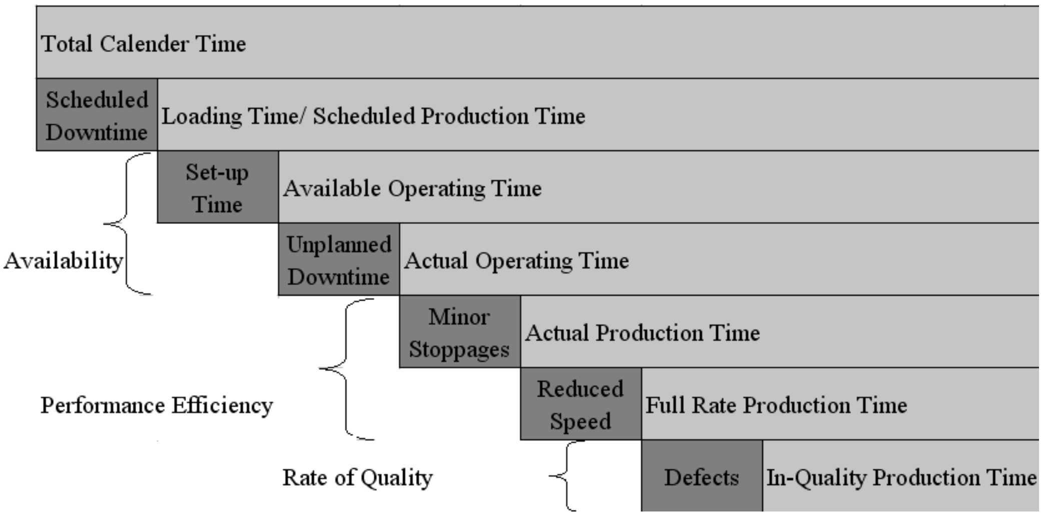


Figure-2.2: Three basic indicators of OEE

Thus OEE is a function of the three factors: Equipment Availability multiplied by Performance Efficiency and Rate of Quality Products.

OEE = Equipment Availability X Performance Efficiency X Rate of Quality Products X 100 % .... (1)

2.7 Pillars of TPM

Some important factors have to be considered to practice TPM properly which are termed as pillars. TPM stands on 8 pillars, which are shown in the figure and described below:

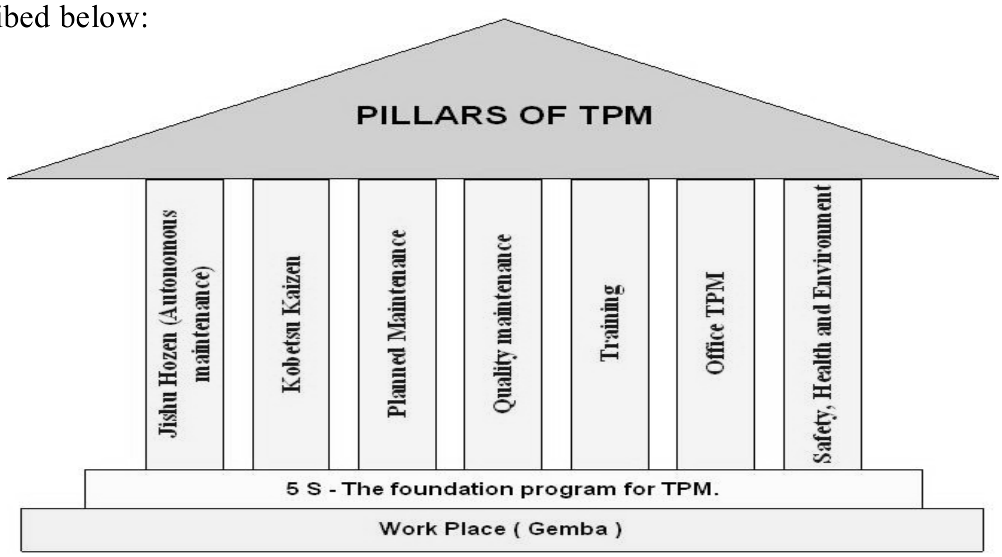


Figure 2.3: Pillars of TPM

2.7.1 PILLAR -1: 5S

TPM starts with 5S. It is a systematic process of housekeeping to achieve a serene environment in the work place involving the employees with a commitment to sincerely implement and practice house keeping. Problems cannot be clearly seen when the work place is unorganized. Cleaning and organizing the workplace helps the team to uncover problems. 5s is a foundation program before the implementation of TPM, hence in the above figure, 5s has been positioned in the base. If this 5S is not taken up seriously, then it leads to 5D. They are Delays, Defects, Dissatisfied customers, Declining profits and Demoralized employees. Following are the pillars of 5S.

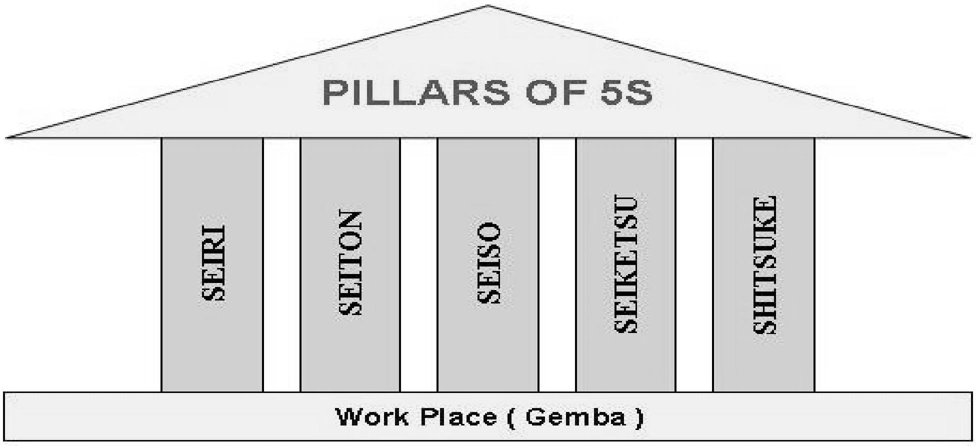


Figure 2.4: Pillars of 5S

i. **SEIRI (Sort out):** This means sorting and organizing the items as critical, important, frequently used items, useless, or items that are not need as of now. Unwanted items can be salvaged. Critical items should be kept for use nearby and items that are not be used in near future, should be stored in some place. For this step, the worth of the item should be decided based on utility and not cost. As a result of this step, the search time is reduced.

ii. **SEITON (Organize/ Systematize):** The concept here is that "Each item has a place and only one place". The items should be placed back after usage at the same place. To identify items easily, name plates and colored tags has to be used. Vertical racks can be used for this purpose, and heavy items occupy the bottom position in the racks.

iii. **SEISO (Shine the workplace):** Keeping the work area clean. Retain only the information and items needed to work on the specific tasks. This involves cleaning the work place free of burrs, grease, oil, waste, scrap etc. No loosely hanging wires or oil leakage from machines.

iv. **SEIKETSU (Standardization):** Creating good conditions of hygiene, checking, illumination, atmospheric pollution, sound and temperature etc. Employees have to discuss together and decide on standards for keeping the work place / Machines / pathways neat and clean. These standards are implemented for whole organization and are tested / inspected randomly.

v. **SHITSUKE (Self discipline):** Developing the habit of looking at procedures and rules. Considering 5S as a way of life and bring about self-discipline among the employees of the organization. This includes wearing badges, following work procedures, punctuality, dedication to the organization etc.

2.7.2 PILLAR - 2: AUTONOMOUS MAINTENANCE

This pillar deals with making the machine operators more responsible for the equipment they operate. This pillar is geared towards developing operators to be able to take care of small maintenance tasks, thus freeing up the skilled maintenance people to spend time on more value added activity and technical repairs. By use of this pillar, the aim is to maintain the machine in new condition. The activities involved are very simple nature. This includes cleaning, lubricating, visual inspection, tightening of loosened bolts etc. Benefits of the autonomous maintenance are: 1) Uninterrupted operation of equipments. 2) Flexible operators to operate and maintain other equipments. 3) Eliminating the defects at source through active employee participation.

Steps in Autonomous Maintenance: The bellow mentioned steps should be taken to implement autonomous:

1. Training of the employees: Employees should be educated the about TPM, its advantages, AM advantages and steps in AM and also about the equipment they use, the frequency of oiling, day-to-day maintenance activities required and the abnormalities that could occur in the machine and way to find out the abnormalities.

2. Initial cleanup of machines: Management should arrange all items needed for cleaning. On the very first day, operators clean the equipment with the help of maintenance department.
3. Counter Measures: Inaccessible regions had to be reached easily.

4. Tentative Standard: A standard schedule has to be made and followed strictly. Schedule should be made regarding cleaning, inspection and lubrication and it also should include details like when, what and how.

5. General Inspection: The employees are trained in disciplines like Pneumatics, electrical, hydraulics, lubricant and coolant, drives, bolts, nuts and Safety. This is necessary to improve the technical skills of employees and to use inspection manuals correctly.

6. Autonomous Inspection: New methods of cleaning and lubricating are used. Each employee prepares his own autonomous chart / schedule in consultation with supervisor. Parts, which have never given any problem, or part, which don't need any inspection, are removed from list permanently based on experience including good quality machine parts.

7. Standardization: Up to the previous step only the machinery / equipment was the concentration. However in this step the surroundings of machinery are organized. Necessary items should be organized, such that there is no searching and searching time is reduced. Everybody should follow the work instructions strictly. Necessary spares for equipments is planned and procured

8. Autonomous management: OEE and OPE and other TPM targets must be achieved by continuous improve through Kaizen. PDCA (Plan Do Check and Act) cycle must be implemented for Kaizen.

2.7.3 PILLAR – 3: KOBETSU KAIZEN (CONTINUOUS IMPROVEMENT)

"Kai" means change, and "Zen" means good (for the better). Basically kaizen is for small improvements, but carried out on a continual basis and involve all people in the organization. Kaizen requires no or little investment. The principle behind is that "a very large number of small improvements are more effective in an organizational environment than a few improvements of large value". This pillar is aimed at reducing losses in the workplace that affect our efficiencies. By using a detailed and thorough procedure we eliminate losses in a systematic method using various Kaizen tools. These activities are not limited to production areas and can be implemented in administrative areas as well. KAIZEN Targets to achieve and sustain zero losses with respect to minor stops, measurement and adjustments, defects and unavoidable downtimes. It also aims to achieve manufacturing cost reduction. Various tools are used in KAIZEN to identify causes and to eliminate the losses. Such as: PM analysis, why - why analysis, summary of losses, Kaizen register, Kaizen summary sheet etc.

Kaizen to eliminate of Six Big Losses

The objective of TPM is maximization of equipment effectiveness. TPM aims at maximization of machine utilization and not merely machine availability maximization. As one of the pillars of TPM activities, Kaizen pursues efficient equipment, operator and material and energy utilization that is extremes of productivity and aims at achieving substantial effects. Kaizen activities try to thoroughly eliminate Six Big Losses, which affect OEE. Six major losses that were identified, details of which is given below:

1. Equipment failure: Equipment failure causes production downtime. Equipment failure requires maintenance assistance and can be prevented with the use of appropriate preventive maintenance actions, developed and applied operating procedures, and design changes. Most importantly, equipment failure requires an improvement effort that should be the result of a successful partnership between production and maintenance. If the failure occurs, it is important to use Root Cause Failure Analysis (RCFA) techniques to identify the root cause of the problem and effective and applicable solutions that will eliminate or mitigate the failure occurrence and impact.

2. Set-up and adjustments: This refers to loss of productive time between product types, and includes the warm-up after the actual changeover. Changeover time should be included in this loss opportunity and it should not be part of the planned downtime.

3. Idling & Minor stoppage: Small stops are typically less than 5-10 minutes and they are typically minor adjustments or simple tasks such as cleaning. They should not be caused by logistics. They may be occur due to the abnormal operation of sensors, blockage etc.

4. Reduced Speed: Speed losses are caused when the equipment runs slower than its optimal or designed maximum speed. Examples include machine wear, substandard materials, operator inefficiency, and equipment design not appropriate to the application, etc.

5. Defect/ rework loss: Losses due to scarp, rework and the product that does not meet the quality. Losses during production include all losses caused by less-than-acceptable quality after the warm-up period.

6. Reduced yield: Losses during production include all losses caused by less-than-acceptable quality during the warm-up period. It starts from machine start-up to stable production

However with the passage of time, more losses were added to the above list. Each organization has its own classification of losses. Given below is one such elaborate classification listing 16 types of losses:

Table 2.2: 16 types of losses in an organization

Loss		Category
1	Failure losses/Breakdown loss	Losses that impede equipment efficiency
2	Setup/ adjustment loss	
3	Cutting blade loss	
4	Minor stoppage	
5	Speed loss	
6	Start up loss	
7	Defect/ rework loss	
8	Scheduled down time loss	
9	Management loss	Losses that impede human work efficiency
10	Operating motion loss	
11	Line organization loss	
12	Logistics loss	
13	Measurement loss	
14	Energy loss	Losses that impede effective use of production resources
15	Die, jig and tool breakage loss	
16	Yield loss	

2.7.4 PILLAR –4: PLANNED MAINTENANCE

This pillar focuses on the maintenance department and the activities they conduct. Effectively planning and managing activities like preventive maintenance, scheduled maintenance, predictive maintenance, condition based maintenance and reliability centered maintenance among others are part of this pillar. It is aimed to have trouble free machines and equipments producing defect free products for total customer satisfaction. With Planned Maintenance we evolve our efforts from a reactive to a proactive method and use trained maintenance staff to help train the operators to better maintain their equipment.

2.7.5 PILLAR – 5: QUALITY MAINTENANCE

This pillar deals with the quality of processes and products in the plant. Process control and addressing customer complaint issues are some issues covered under this. It is aimed towards customer delight through highest quality through defect free manufacturing. Focus is on eliminating non-conformances in a systematic manner, much like Focused Improvement. QM activities are to set equipment conditions that preclude quality defects, based on the basic concept of maintaining perfect equipment to maintain perfect quality of products. The conditions are checked and measured if the measured values are within standard values to prevent defects.

2.7.6 PILLAR – 6: TRAINING

Education and Training Employees are graded here on the basis of their skill levels and on their willingness to learn. It is aimed to have multi-skilled revitalized employees whose morale is high and who has eager to come to work and perform all required functions effectively and independently. Education is given to operators to upgrade their skill, it is not sufficient to know only "Know-How" but also learn "Know-why". The goal is to create a factory full of experts.

2.7.7 PILLAR – 7: OFFICE TPM

This deals with the administrative aspects of a manufacturing organization. Office and administration are a part of TPM based on the realization that they have a direct bearing on the productivity of the manufacturing organization. This pillar tries to minimize wastage in office in the form of communication, data processing, and decision-making among others. Office TPM should be started after activating four other pillars of TPM (AM, KK, QM, and PM). Office TPM must be followed to improve productivity, efficiency in the administrative functions and identify and eliminate losses. This includes analyzing processes and procedures towards increased office automation.

2.7.8 PILLAR – 8: SAFETY, HEALTH AND ENVIRONMENT

Safety Health And Environment deals with the aspect of safety and workplace environment in the plant. It involves issues related to productivity, equipment, and human resources too. The target of this pillar is zero accident, zero health damage and zero fires. In this area focus is on to create a safe workplace and a surrounding area that is not damaged by the process or procedures. This pillar will play an active role in each of the other pillars on a regular basis.

2.8 TPM Organization Structure

The below figure depicts a typical organization structure for TPM implementation:

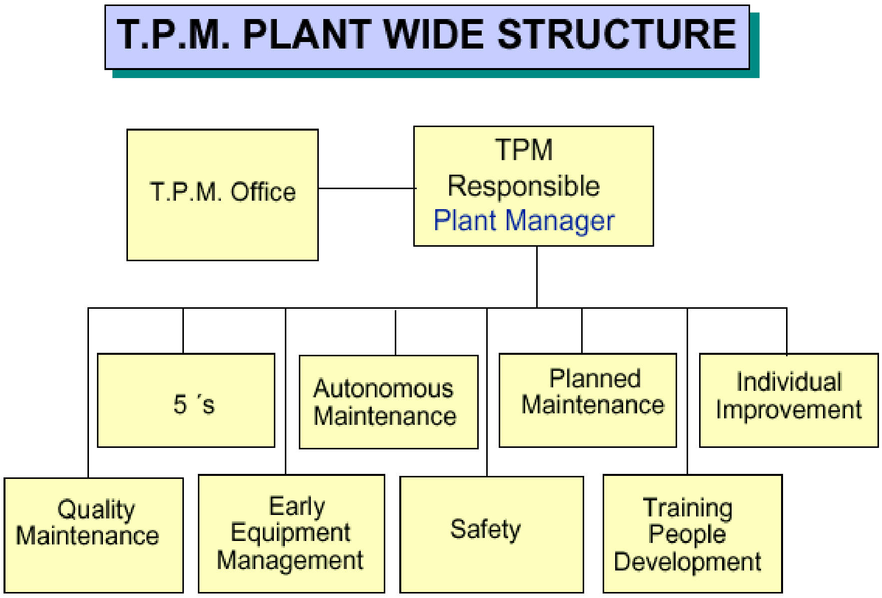


Figure 2.5: TPM Organization Structure

2.9 Stages in TPM implementation

The Steps in introduction of TPM in an organization can be shown in a table as follows:

Stage A – Preparatory Stage

Step 1 - Announcement: Announcement by Management to all about TPM introduction in the organization. Proper understanding, commitment and active involvement of the top management in needed for this step. Senior management should have awareness programs, after which announcement is made to all.

Step 2 - Initial education and propaganda for TPM: Training is to be done based on the need. Some need intensive training and some just awareness. Take people who matter to places where TPM already successfully implemented.

Step 3 - Setting up TPM and departmental committees: TPM includes improvement, autonomous maintenance, quality maintenance etc., as part of it when committees are set up it should take care of all those needs.

Step 4 - Establishing the TPM working system and target: Now each area is benchmarked and fix up a target for achievement.

Step 5 - A master plan for institutionalizing: Next is implementation leading to institutionalizing where in TPM becomes an organizational culture. Achieving PM award is the proof of reaching a satisfactory level.

Stage B- Introduction Stage

This is a ceremony and should invite all, such as Suppliers as they should know that we want quality supply from them, related companies and affiliated companies who can be our customers, sisters concerns etc. Some may learn from us and some can help us and customers will get the communication from us that we care for quality output.

Stage C – Implementation

In this stage eight activities are carried which are called eight pillars in the development of TPM activity. Of these four activities are for establishing the system for production efficiency, one for initial control system of new products and equipment, one for improving the efficiency of administration and one for control of safety, sanitation as working environment.

Stage D-Institutionalizing Stage

By all the activities one would has reached maturity stage. Now is the time for applying for PM award. Also think of challenging level to which one can take this movement [9-10].

2.10 Difficulties in TPM implementation

One of the difficulties in implementing TPM as a methodology is that it takes a considerable number of years. The time taken depends on the size of the organization. There is no quick way for implementing TPM. This is contradictory to the traditional management improvement strategies. Following are the other difficulties faced in TPM implementation:

- Typically people show strong resistance to change.

- Many people treat it just another ―Program of the month" without paying any focus and also doubt about the effectiveness.
- Not sufficient resources (people, money, time, etc.) and assistance provided
- Insufficient understanding of the methodology and philosophy by middle management
- TPM is not a ―quick fix " approach, it involve cultural change to the ways we do things
- Many people considered TPM activities as additional work/threat and
- Data collection is also a challenge.

Chapter 3

Plant overview & data collection

3.1 Plant Overview

The plant is designed to produce Technical Grade (50% con.) Hydrogen Peroxide (H_2O_2) with the capacity of 36 MT per day. Raw materials used in here are natural gas, oxygen from Air, Demineralized water. Main Consumers are textile, paper, food, pharmaceuticals and beverage industry and many other industries.

The plant was divided in to three sections to study properly. They are Hydrogen production unit, Peroxide production unit and Utility section.

3.1.1 Hydrogen Production Unit: The Hydrogen production unit is designed to produce ultra pure hydrogen. The Natural Gas (NG) is first compressed by natural gas compressor and preheated in the gas-to-gas heat exchanger. In the reactors the hot feed the passes over CoMo Alumina catalyst to convert sulphur compound, into H_2S, which is removed by a Zinc Oxide catalyst. The sulphur free feed gas is then mixed with superheated steam and flows to the reformer.

In the reformer tubes, the hydrocarbon and steam are heated further and react in the presence of Ni catalyst to produce a mixture of hydrogen, carbon monoxide, carbon dioxide, water and methane. The hot gases from the reformer flow to the quench pot. Condensate is sprayed to the gas, cooling it from 840 to 370°C. The gas flows next to the high temperature sift converter, where steam and carbon monoxide react in the presence of a catalyst to form hydrogen and carbon dioxide. There is a temperature rise of approximately 50°C by means of water-cooled exchanger condensed water is removed from the process gas in the condensate drums. The process gas is then flows to the pressure sewing adsorber (PSA). Granular adsorbents in the adsorber vessel trap all of the impurities, leaving ultra pure hydrogen. One adsorber is in operation while the other two are being regenerated.

Major equipments of hydrogen production unit are Natural Gas Compressor, preheater, desulphurizer, reformer, quence pot, HT Shift converter, heat exchanger, deaerator, steam drum, condensate separator, PSA, Guard vessel and different types of pumps.

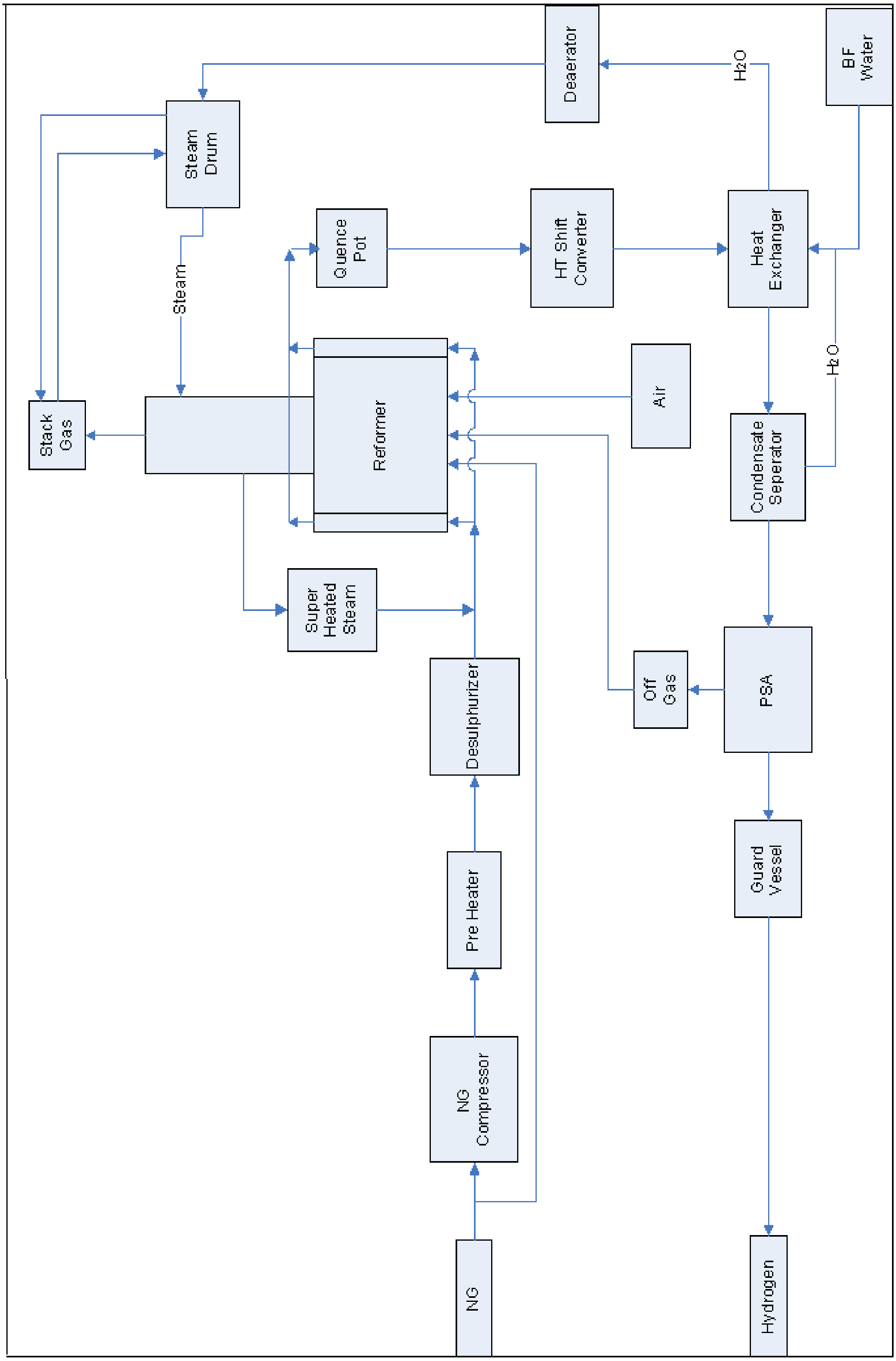


Figure 3.1: Block diagram of Hydrogen production unit

3.1.2 Peroxide production unit: Peroxide production unit is designed to produce Hydrogen Peroxide of various concentrations. Ultra pure hydrogen and Oxygen from the air react in presence of working solution and produce Hydrogen Peroxide. Working solution is a mixture of ethyl anthraquinone, two solvents (one polar and one non polar organic solvent) and a corrosion inhibitor. This working solution is pre heated and feed is given to the hydrogenation reactor where it reacts with hydrogen in presence of palladium catalyst and produce hydrogenated working solution. Working solution is filtered in a series of filter to free from Pd catalyst. A small stream of working solution circulated through reversion system to revert unwanted Quinone in to useful Quinone. Then Hydrogenated-working solution is feed to the oxidizer through the top of the oxidizer and from the bottom counter current process air enters into the oxidizer. Oxygen from process air reacts with hydrogenated working solution and produce hydrogen peroxide and hydrogenated working solution comes back to its original oxidized state. Excess air from the oxidizer passes through solvent recovery unit to recovers entrained solvents. Mixture of hydrogen peroxide and working solution enter into the extractor where DM water extracts Hydrogen Peroxide from working solution. Due to high specific gravity of DM water and Hydrogen Peroxide mixture named crude peroxide removed through the extractor bottom and after passing through the crude wash column it is stored in CHP tank. Working solution leaves extractor through the top of the extractor and passes through the coaliscer and then it is again feed to the hydrogenation reactor. Crude peroxide concentration is 25% to 30%. So it is again sent to another concentration increasing unit called distillation unit. From distillation unit bottom product is of high concentration (55to 65%) and lean product is of low concentration (25 to 45%) received. after mixing and blending of these two components, desired 50 % concentrated hydrogen per oxide obtained. so there is no by product in this industry and theoretically almost no wastage.

Major equipments Peroxide production unit are Feed pumps, Heaters, Hydrogenation Reactor, Primary filter, Degassers, Secondary and polish filter, Oxidizer, Coolers, Extractor, Coalescer, Wash column, evaporator, cyclone separator, distillation column, process Air Compressor etc.

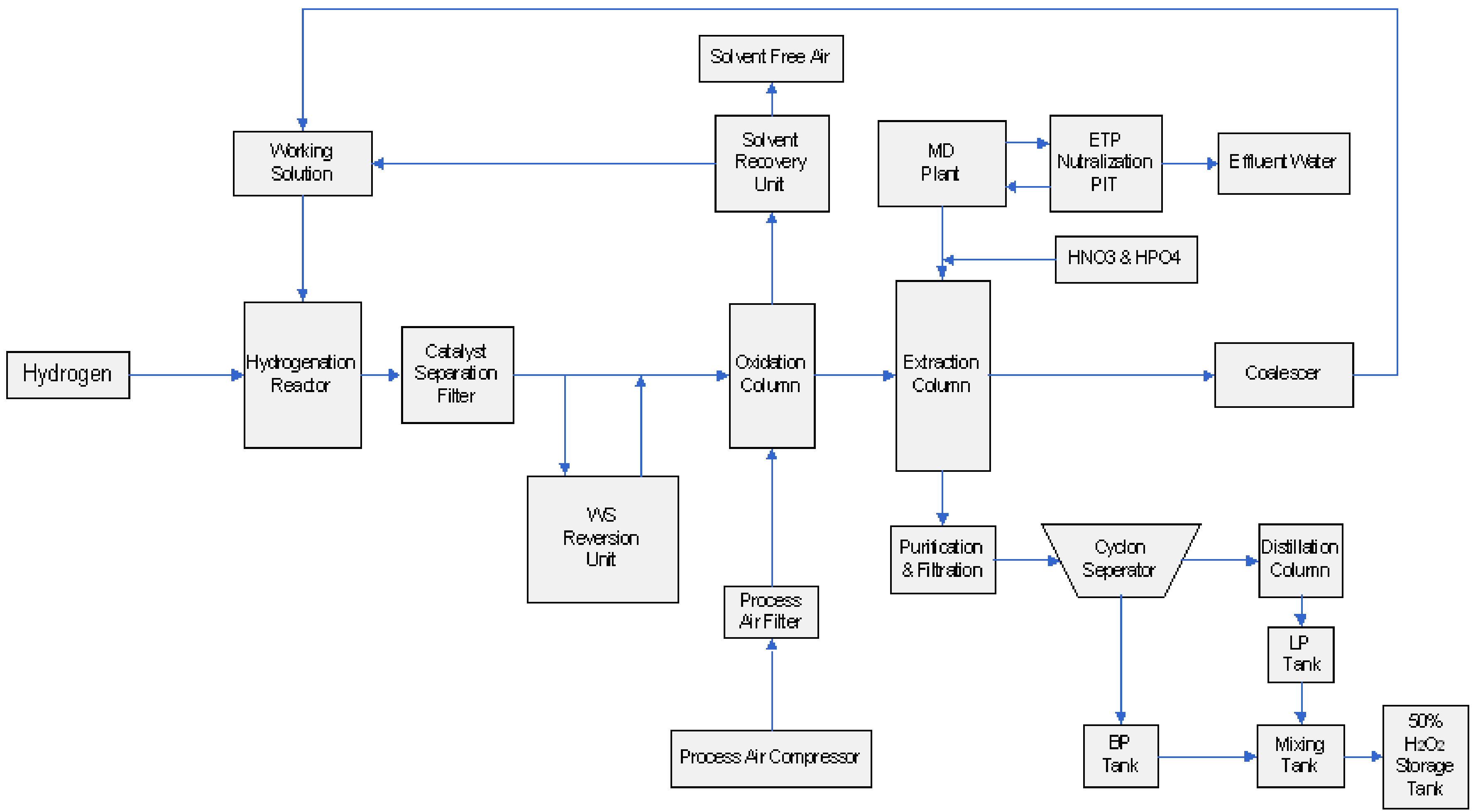


Figure 3.2: Block diagram of Peroxide production unit

3.1.3 Utility Section: In utility section there is Generator for power, Instrument air plant, Nitrogen Plant, Cooling Tower, Chiller, Boiler, Steam generation unit and DM water plant.

Steam is generated in the plant by utilizing heat from the process gas stream and flue gases. Boiler feed water is preheated. The boiler feed water is then pumped through convection tubes in the flue stack of the reformer where steam is generated. The process steam is superheated in the convection section of the reformer and then enters the process stream. In dematerialized water (DM) plant some resin is used which is needed to regenerate. To regenerate resin low concentrated HCl acid and low concentrated caustic soda is used which is later mixed in one pit where it is neutralized automatically and maintain pH value 7 of the effluent water.

3.2 Data Collection – A Challenge

To implement TPM it is essential to get appropriate data on stoppage and losses from the sources. In the TPM literature it is not clearly stated how the data of losses should be collected and classified according to types and reasons. Most of the companies have different system for collecting data on machinery disturbance. In this paper it was tried to get information over the magnitude and reason for machinery or equipment losses. The information of machinery losses will provide the appropriate base for planning activities in the TPM framework.

Often administrative maintenance systems record the repair time, which is not the same as stoppage time. Further, there exist logbooks where the operators record major stoppages. Neither of those two data collection systems gives, in most cases, an appropriate and comprehensive picture of the losses and their reasons. Moreover it is quit difficult to get the accurate data in a process industry.

In some industrial branches, the data collection is of high quality. In many industries there is a resistance against data collection from operators and foremen. To succeed with data collection, it is necessary to find a less time consuming method that is also precise. Further, it is necessary to convince operators and foremen. In some cases, the operators believe that some disturbances have a major impact on efficiency; later measurements can show that this was completely wrong. However, an automatic data collection system is expensive, complex and the data are collected at an aggregated level. A manual data collection can be very detailed and failures can be carefully examined [11].

Chapter 4

Improvement of Overall Equipment Efficiency

4.1 Approach

In this study we choose the plant side only to improve. We tried to improve the OEE ratio by providing a formula to quantify losses and by giving priority to the most important ones. Among the eight pillars, the third pillar KOBETSU KAIZEN (Continuous Improvement) is used in this study as the impact of this pillar on OEE can be shown within the shortest possible time. This pillar is aimed at reducing different types of losses in the workplace that affect the efficiencies. Kaizen tools are used in a systematic method to eliminate losses. As the study was made in a chemical process industry we divided our time span into three stages and all the stages are of four months duration.

4.1.1 General Approach

To do the work the approach that has been followed according to the TPM pillar are:

i. Data Collection & Data Analysis

a. Data accumulation
b. Identification of critical section
c. Loss Identification & classification
d. Determination of OEE in 1st step

ii. Problem Identification & Possible Solution

a. Identification of Significant Losses (Pareto & Loss Tree)
b. Identifying possible causes of Significant Losses
c. Minimizing the Losses by Analytical Technique (WWBLA)

iii. Review & Monitoring

a. Impact of WWBLA on losses at the end of 2nd Stage
b. Impact of WWBLA on OEE at the end of 2nd Stage
c. Next steps should be taken for maximizing OEE
d. Determination of OEE at the end of 3rd Stage

After a through study of all the sections, we tried to identify the daily production losses according to the daily production capacity, because of excess market demand. At the same time we tried to identify the causes of the losses to eliminate them. Most of the losses are influenced by the both independent and dependent variables and affect overall equipment efficiency (OEE).

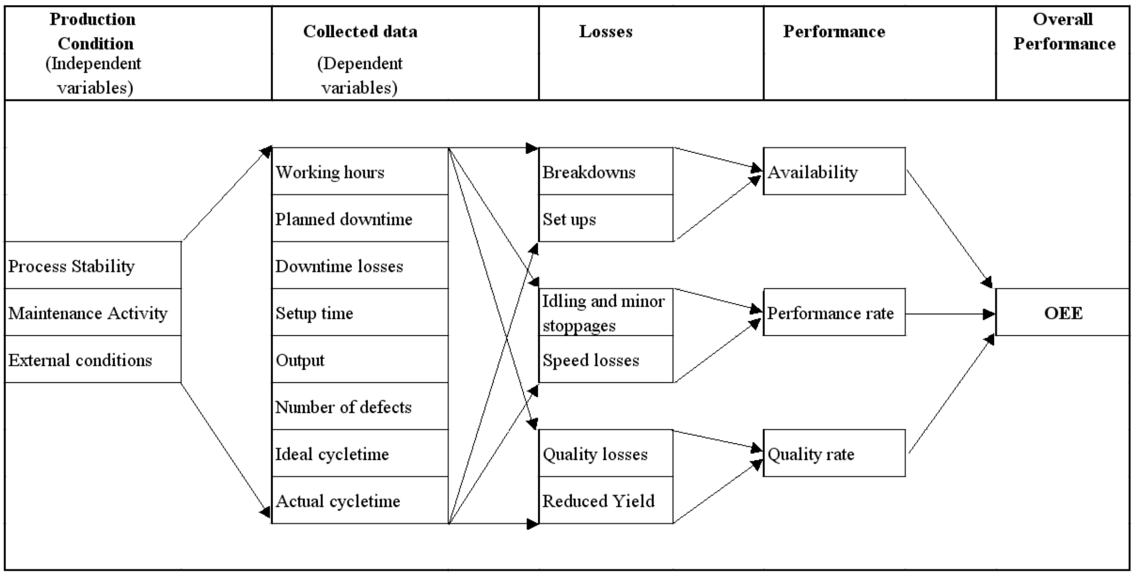


Figure 4.1: Relations among the variables, losses and OEE

The plant was capable to produce maximum 36 MT H_2O_2 per day. Forms for collecting data on disturbance or losses were developed in co-operation with plant manager, shift engineers & maintenance people. Data on losses were collected during a period of four months. Shift engineer from the DCS control panel recorded the downtime & the production losses. Minor stoppages and speed losses were determined by analyzing by abnormal flow rate of H_2 & H_2O_2 and the corresponding time duration. Losses from quality defects and drainage were registered separately. The losses were also categories to show the impact of independent variables as:

1. Loss due to Process
2. Loss due to Equipment
3. Raw Material Wastage (RMW)/ Defects/ Drainage/ Yield loss.

The reliability of collected data is in some cases low. It is not unrealistic to believe that operators indicate, e.g. breakdown or set-up as a reason for losses when the reason could be personal activities of the operator. Those biases are to be taken in account in the analysis.

4.1.2 Measurement & Classification of Losses

In this case study, the whole process plant is DCS controlled and the data collection procedure was semi automatic. To identify losses, the production flow rate of H_2 and H_2O_2 are monitored. If there arise any problem with the machinery or equipment the control panel provide signal itself. The shift engineer locates the problem and note down it with the abnormal flow rate and its duration. Maintenance department uses a logbook to record the description of the problem & action taken, repair time and materials required.

Raw material wastage was calculated by deducting Standard RM consumption from actual RM consumption. Then equivalent production loss due to RWM was calculated by dividing 140 and 4, here 140 unit RM required for 1 MT H_2O_2 and production cost of H_2O_2 is 4 times than RM. Loss due to poor chemistry of WS is calculated by observing the hydrogenation degree (gpl) of working solution. For the maximum production hydrogenation degree should be 14.4 gpl. The plant manager found out the equivalent production losses of the respective problem and provided to us. The details how the losses are classified are mentioned bellow:

- ❖ **Losses due to downtime:** There exists no flow of H_2 or H_2O_2 or both of them on DCS panel.

1. Equipment failure: Equipment failures are causing the most losses in process industry. If any crucial equipment failed or the process become unstable it is needed to taken the whole plant shutdown. If there is no flow of H_2 or H_2O_2 showed on DCS panel, the kind of losses is taken as equipment failure. Actually it should be termed as process failure in case of process industry.

2. Set-up and adjustments: The set – up and adjustment time counts from the completion of maintenance work until the first end product comes out and the loss during this time is termed as Set-up and adjustments loss. Mainly it counts from the firing of the burner of the reformer or starting of the agitator of reactor.

- ❖ **Speed losses:** There exists reduced flow rate of H_2 or H_2O_2 or both of them on DCS panel.

3. Idling & Minor stoppage: All most these types of stoppages are operational disturbances. Duration of this type of losses is little but affects the production rate.

4. Reduced Speed: Often the optimum running speed/flow can't be achieved due to process instability & other things like low reactor agitator rpm.

- ❖ **Losses due to defects**: It may not affect the production rate but the product quality is below standard.

5. Process defect/ rework loss: Quality defects and rework losses are reducing the effective production time. This may be due to process instability, equipment or low quality raw material.

6. Reduced yield: During the start – up phase a machine or a system may first manufacture parts, which must be rejected because of the bad quality, until the normal operation level is reached.

4.2 Data Collection & Data Analysis

4.2.1 Data accumulation

Data was accumulated on daily basis and summarized as monthly report. The monthly report was the basis of all analysis. One of the monthly reports is given bellow as a sample:

Table 4.1: Monthly data collection sample sheet

Ist Stage: Data Collection & Data Analysis
Month - 01
Production Target: 36 MTPD (From 8:00 AM to 8:00 AM)

Date	Production	Actual RM	Sd RM	Eq. Loss due to				Section	Equipment	Downtime			Reason of Low	Production	Type of Loss	Action Taken/
	(MT)	consumption	consumption	RMW	P	E	W & D		Tag	Reason	Stop	Start	Production Rate	Loss		Maintenance Work
1	27.00	6127.00	3780.00	4.19	4.50	0.00	0.31	H_2O_2	WS				Poor chemistry of W S	4.50	Reduced Load/ speed	EAQ addition continuing to improve WS
2	27.00	6411.00	3780.00	4.70	4.00	0.00	0.30	H_2O_2	WS				Poor chemistry of W S	4.00	Reduced Load/ speed	
3	27.50	6320.00	3850.00	4.41	4.00	0.00	0.09	H_2O_2	WS				Poor chemistry of W S	4.00	Reduced Load/ speed	EAQ addition continuing to improve WS
4	26.50	6364.80	3710.00	4.74	4.00	0.50	0.26	H_2O_2	WS				Poor chemistry of W S	4.00	Reduced Load/ speed	
								H_2O_2	R 1102				Low rpm of agitator	0.50	Reduced Load/ speed	Abnormal sound assume bearing jam
								H_2O_2	P 1702				Abnormal discharge			Pump suction pipe cleaned as it was blocked by dirty hose pipe
5	26.50	6430.00	3710.00	4.86	4.00	0.50	0.14	H_2O_2	WS				Poor chemistry of W S	4.00	Reduced Load/ speed	EAQ addition continuing to improve WS
								H_2O_2	R 1102				Low rpm of agitator	0.50	Reduced Load/ speed	Abnormal sound assume bearing jam
6	15.00	6452.00	2100.00	7.77	4.00	9.00	0.23	H_2O_2	WS				Poor chemistry of W S	4.00	Reduced Load/ speed	
								H_2O_2	R 1102				Low rpm of agitator	1.00	Reduced Load/ speed	Abnormal sound assume bearing jam
								H_2O_2	R 1102				Pressure fluctuating & out of control	2.00	Reduced Load/ speed	
								H_2	PSA	Valve 505 A& C got stuck	4:00			6.00	Equipment failure	
7	2.00	1724.00	280.00	2.58	16.00	15.00	0.42	H_2	PSA	Valve 505 A& C got stuck		16:00		12.00	Equipment failure	Valve cleaned
								H_2	HTSC				Maintenance of outlet pipe line leakage delayed startup	3.00	Idling/minor stoppages	Leakage portion was cut & welded new MS pipe of 3 m length
								H_2O_2	F 1101							Primary filter cleaned
								H_2O_2	F 1102							Primary filter cleaned
								H_2O_2	K 1801C							Cooling water strainer cleaned of process air compressor
													Plant startup	12.00	Set up and adjustment	
													Plant stabilization	4.00	Reduced yield	
8	20.00	5942.20	2800.00	5.61	5.00	5.00	0.39						Plant stabilization	5.00	Reduced yield	
								H_2O_2	WS				Poor chemistry of W S	5.00	Reduced Load/ speed	
9	24.50	5984.20	3430.00	4.56	4.50	2.00	0.44						Plant stabilization	2.00	Reduced yield	
								H_2O_2	WS				Poor chemistry of W S	4.50	Reduced Load/ speed	
10	24.50	5925.00	3430.00	4.46	4.50	2.00	0.54						Plant stabilization	2.00	Reduced yield	
								H_2O_2	WS				Poor chemistry of W S	4.50	Reduced Load/ speed	
11	21.00	5794.00	2940.00	5.10	4.50	5.00	0.40	H_2O_2	WS				Poor chemistry of W S	4.50	Reduced Load/ speed	
								H_2O_2	K 1801C				Plummer blocked temperature increasing rapidly	5.00	Idling/minor stoppages	Disassembled & cleaned
12	20.00	5371.00	2800.00	4.59	4.00	7.00	0.41	H_2O_2	WS				Poor chemistry of W S	4.00	Reduced Load/ speed	
								H_2O_2	K 1801C				Plummer blocked temperature increasing rapidly	7.00	Idling/minor stoppages	Properly greased
13	10.00	4779.00	1400.00	6.03	15.00	4.50	0.47	H_2O_2	WS				Poor chemistry of W S	2.00	Reduced Load/ speed	
								H_2	PSA	FCV -501 blocked by molecular sieve dust	8:00	14:00		4.50	Equipment failure	Disassembled & cleaned
									F 1102							Primary filter bundle of reactor changed
									R 1102							3 way valve maintenance
								H_2O_2	K 1801C							Machining of flywheel
								H_2O_2	K 1801C							Maintenance completed & started
													Plant startup	12.00	Set up and adjustment	
													Plant stabilization	1.00	Reduced yield	
14	17.00	5643.00	2380.00	5.83	6.50	6.50	0.17	H_2O_2	WS				Poor chemistry of W S	4.50	Reduced Load/ speed	
													Plant stabilization	2.00	Reduced yield	
								H_2O_2	R 1102				3 way control valve is not working	6.50	Idling/minor stoppages	Unable to maintenance & reactor is stopped
15	17.00	5440.00	2380.00	5.46	5.50	8.00	0.04	H_2O_2	WS				Poor chemistry of W S	4.50	Reduced Load/ speed	
													Plant stabilization	1.00	Reduced yield	
								H_2O_2	K 1801B				High temperature in inter cooler & 1st stage discharge	5.00	Reduced Load/ speed	Every valve checked & Plummer block grease changed & running on test
								H_2O_2	R 1102				Pd catalyst accumulation in primary filter restricting H2	3.00	Idling/minor stoppages	3 way control valve is changed by a new one
16	25.00	5859.00	3500.00	4.21	4.00	2.50	0.29	H_2O_2	WS				Poor chemistry of W S	4.00	Reduced Load/ speed	
								H_2O_2	K 1801B				High temperature in inter cooler & 1st stage discharge	2.50	Idling/minor stoppages	Slide loosen the bolt of plummer block & temp coming down &taken to on line
17	27.00	6117.00	3780.00	4.17	4.00	0.50	0.33	H_2O_2	WS				Poor chemistry of W S	4.00	Reduced Load/ speed	
								H_2O_2	K 1801C				Cooling water valve has broken	0.50	Idling/minor stoppages	Valve replaced
18	25.00	6208.00	3500.00	4.84	4.00	2.00	0.16	H_2O_2	WS				Poor chemistry of W S	4.00	Reduced Load/ speed	
								H_2O_2	R 1102				Level transmitter showing higher consumption of H2	2.00	Reduced Load/ speed	
19	26.00	6325.00	3640.00	4.79	4.00	1.00	0.21	H_2O_2	WS				Poor chemistry of W S	4.00	Reduced Load/ speed	
								H_2O_2	R 1102				Level transmitter showing higher consumption of H2	1.00	Reduced Load/ speed	
20	23.00	6190.00	3220.00	5.30	4.00	3.50	0.20	H_2O_2	WS				Poor chemistry of W S	4.00	Reduced Load/ speed	
								H_2O_2	R 1102				Level transmitter showing higher consumption of H2	3.50	Reduced Load/ speed	Level transmitter diaphram cleaned
21	27.00	6385.00	3780.00	4.65	4.00	0.00	0.35	H_2O_2	WS				Poor chemistry of W S	4.00	Reduced Load/ speed	EAQ addition continuing to improve WS
22	17.50	6048.00	2450.00	6.43	12.00	0.00	0.07	H_2O_2	WS				Poor chemistry of W S	4.00	Reduced Load/ speed	
								H_2O_2	C 1301				Emulsion formation	8.00	Reduced Load/ speed	
23	21.00	5954.00	2940.00	5.38	9.50	0.00	0.12	H_2O_2	WS				Poor chemistry of W S	4.00	Reduced Load/ speed	
								H_2O_2	C 1301				Emulsion formation	5.50	Reduced Load/ speed	
								UT	P 2202							Motor brunt, it was rewinded
24	22.00	6070.00	3080.00	5.34	6.00	2.50	0.16	H_2O_2	WS				Poor chemistry of W S	4.00	Reduced Load/ speed	
								H_2O_2	C 1301				Emulsion formation	2.00	Reduced Load/ speed	
								H_2O_2	R 1102				Level transmitter showing higher consumption of H2	2.50	Reduced Load/ speed	Pd catalyst accumulation in primary filter restricting H2 consumption. New 3 way control valve FCV-1108 is changed by old
25	27.50	6435.00	3850.00	4.62	3.50	0.00	0.38	H_2O_2	WS				Poor chemistry of W S	3.50	Reduced Load/ speed	EAQ addition continuing to improve WS
								H_2O_2	P 1701C							Bearing changed
26	27.50	6543.00	3850.00	4.81	3.50	0.00	0.19	H_2O_2	WS				Poor chemistry of W S	3.50	Reduced Load/ speed	
27	25.00	6527.00	3500.00	5.41	3.50	2.00	0.09	H_2O_2	WS				Poor chemistry of W S	3.50	Reduced Load/ speed	
								UT	P 2001A				Cooling water pump cupling damage	2.00	Idling/minor stoppages	Cupling bush & nut-bolts changed
28	27.50	6582.00	3850.00	4.88	3.50	0.00	0.12	H_2O_2	WS				Poor chemistry of W S	3.50	Reduced Load/ speed	EAQ addition continuing to improve WS
29	27.00	6535	3780.00	4.92	3.50	0.50	0.08	H_2O_2	WS				Poor chemistry of W S	3.50	Reduced Load/ speed	
								UT	P 2001C				Cooling water pumps showing high amps & abnormal sound	0.50	Idling/minor stoppages	Bearing of motor replaced
30	26.50	6479.00	3710.00	4.94	4.50	0.00	0.06	H_2O_2	WS				Poor chemistry of W S	3.50	Reduced Load/ speed	
								H_2O_2	C 1301				Emulsion formation	1.00	Reduced Load/ speed	
Total	**680.00**	178964.2	95200.0	**149.58**	**163.50**	**79.50**	**7.42**							**243.00**		

4.2.2 Loss Identification & classification: Month wise losses are identified and then classified according to the above classification as bellow:

Table 4.2: 1st Stage Loss Identification & classification

a) Losses due to downtime

1. Equipment failure

Month	Equipment	Reason	Frequency	Loss (MT)	Downtime (hr)
1	PSA	Valve 505 A& C got stuck up	1	18.00	12.00
	PSA	FCV -501 blocked by molecular sieve dust	1	4.50	3.00
		Sub Total		**22.50**	**15.00**
2	PSA	Water entered in to PSA		31.50	21.00
		Sub Total		**31.50**	**21.00**
3	PSA	Fire caught at drain line	1	59.00	39.33
	Gen	Generator tripped	2	20.50	13.67
	Gen	Cable short circuited	1	6.00	4.00
	PSA	H_2 Line blocked	1	6.00	4.00
		Sub Total		**91.50**	**61.00**
4	Gen	Cooling water supply failed	1	7.00	4.67
		Sub Total		**7.00**	**4.67**
Total				**152.50**	**101.67**

2. Set-up and adjustments

Month	Equipment	Reason	Frequency	Loss (MT)	Downtime (hr)
1		Plant startup	2	24.00	16.00
		Sub Total		**24.00**	**16.00**
2		Plant startup	1	12.00	8.00
		Sub Total		**12.00**	**8.00**
3		Plant startup	3	26.00	17.33
		Sub Total		**26.00**	**17.33**
4		Plant startup	1	10.00	6.67
		Sub Total		**10.00**	**6.67**
Total				**72.00**	**48.00**

b) Speed losses

3. Idling & Minor stoppage

Month	Equipment	Reason	Frequency	Loss (MT)	Eq. Downtime
1	K 1801C	Plummer blocked temperature increasing rapidly	2	12.00	8.00
	R 1102	3 way control valve is not working	1	6.50	4.33
	HTSC	Maintenance of outlet pipe line leakage delayed startup	1	3.00	2.00
	R 1102	Pd catalyst accumulation in primary filter	1	3.00	2.00
	K 1801B	High temperature in inter cooler & 1st stage discharge	1	2.50	1.67

	P 2001A	Cooling water pump coupling damage	1	2.00	1.33
	K 1801C	Cooling water valve has broken	1	0.50	0.33
	P 2001C	Cooling water pumps showing high amps & abnormal sound	1	0.50	0.33
		Sub Total		**30.00**	**20.00**
2	C 1301	Emulsion formation	3	42.00	28.00
	F 1101A	Secondary filter blocked		21.50	14.33
	R 1102	Problem in gearbox	3	21.00	14.00
	K 1801B	Plummer blocked temperature increase	1	3.50	2.33
	P 1903	Pump stopped	1	2.00	1.33
	K 1801B	Suction valve problem	1	1.50	1.00
	P 1301B	Seal joint leakage	1	1.00	0.67
	P 1701A	Bearing damaged		1.00	0.67
		Sub Total		**93.50**	**62.33**
3	C 1201	Problem in temp transmitter	1	10.00	6.67
	PSA	Molecular sieve blocked H_2 line	1	6.50	4.33
	K 1801A	2nd stage valve damaged	1	3.00	2.00
	K 1801C	Preventive maintenance	1	2.50	1.67
	F 1101B	Filter cleaned	1	1.00	0.67
	F 1101A	Filter cleaned	1	0.50	0.33
		Sub Total		**23.50**	**15.67**
4	PSA	H_2 line blocked by molecular sieves	1	9.50	6.33
	PSA	Control valve 503 B problem	1	5.00	3.33
		Sub Total		**14.50**	**9.67**
		Total		**161.50**	**107.67**

4. Reduced Speed

Month	Equipment	Reason	Frequency	Loss (MT)	Eq. Downtime
1	WS	Poor chemistry of W S		115.00	76.67
	C 1301	Emulsion formation	4	16.50	11.00
	R 1102	Level transmitter showing higher consumption of H_2	4	9.00	6.00
	K 1801B	High temperature in inter cooler & 1st stage discharge	1	5.00	3.33
	R 1102	Low rpm of agitator	3	2.00	1.33
	R 1102	Pressure fluctuating & out of control	1	2.00	1.33
		Sub Total		**149.50**	**99.67**
2	WS	Poor chemistry of W S		87.00	58.00
	C 1301	Emulsion formation	13	41.00	27.33
	PSA	PSA alumina bed blocked	3	16.00	10.67
	WS	Active quinone increased	1	5.00	3.33
		Sub Total		**149.00**	**99.33**
3	WS	Poor chemistry of W S		82.50	55.00
	C 1301	Emulsion formation	15	38.50	25.67
	C 1301	Level controlling problem	1	8.00	5.33
	C 1301	Valve is not working properly	1	5.00	3.33
		Sub Total		**134.00**	**89.33**
4	WS	Poor chemistry of W S		79.50	53.00

	C 1301	Emulsion formation	16	19.00	12.67
	R 1101	Level transmitter problem	4	3.50	2.33
		Sub Total		**102.00**	**68.00**
Total				**534.50**	**356.33**

c) Losses due to defects

5. Process defect/ rework loss

Month	Equipment	Reason	Frequency	Loss (MT)
1		Raw material wastage		149.58
		Drainage/ Leakage loss		7.42
		Sub Total		**157.00**
2		Raw material wastage		180.44
		Drainage/ Leakage loss		8.06
		Sub Total		**188.50**
3		Raw material wastage		149.18
		Drainage/ Leakage loss		9.32
		Sub Total		**158.50**
4		Raw material wastage		149.06
		Drainage/ Leakage loss		6.94
		Sub Total		**156.00**
Total				**660.00**

6. Reduced yield

Month	Equipment	Reason	Frequency	Loss (MT)
1		Plant stabilization		17.00
		Sub Total		**17.00**
2		Plant stabilization		3.00
		Sub Total		**3.00**
3		Plant stabilization		6.00
		Sub Total		**6.00**
4		Plant stabilization		3.00
		Sub Total		**3.00**
Total				**29.00**

Table 4.3: 2^{nd} Stage Loss Identification & classification

a) Losses due to downtime

1. Equipment failure:

Month	Equipment	Reason	Frequency	Loss (MT)	Downtime (hr)
1	PSA	Control valve 503 B problem	1	29.50	19.67
		Sub Total		**29.50**	**19.67**
2	PSA	PCV 503A leakage	1	17.00	11.33
	PSA	PSA solenoid valve failure	1	9.00	6.00
		Sub Total		**26.00**	**17.33**
3	BFW	BFW line leakage	1	18.00	12.00
	H2 line	Leakage in reformed gas line	2	38.50	25.67
		Sub Total		**56.50**	**37.67**
4	Gen	Fire caught in quench pot	1	83.00	55.33
		Solenoid valve failure	1	1.50	1.00
		Leakage in inlet reformed gas line	1	9.50	6.33
		Sub Total		**94.00**	**62.67**
		Total		**206.00**	**137.33**

2. Set-up and adjustments:

Month	Equipment	Reason	Frequency	Loss (MT)	Eq. Downtime
1		Plant startup	1	12.00	8.00
		Sub Total		**12.00**	**8.00**
2		Plant startup	2	16.00	10.67
		Sub Total		**16.00**	**10.67**
3		Plant startup	3	32.00	21.33
		Sub Total		**32.00**	**21.33**
4		Plant startup	4	28.00	18.67
		Sub Total		**28.00**	**18.67**
		Total		**88.00**	**58.67**

b) Speed losses

3. Idling & Minor stoppage:

Month	Equipment	Reason	Frequency	Loss (MT)	Eq. Downtime
1	K 1801C	H_2 line blocked by molecular sieves	1	8.00	5.33
	R 1101	Level transmitter problem	4	7.00	4.67
	F 1101A	Filter blocked	1	6.00	4.00
		Sub Total		**21.00**	**14.00**
2	R 1101	Level transmitter problem	1	1.50	1.00
	R 1102	Level transmitter problem	1	2.00	1.33
	F 1101B	Primary filter bundle changed	1	2.50	1.67
		Sub Total		**6.00**	**4.00**
3	R 1102	Level transmitter problem	1	1.50	1.00
	F 1403A	Alox charged	1	0.50	0.33

	C 1301	Emulsion formation	1	9.00	6.00
	K 1801C	Valve damaged in 1st stage	1	5.00	3.33
	K 1801C	Valve damaged in 2nd stage	2	6.00	4.00
	PSA	PCV 503A leakage	1	2.00	1.33
	PSA	PSA solenoid valve failure	1	8.00	5.33
		Sub Total		**32.00**	**21.33**
4	K 1801B	Stopped due to power failure	1	2.00	1.33
	SG 2201	Boiler tripped	1	3.00	2.00
	R 1101	Level Transmitter Problem	1	1.00	0.67
	K 1801B	Valve damaged in 1st & 2nd stage	1	14.00	9.33
	R 1102	Gear Box problem	1	12.50	8.33
		Sub Total		**32.50**	**21.67**
		Total		**91.50**	**61.00**

4. Reduced Speed:

Month	Equipment	Reason	Frequency	Loss (MT)	Eq. Downtime
1	WS	Poor chemistry of W S		54.50	36.33
	WS	Solid reversion bed change	1	1.00	0.67
	R 1102	Level transmitter showing higher consumption of H_2	1	0.50	0.33
	F 1101A	Filter blocked	1	0.50	0.33
		Sub Total		**56.50**	**37.67**
2	WS	Poor chemistry of W S		40.00	26.67
	PSA	FCV 501 problem	1	3.00	2.00
		Sub Total		**43.00**	**28.67**
3	WS	Poor chemistry of W S		46.00	30.67
	C 1301	Emulsion formation	2	4.00	2.67
	R 1101	Level transmitter problem	1	1.00	0.67
		Sub Total		**51.00**	**34.00**
4	WS	Poor chemistry of W S		42.50	28.33
	K 1801B	Process air flow restriction	1	0.50	0.33
	K 1801C	Process air flow restriction	7	8.00	5.33
	F 1201	Filter inlet pressure high	1	2.00	1.33
		Sub Total		**53.00**	**35.33**
		Total		**203.50**	**135.67**

c) Losses due to defects

5. Process defect/ rework loss:

Month	Equipment	Reason	Frequency	Loss (MT)
1		Raw material wastage		117.79
		Drainage/ Leakage loss		7.21
		Sub Total		**125.00**
2		Raw material wastage		91.72
		Drainage/ Leakage loss		5.28
		Sub Total		**97.00**
3		Raw material wastage		99.50

		Drainage/ Leakage loss		12.50
		Sub Total		**112.00**
4		Raw material wastage		85.07
		Drainage/ Leakage loss		6.93
		Sub Total		**92.00**
Total				**426.00**

6. Reduced yield:

Month	Equipment	Reason	Frequency	Loss (MT)
1		Plant stabilization		3.00
		Sub Total		**3.00**
2		Plant stabilization		8.50
		Sub Total		**8.50**
3		Plant stabilization		9.50
		Sub Total		**9.50**
4		Plant stabilization		9.50
		Sub Total		**9.50**
Total				**30.50**

Table 4.4: 3rd Stage Loss Identification & classification

a) Losses due to downtime

1. Equipment failure:

Month	Equipment	Reason	Frequency	Loss (MT)	Downtime (hr)
1	Gen	Generator tripped	1	0.50	0.33
	PSA	FCV -501 blocked by molecular sieve dust	1	4.50	3.00
		Sub Total		**5.00**	**3.33**
2	PSA	On/Off valve XV-503 B failure	1	3.50	2.33
	Gen	Generator tripped	1	8.00	5.33
		Sub Total		**11.50**	**7.67**
3	Gen	Generator tripped	2	21.00	14.00
	RF 301	FD fan tripped due to overload	1	3.50	2.33
	SD 401	Inlet valve leakage	1	17.50	11.67
		Sub Total		**42.00**	**28.00**
4	RF 301	FD Fan tripped	1	1.50	1.00
		Sub Total		**1.50**	**1.00**
Total				**60.00**	**40.00**

2. Set-up and adjustments:

Month	Equipment	Reason	Frequency	Loss (MT)	Eq. Downtime
1		Plant startup	1	9.00	6.00
		Sub Total		**9.00**	**6.00**
2		Plant startup	3	29.00	19.33
		Sub Total		**29.00**	**19.33**
3		Plant startup	2	13.00	8.67
		Sub Total		**13.00**	**8.67**
4		Plant startup	1	17.00	11.33
		Sub Total		**17.00**	**11.33**
		Total		**68.00**	**45.33**

3. Idling & Minor stoppage:

Month	Equipment	Reason	Frequency	Loss (MT)	Eq. Downtime
1	R 1102	Level transmitter problem	2	3.50	2.33
	F 1101	Primary filter choked.	1	4.00	2.67
	F 1102	Primary filter choked.	1	17.50	11.67
	SRU	New catalyst added	1	0.50	0.33
	PSA	On/off solenoid valve failure	1	1.50	1.00
	K 1800B	Internal valve broken	1	6.00	4.00
		Sub Total		**33.00**	**22.00**
2	K 1800C	Valve failure	1	9.50	6.33
		Sub Total		**9.50**	**6.33**
3	F 1101	Primary filter blocked	1	8.00	5.33
	K 1801A	2nd stage valve failure	1	5.00	3.33
	K 1801B	Low discharge flow	1	2.00	1.33
	K 1801C	1st & 2nd stage valve failure	1	9.00	6.00
	PSA	XV 503B not working	1	5.00	3.33
		Sub Total		**29.00**	**19.33**
4	F 1103A	Filter cartridge blocked	1	2.00	1.33
	K 1801A	2nd stage valve failure	1	3.50	2.33
		Sub Total		**5.50**	**3.67**
		Total		**77.00**	**51.33**

4. Reduced Speed:

Month	Equipment	Reason	Frequency	Loss (MT)	Eq. Downtime
1	WS	Poor chemistry of W S		51.50	34.33
	F 1101	Primary filter choked.	1	3.00	2.00
	F 1102	Primary filter choked.	1	1.00	0.67
	K 1801B	Low discharge rate	1	1.00	0.67
		Sub Total		**56.50**	**37.67**
2	WS	Poor chemistry of W S		39.50	26.33
	K 1800C	Running at lower speed	1	1.00	0.67
		Sub Total		**40.50**	**27.00**

3	WS	Poor chemistry of W S		39.25	26.17
	SRU	Solid reversion bed change	1	1.00	0.67
	R 1101	Level transmitter problem	1	2.75	1.83
		Sub Total		**43.00**	**28.67**
4	WS	Poor chemistry of W S		52.00	34.67
	C 1301	Emulsion formation	1	3.00	2.00
		Sub Total		**55.00**	**36.67**
		Total		**195.00**	**130.00**

5. Process defect/ rework loss:

Month	**Equipment**	**Reason**	**Frequency**	**Loss (MT)**
1		Raw material wastage		89.30
		Drainage/ Leakage loss		9.20
		Sub Total		**98.50**
2		Raw material wastage		73.47
		Drainage/ Leakage loss		13.03
		Sub Total		**86.50**
3		Raw material wastage		88.61
		Drainage/ Leakage loss		11.39
		Sub Total		**100.00**
4		Raw material wastage		65.14
		Drainage/ Leakage loss		7.86
		Sub Total		**73.00**
.		**Total**		**358.00**

6. Reduced yield:

Month	**Equipment**	**Reason**	**Frequency**	**Loss (MT)**
1		Plant stabilization		2.50
		Sub Total		**2.50**
2		Plant stabilization		10.00
		Sub Total		**10.00**
3		Plant stabilization		4.00
		Sub Total		**4.00**
4		Plant stabilization		6.00
		Sub Total		**6.00**
		Total		**22.50**

4.2.3 Determination of OEE in 1st step: Monthly OEE was determined to observe the fluctuation of OEE. After four month the 1st step OEE was calculated as bellow:

Table 4.5: 1st Step Overall Equipment Efficiency (OEE) Calculation

		Month	1	2	3	4	**1st step**
a	Total Production or Output	MT	854.00	830.00	805.00	982.50	3471.50
b	Average Production per day	MT/Day	28.47	26.77	26.83	31.69	28.45
c	Standard cycle time	Hr/MT	0.67	0.67	0.67	0.67	0.67
	Losses due to downtime						
A	Downtime due to Equipment failure	Hr	15.00	21.00	61.00	4.67	101.67
B	Production Loss due to Equipment failure	MT	22.50	31.50	91.50	7.00	152.50
C	Production Loss due to Set-up and adjustments	MT	24.00	12.00	26.00	10.00	72.00
D	Eq. Downtime due to Set-up and adjustments	Hr	16.00	8.00	17.33	6.67	48.00
	Speed losses						
E	Production Loss due to Idling & Minor stoppage	MT	30.00	93.50	23.50	14.50	161.50
F	Eq. Downtime due to Idling & Minor stoppage	Hr	20.00	62.33	15.67	9.67	107.67
G	Production Loss due to Reduced Speed	MT	149.50	149.00	134.00	102.00	534.50
H	Eq. Downtime due to Reduced Speed	Hr	99.67	99.33	89.33	68.00	356.33
	Losses due to defects						
I	Defect/ Wastage /Drainage	MT	157.00	188.50	158.50	156.00	660.00
J	Reduced yield	MT	17.00	3.00	6.00	3.00	29.00
	OEE Calculation						
K	Working Time [24 Hr per day]	Hr	720.00	744.00	720.00	744.00	2928.00
L	Schedule Downtime	Hr	0.00	0.00	0.00	0.00	0.00
M	Loading Time [K-L]	Hr	720.00	744.00	720.00	744.00	2928.00
N	Operating Time [M-A-D]	Hr	689.00	715.00	641.67	732.67	2778.33
O	**Availability [N/M]**		**0.96**	**0.96**	**0.89**	**0.98**	**0.95**
P	Actual cycle time [N+(F+H)/a]	Hr/MT	0.95	1.06	0.93	0.82	0.93
Q	Operating speed rate [c / P]		0.70	0.63	0.72	0.81	0.71
R	Net operating rate [(a.P)/N]		1.17	1.23	1.16	1.11	1.17
S	**Performance rate [Q.R]**		**0.83**	**0.77**	**0.84**	**0.89**	**0.83**
T	**Quality rate [(a-I-J)/a]**		**0.80**	**0.77**	**0.80**	**0.84**	**0.80**
U	**Overall Equipment Efficiency, OEE [O.S.T]**	**%**	**62.96**	**57.21**	**59.31**	**73.79**	**63.35**
V	Idling & Minor stoppage [N.(1-S)]	Hr	119.67	161.67	105.00	77.67	464.00
W	Ideal productivities [M/c]	MT	1080.00	1116.00	1080.00	1116.00	4392.00
X	Quality Product [a-I-J]	MT	680.00	638.50	640.50	823.50	2782.50

So, the average overall equipment efficiency in the first stage is (0.95X0.83X0.80) X100 = **63.35%**. Now, the target is to increase the OEE by minimizing the losses.

4.3 Problem Identification & Possible Solution

In this study Pareto Analysis was used to identify and prioritize the significant losses. To set target for the reduction of losses we have used Loss Tree Diagram. Both tools are popular and easy to understand and visualize the problem. WWBLA tool was used to find out root causes and to eliminate them. It's a very effective tool to find out root causes.

4.3.1 Identification of Significant Losses by Loss Pareto Analysis

The Loss Pareto analysis was used to identify most significant losses among the six major losses.

Table 4.6: Production Losses in 1st stage

Production Losses due to	Loss (MT)
Equipment failure	152.50
Set-up and adjustments	72.00
Idling & Minor stoppage	161.50
Reduced Speed	534.50
Defect loss	660.00

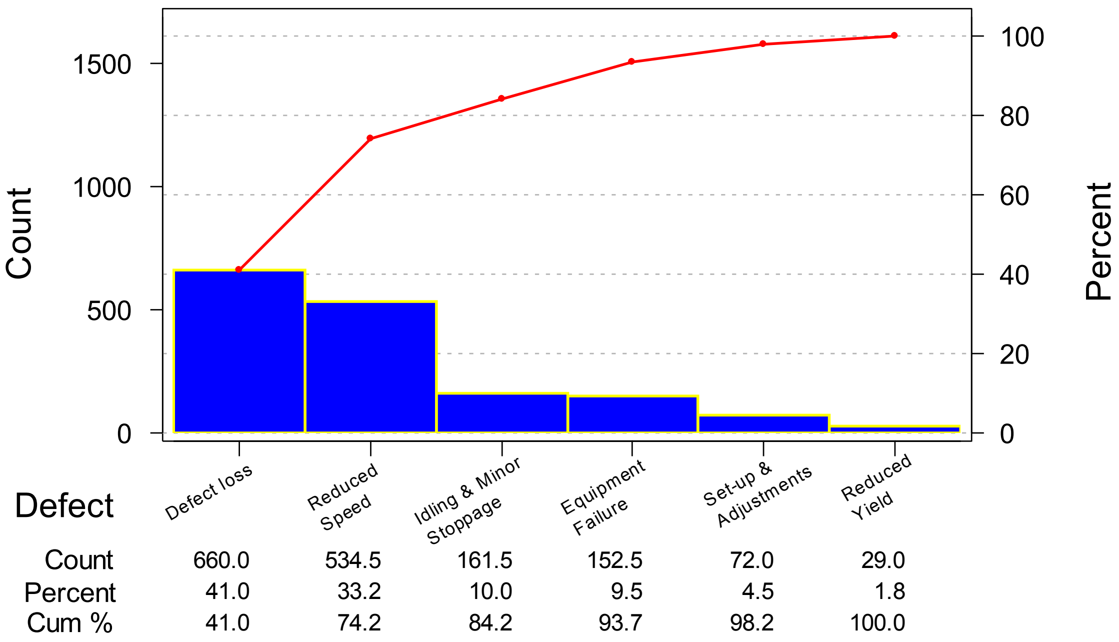


Figure 4.2: Loss Pareto Chart of 1st stage

So, from the Loss PARETO Chart it is seen that the most significant sources of losses are Defect Loss and Reduced Speed, which cover 74.20% of total loss. And the third significant loss was Idling & Minor Stoppages. We are considering these three as most significant losses (84.20% of total loss) and there impact on OEE is vital.

4.3.2 Identification of Vital Few Causes of Significant Losses

Cause Pareto Analysis was introduced here to identify the repeated major causes of the most significant losses. After that Loss Tree Diagram was used to set loss reduction target.

4.3.2.1 Cause Pareto Analysis: By using cause Pareto analysis the main causes or vital few causes of the most significant losses found out are:

Table 4.7: Causes of losses in the 1st stage

Production losses with causes in the1st Stage		
Production Loss due to	**Frequency**	**Production Loss in MT**
Raw Material Wastage (RMW)	-	628.26
Poor Working Solution (PWS)	-	369.00
Extractor Column (C 1301)	53	170.00
Hydrogenation Reactor (R 1102)	14	43.50
Pressure Sewing Adsorber (PSA)	2	37.00
Drainage	-	31.74
Primary Filter (F 1101)	3	22.00
Process Air Comp (K 1801C)	4	15.00
Process Air Comp (K 1801B)	4	12.50
Oxidation Column (C 1201)	1	10.00
Hydrogenation Reactor (R 1101)	4	3.50
HT Shift Converter (HTSC)	1	3.00
Process Air Comp (K 1801A)	1	3.00
Pump (P 1903)	1	2.00
Pump (P 2001A)	1	2.00
Primary Filter (F 1102)	1	1.00
Pump (P 1301B)	1	1.00
Pump (P 1701A)	1	1.00
Pump (P 2001C)	1	0.50
Total		

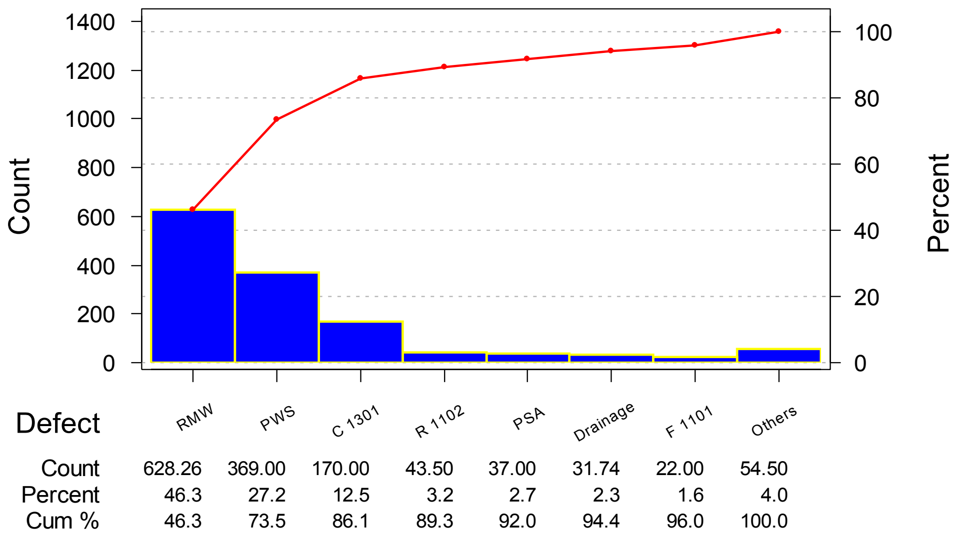


Figure 4.5: Cause Pareto Chart at the end of 1st stage

In the above figure, we see the main causes are Raw Material Wastage (RMW), Poor Working Solution (PWS) and Extractor Column (C 1301) problem and responsible for most significant losses. These three causes are responsible for 86.10% losses. So the next target is to eliminate these vital few causes to improve OEE by using WWBLA during the 2nd stage.

4.3.2.2 Loss Tree Diagram: Loss Tree Diagram was used to set target to reduce the losses by eliminating the vital few causes. It's a tool used to easily visualize the target to ground level up to the top management. During 2nd stage our target is to reduce the losses by 25% by identifying & minimizing root causes.

Table 4.8: Target made to reduce losses in the 2nd stage

Causes of Production Loss	1st Stage		Reduction 25%	Target to Reduce Loss Below (MT)
	Loss (MT)	Percent (%)		
Extractor Column (C 1301) Problem	170.00	12.54	42.5	127.50
Poor Working Solution (PWS)	369.00	27.21	92.25	276.75
Raw Material Wastage (RMW)	628.26	46.33	157.07	471.20

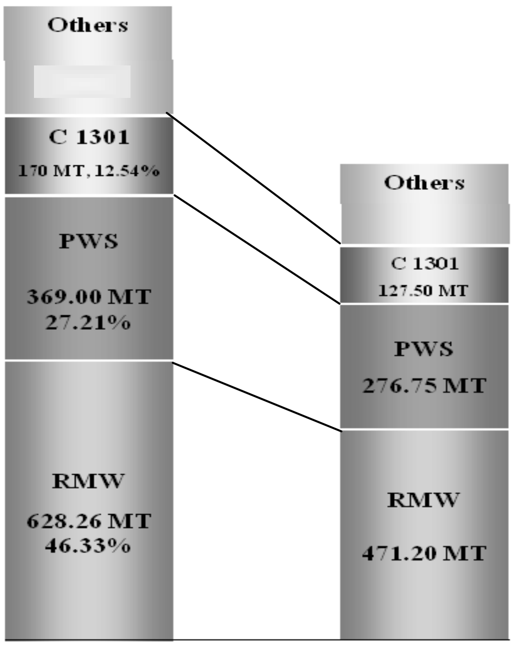


Figure 4.4: Loss Tree Diagram for 2nd stage

4.3.3 Minimizing the Losses by Analytical Technique (WWBLA)

WWBLA is an analytical tool used systematically to identify root causes of production losses with a view to minimize them. We used WWBLA to eliminate the first three causes of the significant losses. They are Raw Material Wastage (RMW), Poor Working Solution (PWS) and Problem in Extractor Column (C1301).

a) Raw Material Wastage (RMW), 46.30%

Size of problem: 628.26 MT H_2O_2 Loss in 1st Step (1st 4 months)

Mechanism: Natural gas is used as raw material in presence of catalyst to produce H_2 by cracking process, which is oxidized in presence of working solution and extracted H_2O_2 from working solution. Loss may occur from the very first step to the last step as unreacted CH_4, unreacted H_2, leakage and shortage of storage facility of H_2.

b) Poor Working Solution (PWS), 27.20%

Size of problem: 369.00 MT H_2O_2 Loss in 1st Step (1st 4 months)

Mechanism: Working Solution is a media and a catalyst used in Hydrogenation and Oxidation. Gpl of immature working solution is less than 14.4. But it is necessary to achieve 14.4 gpl to reach full capacity production (36MT/day). In maturity total active quinone (EAQ + H_4EAQ+ AAQ+H_4AAQ) ≥ 180 gpl & (AAQ+H4AAQ) ≥ 20 gpl and solvent ratio Polar/Nonpolar/corrosion inhibitor = 72.5/26/1.5%. This problem may arise due to process instability and for poor catalysts.

c) Problem in Extractor Column (C1301), 12.50%

Size of problem: 170.00 MT H_2O_2 Loss in 1st Step (1st 4 months)

Mechanism: Mixture of H2O2and WS enters into the Extractor where DM water extracts H2O2 from WS using different density. WS at top, water in middle & H2O2 at the bottom. But process instability & higher temperature of mixture creates emulsification.

The detailed analysis of the above three phenomena are given bellow:

4.3.3.1 WHY WHY BECAUSE LOGICAL ANALYSIS (WWBLA) - 01

Description of phenomenon

Size of problem

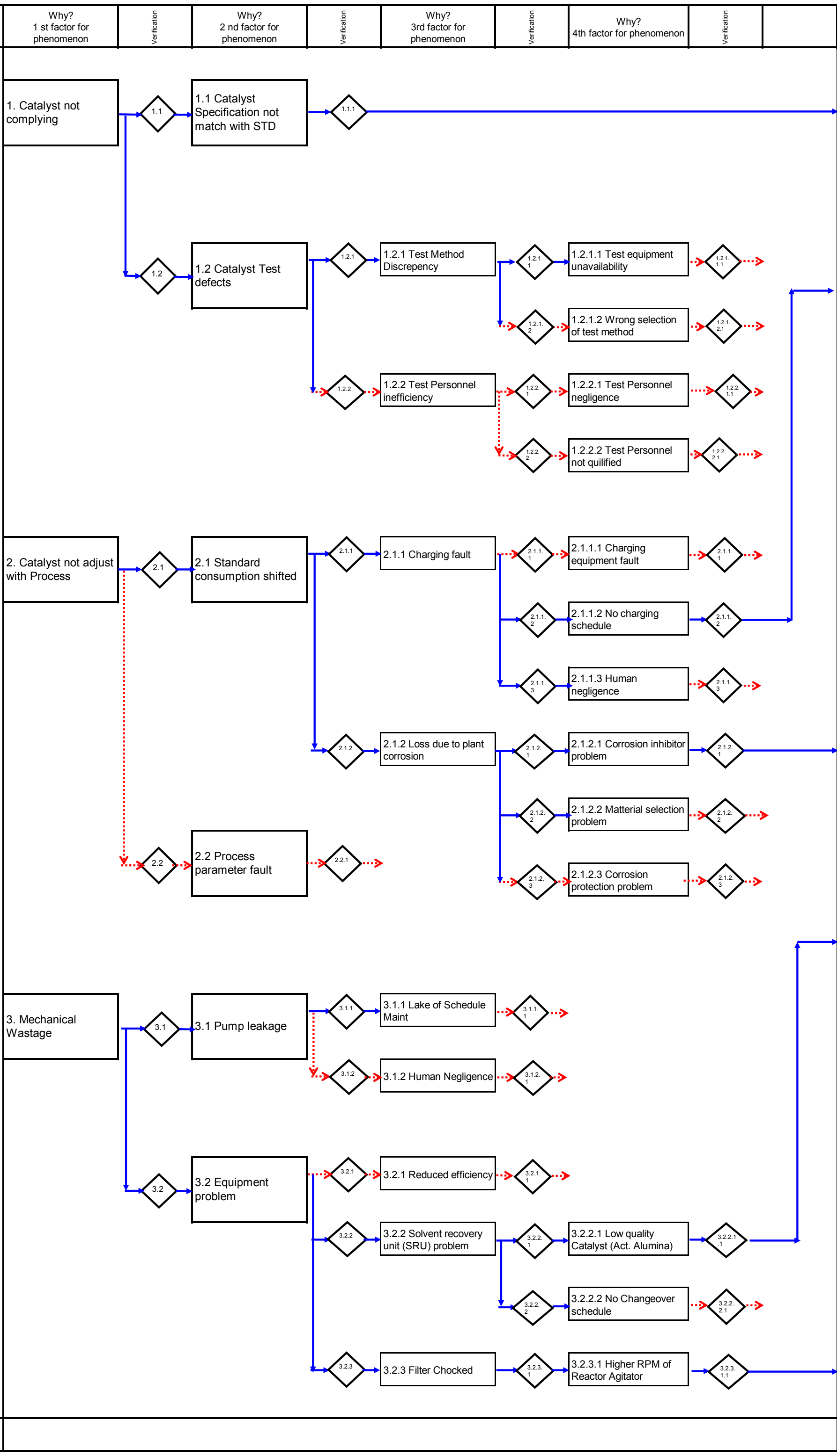
628.26 MT H2O2 Loss in 1st Step (1st 4 months)

Phenomenon

Raw Material Wastage (RMW)

Mechanism

Natural gas is used as raw material in presence of catalyst to produce H2 by cracking process, which isoxidized in presence of working solution and extracted H2O2 from working solution. Loss may occur from the very frist step to the last step as unreacted CH4, unreacted H2, leakage and shortage of storage facility of H2.



Countermeasure

1.1.1 Matching with STD specification was strictly maintained before sourcing and sample testing was included at own lab before decision making and Source of Pd catalyst was changed.

Before

Average RM consumption was 260nm3/MT H2O2.

After

After addition of new Pd catalyst reduced the average RM consumption & it was 210nm3/MT H2O2

2.1.1.2 Charging schedule was introduced under supervision of Shift in charge, stock in floor was removed.

Before

Higher Fluctuation observed in composition of working solution.

After

After maintaining the schedule fluctuation in composition of working solution is eliminated

2.1.2.1 FeCl3 was replaced by NaOH and HCl as corrosion inhibitor.

Before

EAQ consumption was 0.515 kg/MT H2O2

After

And now EAQ consumption is reduced to 0.380 kg/MT H2O2

3.2.2.1.1 Chinese grade Activated Alumina was replaced by USA grade Alox

Before

Consumption of polar Solvent (TBU) was 2.33kg/MT H2O2 whereas SD consumption 0.50kg/MT

After

After introducing Alox consumption of polar Solvent (TBU) was 1.03kg/MT H2O2

3.2.3.1.1 Misalignment of agitator rotor shaft was removed

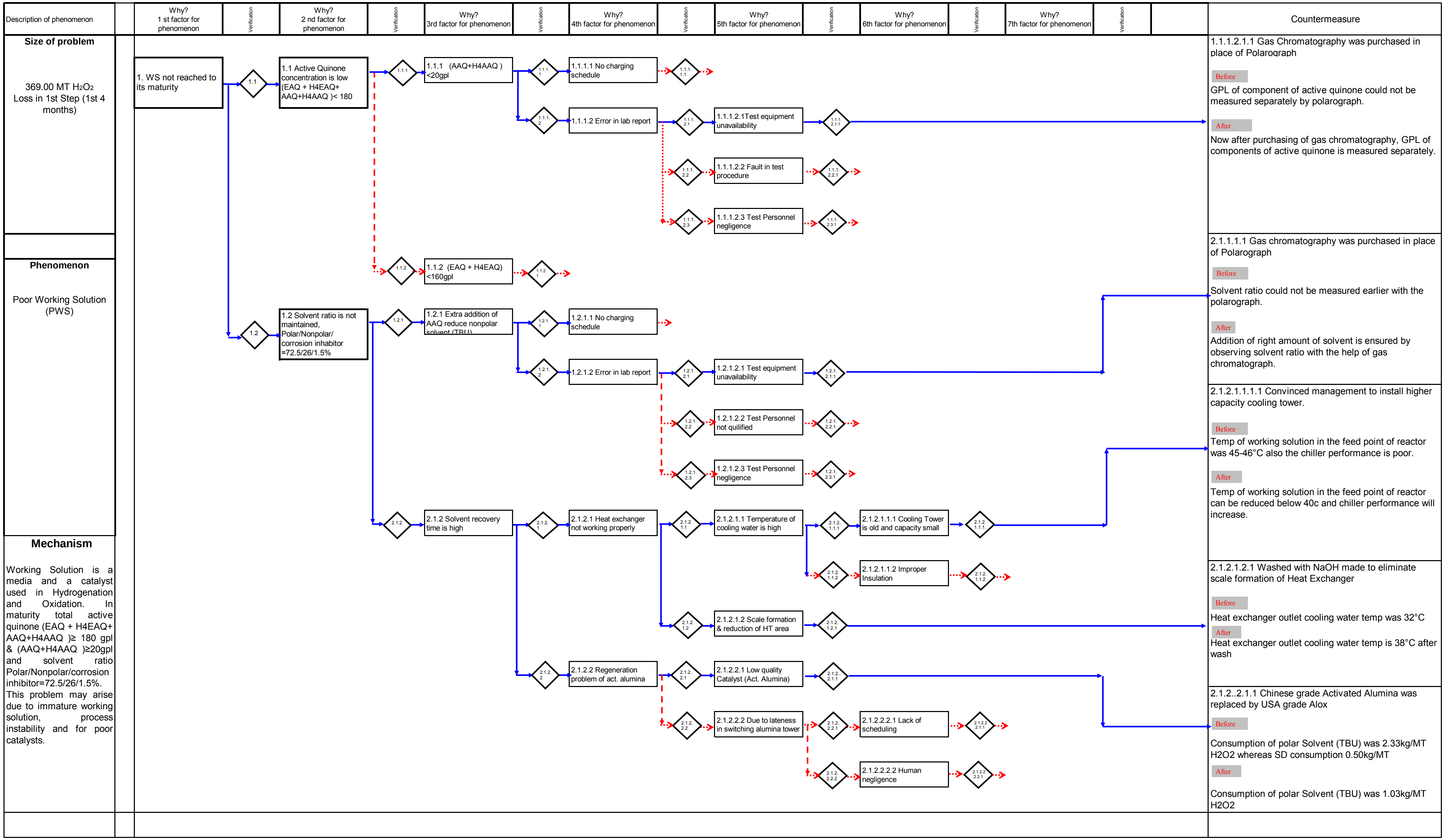
Before

Primary filter cleaning required within few days.

After

Now the duration of Primary filter cleaning has increased around two times.

4.3.3.2 WHY WHY BECAUSE LOGICAL ANALYSIS(WWBLA) - 02



4.3.3.3 WHY WHY BECAUSE LOGICAL ANALYSIS(WWBLA) - 03

Description of phenomenon	Why? 1 st factor for	Verification	Why? 2 nd factor for	Verification	Why? 3rd factor for	Verification	Why? 4th factor for	Verification	Why? 5th factor for	Verification	Why? 6th factor for	Verification	Why? 7th factor for	Verification	Countermeasure

Size of problem

170.00 MT H_2O_2 Loss in 1st Step (1st 4 months)

Phenomenon

Problem in Extractor Column (C1301)

Mechanism

Mixture of Hydrogen Peroxide and working solution enter into the Extractor where DM water extracts H2O2 from working solution due to high specific gravity of H2O2 and water. This problem may arise due to process instability and higher temperature of the mixture.

- 1. Higher viscosity & density of WS (gpl >>180) — [1.1]
  - 1.1 Active Quinone concentration is high (EAQ + H4EAQ+ AAQ+H4AAQ)>> 180 — [1.1.1]
    - 1.1.1 (AAQ+H4AAQ) >>20gpl — [1.1.1.1]
      - 1.1.1.1 No charging schedule — [1.1.1.]
      - 1.1.1.2 Error in lab report — [1.1.1.2.1]
        - 1.1.1.2.1Test equipment unavailability — [1.1.1.2.1.1] → Countermeasure 1.1.1.2.1.1
        - 1.1.1.2.2 Test Personnel not quilified — [1.1.1.]
        - 1.1.1.2.3 Test Personnel negligence — [1.1.1.2.3.1]
    - 1.1.2 (EAQ + H4EAQ) >>160gpl — [1.1.2.1]
  - 1.2 Solvent ratio is not maintained, Polar/Nonpolar/ corrosion inhabitor =72.5/26/1.5% — [1.2]
    - 1.2.1 Extra addition of AAQ reduce nonpolar solvent (TBU) — [1.2.1.1]
      - 1.2.1.1 No charging schedule
      - 1.2.1.2 Error in lab report — [1.2.1.]
        - 1.2.1.2.1 Test equipment unavailability — [1.2.1.] → Countermeasure 2.1.1.1.1
        - 1.2.1.2.2 Test Personnel not quilified — [1.2.1.]
        - 1.2.1.2.3 Test Personnel negligence — [1.2.1.2.3.1]
    - 2.1.2 Solvent recovery time is high — [2.1.2.1]
      - 2.1.2.1 Heat exchanger not working properly — [2.1.2.]
        - 2.1.2.1.1 Temperature of cooling water is high — [2.1.2.1.1.1]
          - 2.1.2.1.1.1 Cooling Tower is old and capacity small — [2.1.2.] → Countermeasure 2.1.2.1.1.1.1
          - 2.1.2.1.1.2 Improper Insulation — [2.1.2.1.1.2.]
        - 2.1.2.1.2 Scale formation & reduction of HT area — [2.1.2.] → Countermeasure 2.1.2.1.2.1
      - 2.1.2.2 Regeneration problem of act. alumina — [2.1.2.]
        - 2.1.2.2.1 Low quality Catalyst (Act. Alumina) — [2.1.2..2.1.1] → Countermeasure 2.1.2..2.1.1
        - 2.1.2.2.2 Due to lateness in switching alumina — [2.1.2.]
          - 2.1.2.2.2.1 Lack of scheduling — [2.1.2.2.2.1.1]
          - 2.1.2.2.2.2 Human negligence — [2.1.2.2.2.2.1]
- 2. Reffinate content increase — [2.1]
  - 2.1 Increased Temp of Oxidizer — [2.1.]
    - 2.1.1 No cooling system — [2.1.]
      - 2.1.1.1 Designed for cold country — [2.1.]
        - 2.1.1.1.1 No Cooling system for oxidizer — [2.1.1] → Countermeasure 2.1.1.1.1.1
    - 2.1.2 Reduced process air flow — [2.1.2]
      - 2.1.2.1 Air filter blocked — [2.1.] → Countermeasure 2.1.2.1.1
      - 2.1.2.2 Low capacity of air compressor — [2.1.2]
  - 2.2 Reduced DM water flow in extractor — [2.2]
    - 2.2.1 Increased load in H2 plant condenser — [2.2.1]
    - 2.2.2 Increased load in BFW — [2.2.2]

Countermeasure

1.1.1.2.1.1 Gas Chromatography was purchased in place of Polarograph

Before

GPL of component of active quinone could not be measured separately by polarograph.

After

Now after purchasing of gas chromatography, GPL of components of active quinone is measured separately.

2.1.1.1.1 Gas Chromatography was purchased in place of Polarograph

Before

Solvent ratio could not be measured earlier with the Polarograph.

After

Addition of right amount of solvent is ensured by observing solvent ratio with the help of gas chromatograph.

2.1.2.1.1.1.1 Convinced management to install higher capacity cooling tower.

Before

Temp of working solution in the feed point of reactor was 45-46°C also the chiller performance is poor.

After

Temp of working solution in the feed point of reactor can be reduced below 40c and chiller performance will increase.

2.1.2.1.2.1 Washed with NaOH made to eliminate scale formation of Heat Exchanger

Before

Heat exchanger outlet cooling water temp was 32°C

After

Heat exchanger outlet cooling water temp is 38°C after wash

2.1.2..2.1.1 Chinese grade Activated Alumina was replaced by USA grade Alox

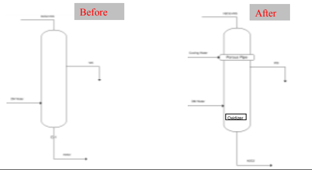
Before

Consumption of polar Solvent (TBU) was 2.33kg/MT H2O2 whereas SD consumption 0.50kg/MT

After

After introducing Alox consumption of polar Solvent (TBU) was 1.03kg/MT H2O2

2.1.1.1.1.1New cooling system designed by which the temperature of WS-H2O2 can be maintained at 38-40°C at the outlet of oxidizer.



2.1.2.1.1 To measure the dp across the filter a differential pressure guage introduced.

Before

No gauge to measure the pressure drop.

After

When there is 4 psi pressure drop occur, filter is cleaned again to smooth the process air flow.

4.3.1 Summary of root causes identified

After analyzing three causes of significant losses we found out ten root causes. After identification of root causes some countermeasures were taken during the second stage and their impact was observed up to the third stage.

i) Catalyst (Pd) Specification don't match with standard - RMW
ii) Test equipment (G.C.) unavailable - PWS, C-1301
iii) No charging schedule of TBU - RMW
iv) Corrosion inhibitor problem- RMW
v) Low quality Catalyst (Act. Alumina) - RMW, PWS, C1301
vi) Higher RPM of Reactor Agitator - RMW
vii) Cooling Tower is old and capacity small - PWS, C1301
viii) Scale formation in heat exchanger & reduction of HT area - PWS, C1301
ix) No cooling system for oxidizer (C 1201) - C 1301
x) Process Air filter blocked - C1301

4.3.2 Summary of countermeasures taken and their impact

1. *Catalyst (Pd) Specification not match with standard*

Countermeasure: Matching with STD specification was strictly maintained before sourcing and sample testing was included at own lab before decision-making and present source of Pd catalyst was changed.

Impact: Before the change average RM consumption was 260nm^3/MT H_2O_2. After addition of new Pd catalyst, average RM consumption reduced to 210 nm^3/MT H_2O_2.

2. *Test equipment (G.C.) unavailable*

Countermeasure: Gas Chromatography was purchased in place of Polarograph.

Impact: *a)* GPL of component of active quinone could not be measured separately by polarograph. Now after purchasing of gas chromatography, GPL of components of active quinone is measured separately.

b) Solvent ratio could not be measured earlier with the Polarograph. Addition of right amount of solvent is ensured by observing solvent ratio test report.

3. *No charging schedule of TBU*

Countermeasure: Charging schedule was introduced under supervision of Shift in charge, stock in floor was removed.

Impact: Higher Fluctuation observed in composition of working solution.

After maintaining the schedule fluctuation in composition of working solution is eliminated.

4. *Corrosion inhibitor problem*

Countermeasure: $FeCl_3$ was replaced by NaOH & HCl as corrosion inhibitor.

Impact: EAQ consumption was 0.515 kg/MT H_2O_2 and now EAQ consumption is reduced to 0.380 kg/MT H_2O_2

5. *Low quality Catalyst (Act. Alumina)*

Countermeasure: Chinese grade Activated Alumina was replaced by USA grade Alox

Impact: Consumption of polar Solvent (TBU) was 2.33kg/MT H_2O_2 whereas SD consumption is 0.50kg/MT. After introducing Alox consumption of polar Solvent (TBU) was 1.03 kg/MT H_2O_2

Benefit Cost Ratio: Activated Alumina required for 1MT H_2O_2= 6.00 kg

TBU required for 1MT H_2O_2= 0.50 kg

Cost of Activated Alumina (USA) =1650 USD/MT

Cost of Activated Alumina (China) =1050 USD/MT

Cost of TBU =7080 USD/MT

Replacement cost of Activated Alumina (USA) for 1MT H_2O_2 = [(1650-1050) X 6]/1000

= USD 3.60

Consumption of TBU reduced to produce 1MT H_2O_2 = [(2.33-1.03) X 7080]/1000

= USD 9.20

Benefit Cost Ratio = 9.20/3.60 = 2.56, which is greater than 1. So the replacement of Activated Alumina (China) with the Activated Alumina (USA) would be cost effective.

6. *Higher RPM of Reactor Agitator*

Countermeasure: Misalignment of agitator rotor shaft was removed

Impact: Primary filter cleaning required within few days. Now the duration of Primary filter cleaning has increased around two times.

7. *Cooling Tower is old and capacity small*

Countermeasure: Convinced management to install higher capacity cooling tower.

Impact: Temp of working solution in the feed point of reactor was 45-46°C also the chiller performance is poor. Temp of working solution in the feed point of reactor can be reduced below 40°C and also chiller performance will increase.

8. *Scale formation in heat exchanger & reduction of HT area*

Countermeasure: Washed with NaOH made to eliminate scale formation of Heat Exchanger.

Impact: Heat exchanger outlet cooling water temperature was 32°C and after wash increases to 38°C.

9. *No cooling system for oxidizer (C 1201)*

Countermeasure: New cooling system designed by which the temperature of WS-H_2O_2 can be maintained at 38-40°C at the outlet of oxidizer.

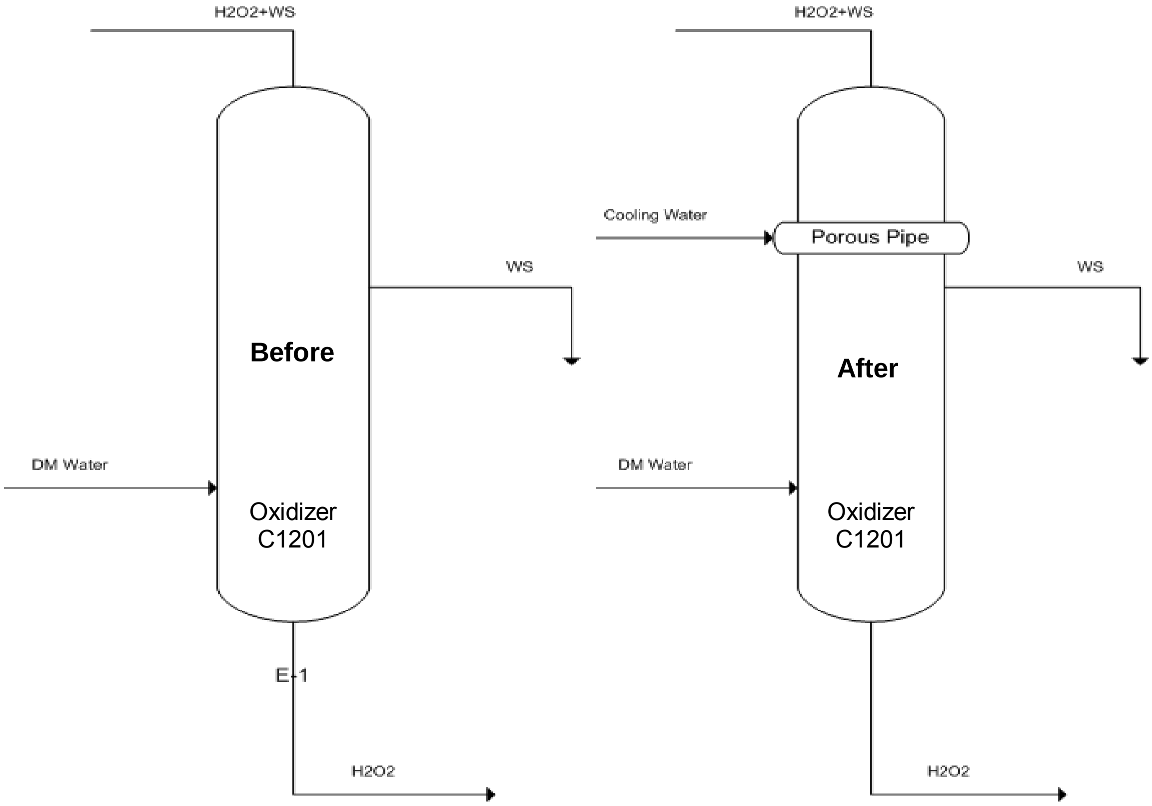


Figure 4.5: New cooling system designed for oxidizer

Impact: Suddenly temperature of oxidizer outlet (WS-H_2O_2) increased above 42°C and caused emulsion formation in extractor. Now the tendency of emulsion formation reduced and become easy to control.

10. *Process Air filter blocked*

Countermeasure: To measure the differential pressure across the filter a differential pressure gauge was introduced.

Impact: No gauge to measure the pressure drop. When there is above 4-psi pressure drop occur, filter is cleaned again to smooth the process airflow.

4.4 Review & Monitoring

In review and monitoring stage we observed the impact of elimination of root causes by using WWBLA on losses as well as on OEE. And then we collected data during next 4 months in 3rd stage to observe that the changes made were stable and consistent.

4.4.1 Impact of WWBLA on losses at the end of 2nd Stage

In the 1st stage total losses was 1609.50 MT and that in the 2nd stage was 1045.50 MT. So, the total losses have been reduced to a significant amount, which have increased the OEE to a certain extent.

Table 4.9: Comparison of losses in the 1st & 2nd stage

Production Losses due to	Loss in 1st Stage (MT)	Loss in 2nd Stage (MT)
Equipment failure	152.50	206.00
Set-up and adjustments	72.00	88.00
Idling & Minor stoppage	161.50	91.50
Reduced Speed	534.50	203.50
Defect loss	660.00	426.00
Reduced yield	29.00	30.50
Total	**1609.50**	**1045.50**

From the figure below, we see that the earlier significant losses have reduced significantly but the losses due to Equipment failure has increased. So in the next step we have to work on it.

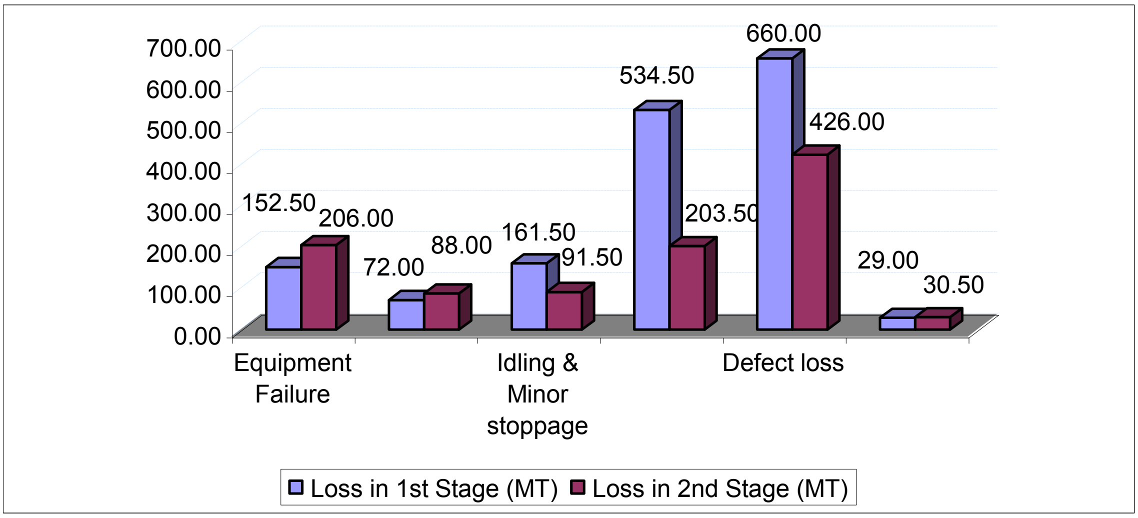


Figure 4.6: Comparison of losses in the 1st & 2nd stage

Table 4.10: Comparison of losses due to major causes in the 1st & 2nd stage

Loss due to	1st Stage		Target to Reduce Loss Below (MT)	2nd Stage	Loss Reduction (%)
	Loss (MT)	Percent (%)		Loss (MT)	
C 1301	170.00	12.54	127.50	14.00	91.76
PWS	369.00	27.21	276.75	184.00	50.14
RMW	628.26	46.33	471.20	394.08	37.27

We target to reduce 25% of previous loss, but after using WWBLA tool it reduced more than that. This is because it was a continuous chemical process and I think little improvement can makes the process to a more stable state.

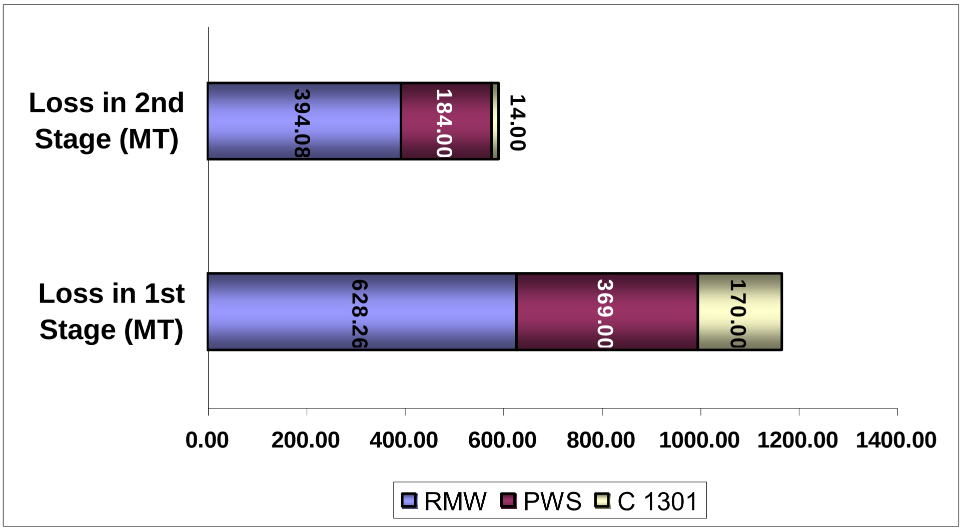


Figure 4.7: Comparison of losses due to major causes in the 1st & 2nd stage

In the above figure, the losses due to the three major causes have reduced significantly. Among them loss due to problem in extractor (C 1301) has been reduced 91.76%. In the next stage our target is to observe that these loss reductions are stable or not.

4.4.2 Impact of WWBLA on OEE at the end of 2nd Stage

Table 4.11: Overall Equipment Efficiency (OEE) Calculation at the end of 2nd Stage

			1	2	3	4	2nd step
a	Total Production or Output	MT	997.00	917.00	944.50	872.50	3731.00
b	Avg Production per day	MT/Day	32.16	32.75	30.47	29.08	31.09
c	Standard cycle time	Hr/MT	0.67	0.67	0.67	0.67	0.67
i	**Losses due to downtime**						
A	Downtime due to Equipment failure	Hr	19.67	17.33	37.67	62.67	137.33
B	Production Loss due to Equipment failure	MT	29.50	26.00	56.50	94.00	206.00
C	Porduction Loss due to Set-up and adjustments	MT	12.00	16.00	32.00	28.00	88.00
D	Eq. Downtime due to Set-up and adjustments	Hr	8.00	10.67	21.33	18.67	58.67
ii	**Speed losses**						
E	Production Loss due to Idling & Minor stoppage	MT	21.00	6.00	32.00	32.50	91.50
F	Eq. Downtime due to Idling & Minor stoppage	Hr	14.00	4.00	21.33	21.67	61.00
G	Production Loss due to Reduced Speed	MT	56.50	43.00	51.00	53.00	203.50
H	Eq. Downtime due to Reduced Speed	Hr	37.67	28.67	34.00	35.33	135.67
iii	**Losses due to defects**						
I	Defect/ Wastage /Drainage	MT	125.00	97.00	112.00	92.00	426.00
J	Reduced yield	MT	3.00	8.50	9.50	9.50	30.50
	OEE Calculation						
K	Working Time [24 Hr per day]	Hr	744.00	672.00	744.00	720.00	2880.00
L	Schedule Downtime	Hr	0.00	0.00	0.00	0.00	0.00
M	Loading Time [K-L]	Hr	744.00	672.00	744.00	720.00	2880.00
N	Operating Time [M-A-D]	Hr	716.33	644.00	685.00	638.67	2684.00
O	**Availability [N/M]**		**0.96**	**0.96**	**0.92**	**0.89**	**0.93**
P	Actual cycle time [N+(F+H)/a]	Hr/MT	0.77	0.74	0.78	0.80	0.77
Q	Operating speed rate [c / P]		0.87	0.90	0.85	0.84	0.86
R	Net operating rate [(a.P)/N]		1.07	1.05	1.08	1.09	1.07
S	**Performance rate [Q.R]**		**0.93**	**0.95**	**0.92**	**0.91**	**0.93**
T	**Quality rate [(a-I-J)/a]**		**0.87**	**0.88**	**0.87**	**0.88**	**0.88**
U	**Overall Equipment Efficiency, OEE [O.S.T]**	**%**	**77.87**	**80.51**	**73.75**	**71.39**	**75.80**
V	Idling & Minor stoppage [N.(1-S)]	Hr	51.67	32.67	55.33	57.00	196.67
W	Ideal productivities [M/c]	MT	1116.00	1008.00	1116.00	1080.00	4320.00
X	Quality Product [a-I-J]	MT	869.00	811.50	823.00	771.00	3274.50

At the end of 2nd stage the OEE has increased significantly than the previous stage. The average OEE is now 75.80%. But the month wise OEE is inconsistent. It may be due to various steps was taken during this stage or may be due to unplanned shutdown occur several times, which was not associated to the improvement work.

4.4.3 Next steps should be taken for maximizing OEE

In the 1st stage the most significant losses were Defect Loss and Reduced Speed, and Idling & Minor Stoppages, which formulate 84.20% loss of total loss. In the 2nd stage the most significant losses have been changed as Defect Loss, Equipment failure and Reduced Speed, which formulate 79.90% loss of total loss.

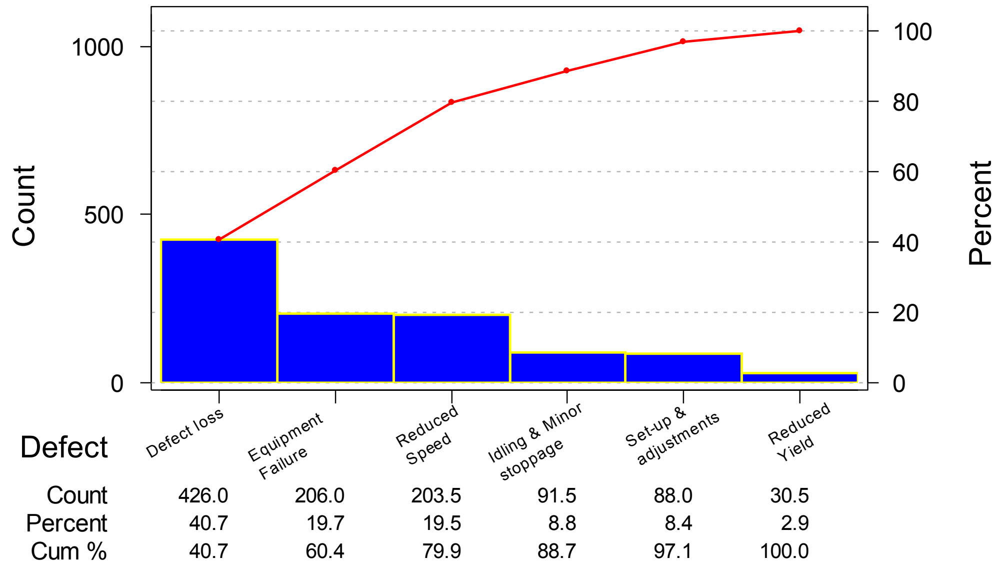


Figure 4.8: Loss Pareto Chart of 2nd stage

In the next it should be worked on defect loss, equipment failure and reduced speed. Considering this three as significant losses major causes should be found out.

Table 4.12: Production losses with causes in the 2nd Stage

Production Loss due to	Frequency	Production Loss in MT
Raw Material Wastage (RMW)		394.08
Poor Working Solution (PWS)		184.00
Quence Pot (Q 301)	1	83.00
Pressure Sewing Adsorber (PSA)	6	69.50
Reformer (RF 301)	2	38.50
Drainage		31.92
Boiler Feed Water Line (BFW)	1	18.00
Compressor (K 1801C)	7	8.00
Extractor Column C 1301	2	4.00
Secondary Filter (F 1201)	1	2.00
Hydrogenation Reactor (R 1101)	1	1.00
Hydrogenation Reactor (R 1102)	1	0.50
Compressor (K 1801B)	1	0.50
Primary Filter (F 1101A)	2	0.50
Total		**835.50**

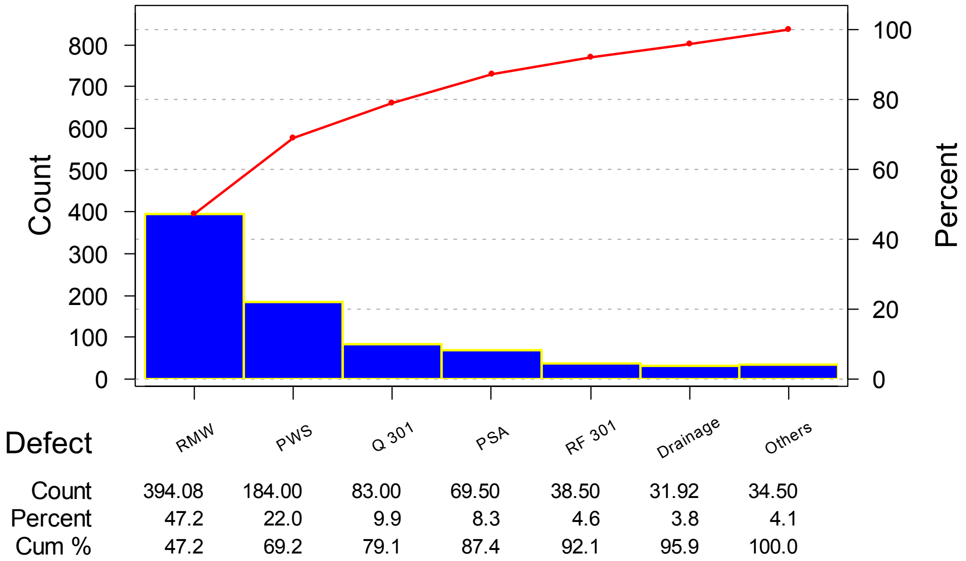


Figure 4.9: Cause Pareto Chart of 2nd stage

Table 4.13: Target setting to reduce losses in next stage

Causes of Production Loss	1st Stage		Reduction 25%	Target to Reduce Loss Below (MT)
	Loss (MT)	Percent (%)		
Pressure Sewing Adsorber (PSA)	69.50	8.32	17.38	52.13
Quence Pot (Q 301) problem	83.00	9.93	20.75	62.25
Poor Working Solution (PWS)	184.00	22.02	46.00	138.00
Raw Material Wastage (RMW)	394.08	47.72	98.52	295.56

After Cause Pareto analysis it was observed that four major causes are responsible for 83.00% loss. So target can be fixed by Loss Tree Diagram.

Then WWBLA can be used to find out deeper root causes and by eliminating them production losses can be reduced further. And thus OEE can be improved continuously by using TPM tools.

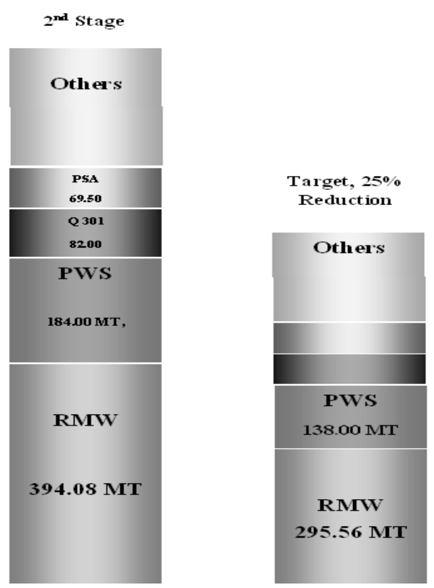


Figure 4.10: Loss Tree Diagram for next stage

4.4.4 Determination of OEE at the end of 3rd Stage

In 3rd stage we only monitored the effect of change completed in 2nd stage to observe the consistency of OEE.

Table 4.14: Overall Equipment Efficiency (OEE) Calculation at the end of 3rd stage

			1	2	3	4	3rd step
a	Total Production or Output	MT	1016.00	959.00	1019.50	928.00	3922.50
b	Avg Production per day	MT/Day	32.77	31.97	32.89	29.94	31.89
c	Standard cycle time	Hr/MT	0.67	0.67	0.67	0.67	0.67
i	**Losses due to downtime**						
A	Downtime due to Equipment failure	Hr	2.00	28.00	7.67	0.33	38.00
B	Production Loss due to Equipment failure	MT	3.00	42.00	11.50	0.50	57.00
C	Porduction Loss due to Set-up and adjustments	MT	9.00	29.00	13.00	17.00	68.00
D	Eq. Downtime due to Set-up and adjustments	Hr	6.00	19.33	8.67	11.33	45.33
ii	**Speed losses**						
E	Production Loss due to Idling & Minor stoppage	MT	31.50	9.50	29.00	7.50	77.50
F	Eq. Downtime due to Idling & Minor stoppage	Hr	21.00	6.33	19.33	5.00	51.67
G	Production Loss due to Reduced Speed	MT	56.50	40.50	43.00	55.00	195.00
H	Eq. Downtime due to Reduced Speed	Hr	37.67	27.00	28.67	36.67	130.00
iii	**Losses due to defects**						
I	Defect/ Wastage /Drainage	MT	98.50	86.50	100.00	73.00	358.00
J	Reduced yield	MT	2.50	10.00	4.00	6.00	22.50
	OEE Calculation						
K	Working Time [24 Hr per day]	Hr	744.00	720.00	744.00	744.00	2952.00
L	Schedule Downtime	Hr	0.00	0.00	0.00	72.00	72.00
M	Loading Time [K-L]	Hr	744.00	720.00	744.00	672.00	2880.00
N	Operating Time [M-A-D]	Hr	736.00	672.67	727.67	660.33	2796.67
O	**Availability [N/M]**		**0.99**	**0.93**	**0.98**	**0.98**	**0.97**
P	Actual cycle time [N+(F+H)/a]	Hr/MT	0.78	0.74	0.76	0.76	0.76
Q	Operating speed rate [c / P]		0.85	0.91	0.88	0.88	0.88
R	Net operating rate [(a.P)/N]		1.08	1.05	1.07	1.06	1.06
S	**Performance rate [Q.R]**		**0.92**	**0.95**	**0.93**	**0.94**	**0.94**
T	**Quality rate [(a-I-J)/a]**		**0.90**	**0.90**	**0.90**	**0.91**	**0.90**
U	**Overall Equipment Efficiency, OEE [O.S.T]**	%	**81.99**	**79.86**	**82.03**	**84.23**	**81.99**
V	Idling & Minor stoppage [N.(1-S)]	Hr	58.67	33.33	48.00	41.67	181.67
W	Ideal productivities [M/c]	MT	1116.00	1080.00	1116.00	1008.00	4320.00
X	Quality Product [a-I-J]	MT	915.00	862.50	915.50	849.00	3542.00

During this stage the OEE was stable and enough consistent and at the end it reached to 81.99%.

Results and Analysis

5.1 Results and Analysis

During 1st stage production losses are accumulated and 1st stage OEE calculated which indicates the existing condition of the plant. After studying and analyzing data we started to implement TPM tools in the 2nd stage, in some cases we have to do trial & error to eliminate losses, which may lead some unsettling condition of the plant. At the end of 2nd stage we got the OEE improved from 63.35% to 75.80%. After implementation stage we started to monitor the OEE of the plant in 3rd stage. At the end of the 3rd stage we found the OEE improvement was consistent and it improved up to 81.99%.

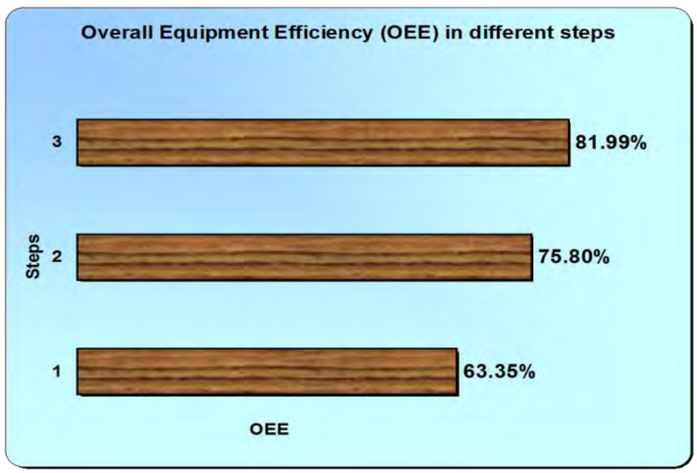


Figure 5.1: OEE in three different stages

5.1.1 Comparison of significant losses

Table 5.1: Comparison of six significant losses in the three stages

Production Losses due to	Loss in 1st Stage (MT)	Loss in 2nd Stage (MT)	Loss in 3rd Stage (MT)
Equipment failure	152.50	206.00	60.00
Set-up and adjustments	72.00	88.00	68.00
Idling & Minor stoppage	161.50	91.50	77.00
Reduced Speed	534.50	203.50	195.00
Defect loss	660.00	426.00	358.00
Reduced yield	29.00	30.50	22.50
Total	**1609.50**	**1045.50**	**780.50**

TPM tools were applied to the in 2nd stage to reduce idling & minor stoppage, reduced speed loss and defect loss. And we were able to reduce the losses to a significant amount.

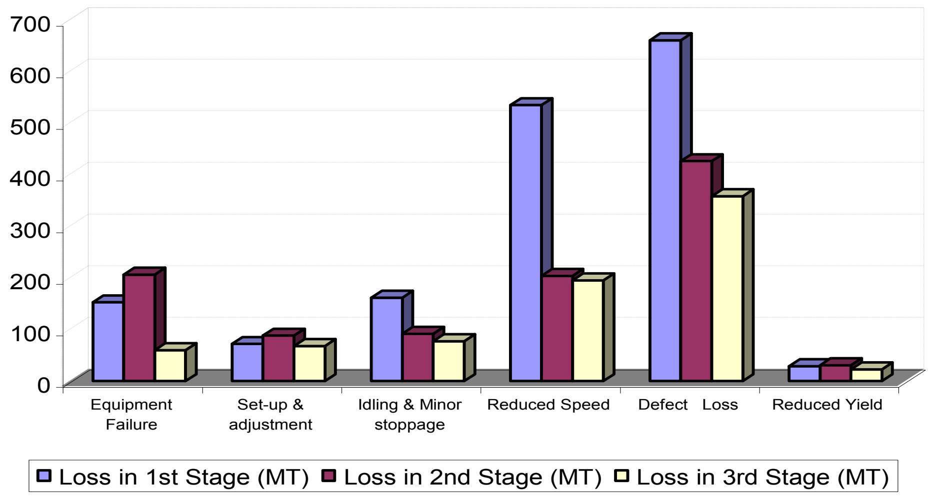


Figure 5.2: Significant losses during the three stages

5.1.2 Comparison of losses due to Major Causes

Table 5.2: Losses due to major causes in three different stages

Stage	RMW (MT)	PWS (MT)	C 1301 (MT)
Stage -1	628.26	369.00	170.00
Stage -2	394.08	184.00	14.00
Stage -3	316.52	185.25	3.00

Losses in 1st Stage have considerably reduced in 2nd Stage as the effect of loss reduction tools of TPM used. In the third stage losses were not increased, rather in a decreasing trend, which indicates the root causes identified and eliminated were accurate.

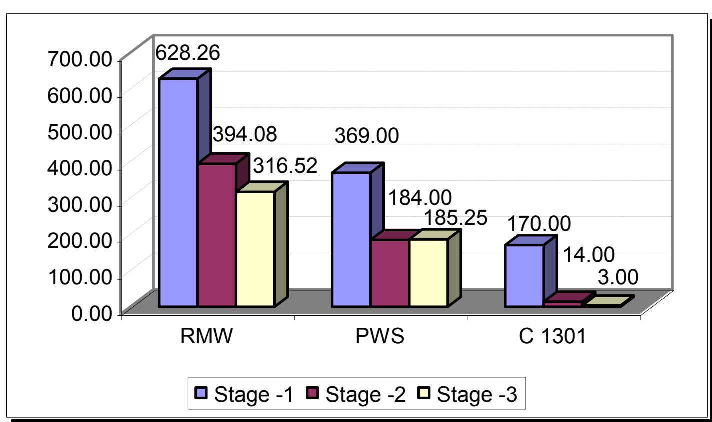


Figure 5.3: Losses due to major causes in three different stages

We observed the month wise significant losses in the figure and found that the losses have a decreasing trend.

Table 5.3: Month wise significant losses in three different stages

	1st Stage				2nd Stage				3rd Stage			
	1	2	3	4	1	2	3	4	1	2	3	4
RMW	149.58	180.44	149.18	149.06	117.79	91.72	99.50	85.07	89.30	73.47	88.61	65.14
PWS	115.00	92.00	82.50	79.50	55.50	40.00	46.00	42.50	51.50	40.50	39.25	54.00
C 1301	16.50	83.00	51.50	19.00	1.00	0.00	13.00	0.00	0.00	0.00	0.00	3.00

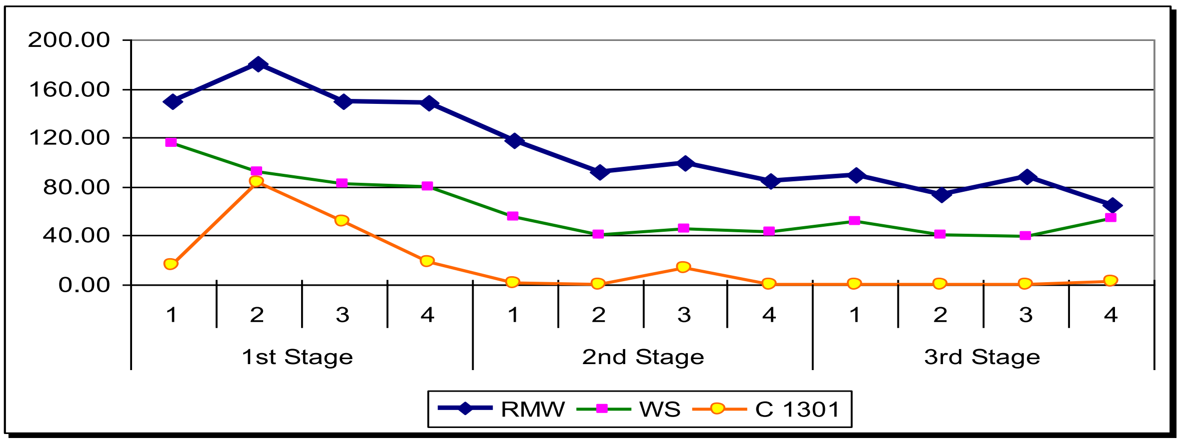


Figure 5.4: Month wise losses due to major causes in three different stages

5.1.3 Comparison of OEE

If we analyze the OEE it can be observed that the performance rate and quality rate have improved in a significant amount within four months. It indicates that the performance rate and the quality rate can be improved earlier than availability in a continuous chemical processing plant.

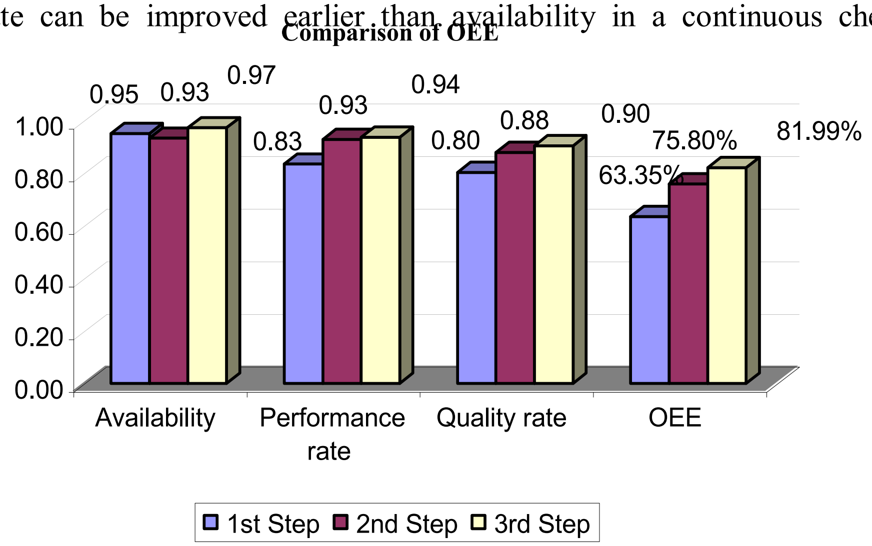


Figure 5.5: OEE with three factors in three different stages

In the 1st stage we observed the OEE was showing unstable & fluctuating behavior. In the 2nd stage it has improved significantly and was shifting towards a more stable behavior. It may be due to various steps was taken during this stage or may be due to unplanned shutdown occur several times, which was not associated to the improvement work.

Table 5.4: Monthly OEE in three different stages

	1st Step OEE				2nd Step OEE				3rd Step OEE			
	1	2	3	4	1	2	3	4	1	2	3	4
Availability	0.96	0.96	0.89	0.98	0.96	0.96	0.92	0.89	0.99	0.93	0.98	0.98
Performance rate	0.83	0.77	0.84	0.89	0.93	0.95	0.92	0.91	0.92	0.95	0.93	0.94
Quality rate	0.80	0.77	0.80	0.84	0.87	0.88	0.87	0.88	0.90	0.90	0.90	0.91
OEE	0.63	0.57	0.59	0.74	0.78	0.81	0.74	0.71	0.82	0.80	0.82	0.84

In the 3rd stage the OEE has maintained a consistent and has rising trend, which indicates TPM tools, has functioned successfully to improve OEE.

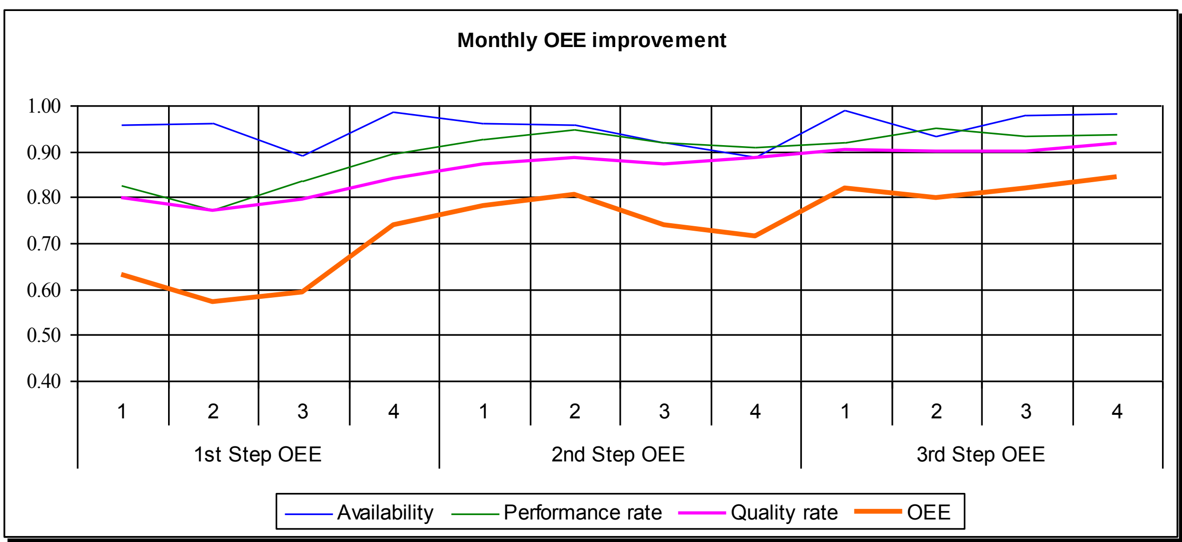


Figure 5.6: Monthly OEE in three different stages

Analyzing our total findings we can summarize the result as:

i) Kobetsu Kaizen can be implemented as a TPM pillar to improve OEE consistently in a continuous chemical processing plant. There is a strong positive impact of loss reduction here on OEE improvement.

ii) Losses due to process instability should be quantified carefully as it affects the performance rate. The performance rate and the quality rate can be improved earlier than availability in a continuous chemical processing plant.

Chapter 6

Conclusion and Recommendation

6.1 Conclusion

After analyzing the total loss of first four months, three major causes were identified as raw material wastage, poor chemistry of working solution, and problem in extractor column (C1301). These three were responsible for the most significant losses among the six major losses. We tried to enter into the root level of the problem by using TPM tool WWBLA. During 2^{nd} stage our target was to eliminate the root causes found in the previous stage. At the end of 2^{nd} stage total production loss reduced to a significant amount as a result of root cause elimination affect. From the comparison of six major losses it is observed that the defect loss, reduced speed loss and idling & minor stoppage loss has reduced but the loss due to equipment failure has increased.

This is because we have not worked on equipment failure as it has a lower priority than the above three or may be due to some unexpected power failure which was not related to the improvement work. As a result the performance rate and quality rate have improved but the availability has decreased and after all we got the improved OEE at the end of 2^{nd} stage. At the initial stage, OEE of the plant was only 63.35% and after improvement works it rises up to 81.99%. If the improvement work continued, it is possible to achieve standard OEE (95.00%) for this type of chemical process plant [12].

In this study it has proven that Kobetsu Kaizen can be implemented as a TPM pillar to improve OEE in chemical process plants within shortest possible time. But to implement TPM it should focus on activities rather than foundation program. Otherwise it’s positive impact on the OEE & productivity can’t be shown earlier.

6.2 Recommendation

In this study the whole plant was considered as a single unit or single machine and a single product output due to unavailability of unit wise consistent data. If there is enough flexibility to collect detailed unit wise data it can be easy to find out root causes and conduct corrective measures easily, which may leads to obtain more accurate and reliable OEE.

In a continuous chemical processing plant OEE depends on process stability rather than equipment performance. So root causes of significant losses are mainly process oriented rather than equipment. Further study can be conducted to establish the point that to improve OEE of a continuous chemical plant, it would be better to improve performance rate and quality rate rather than availability as they can be improved sooner.

It is easier to convince management for maintenance investment with the help of TPM tools as it shows the logic behind, explain the impact of the problem in terms of loss & benefits. Data related to production losses and steps taken for the remedy must be collected in a systematic way, where TPM is newly introduced. After a period this data will help a lot to find out root causes and to take instant decision, which can save a lot of time & money.

Hidden losses i.e. loss due to process instability should be quantified carefully. To apply TPM in a chemical process plant it is necessary to focus on production loss rather than downtime because process stability is more important here than discrete manufacturing process.

It is difficult to implement TPM to change total environment in a systematic approach from necessary foundation for planning and directing activities towards operator maintenance, preventive maintenance, training, maintenance prevention etc. If the magnitude and reasons for losses are not known, the activities will not be allocated towards solving the problem of major losses in an optimal way. If measurable results are not provided within a rather short period, the management and operators can loose reliance in TPM. If the sweet taste of success is not experienced soon enough, so the driving force of change will eventually vanish. So, the initial approach should be objective or goal oriented to implement TPM.

References:

[1] Takahashi, Y., “Maintenance oriented management via total participation: Total productive maintenance, a new task for plant managers in Japan”, Terotechnica, No. 2, (1981), pp. 79-88.

[2] Nakajima, S., “TPM - a challenge to the improvement of productivity by small group activities”, Maintenance Management International, No. 6, (1986), pp. 73-86.

[3] Nakajima, S., “Introduction to Total Productive Maintenance”, Productivity Press, Cambridge, MA, 1988.

[4] Robinson, C.J., & Ginder, A.P., “Implementing TPM: The North American experience. Portland”, Productivity Press, 1995.

[5] Maggard, B.N., and Rhyne, D.M., “Total productive maintenance: A timely integration of production and maintenance”, Production and Inventory Management Journal, vol. 33, No. 4, (1992), pp. 6–10.

[6] Park, K.S., & Han, S.W., “TPM—Total Productive Maintenance: Impact on Competitiveness and a Framework for Successful Implementation”, Human Factors and Ergonomics in Manufacturing, Vol. 11 (4), (2001), pp. 321–338.

[7] Masud, A.K.M., Khaled, A.A., Jannat, S., Khan, S.A., and Islam, K.J., “Total Productive Maintenance in RMG Sector, A Case: Burlingtons Limited, Bangladesh”, Journal of the Institution of Engineers, Bangladesh, Multidisciplinary, vol. mul-dis. 32, no. 1, (2007), pp. 11-18.

[8] Park, K.S., & Han, S.W., “Integrated approach for maintenance management in manufacturing environment”, Journal of Korean Society of Maintenance Engineers, Vol. 3(2), (1998), pp. 83–89.

[9] Venkatesh, J., “An Introduction to Total Productive Maintenance (TPM)”, http://www.plant-maintenance.com/articles/tpm_intro.shtml, 2007.

[10] Takahashi, Y., “Maintenance oriented management via total participation: Total productive maintenance, a new task for plant managers in Japan”, Terotechnica 2, (1981), pp. 79–88.

[11] Ljungberg, O., “Measurement of overall equipment effectiveness as a basis for TPM activities”, Sweden International Journal of Operations & Production Management, Vol. 18, No. 5, (1998), pp. 495-507.

[12] Ahmad, M., and Benson, R., “Benchmarking in the process industries”, IChemE, The Cormwell Press, UK, (1999), pp. 24.