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Embellishing TPM through Losses Analysis to Enhance Overall Plant Effectiveness in Ferro Alloys Plant- A Case Study at JSPL, Raigarh

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Abstract – *Total Productive Maintenance (TPM) is a methodology that increases the efficiency and effectiveness of equipment. Kobetsu Kaizen (Focussed Improvement) is one of the TPM pillar, which has an important role to measure and evaluate performance of an organization. Kobetsu Kaizen pillar has ability to identify the source of problem and its cause factors in terms of losses. Kobetsu Kaizen pillar depends upon Overall Plant Effectiveness (OEE) and the OEE depends upon the three parameters i.e., availability, performance rate and quality rate. These three parameters are directly connected with 16 types of losses.*

SAF (Submerged Arc Furnace), an important plant at JSPL-Raigarh, is engaged in the production of ferro alloys which cannot be separated from the problems related to the proficiency of machine or equipment. Therefore, steps needed to be taken to resolve the problem. This research paper aimed to improve the Overall Plant Effectiveness (OPE) by analysis of different type of losses. The focus of improvement was aimed to reduce the losses occurred at plant by eliminating losses through Kaizens and adoption of some best practices by the plant. The prime purpose of this work is to articulate the positive effect of Kobetsu Kaizen pillar of TPM on increasing plant availability, performance rate, quality rate and reducing losses.

Key Words: **Total Productive Maintenance (TPM), Overall Equipment Effectiveness (OEE), Overall Plant Effectiveness (OPE), Continual Improvement, Why-why analysis, Kaizen, Kobetsu Kaizen Losses, Focussed Improvement.**

1. INTRODUCTION

Total productive maintenance (TPM) is a concept which not only reduces different losses (like, downtime, speed loss etc.) but also provides a positive and safe working conditions for employees and helps in boosting up the morale. TPM is a maintenance practice which aims to maximize overall equipment efficiency (OEE), develop and establish a planned maintenance system for the entire life of equipment, ensure involvement of every single employee from all the departments in TPM activity, and encourage small group activities. It helps in establishing a corporate culture to maximize profitability, system efficiency and reduces chronic losses to zero by involvement of all employees and practicing best practices.

Overall Plant Effectiveness (OPE) is a performance indicator which can be used to analyse the progress or effectiveness of all the equipment of a particular plant. The improvement in OPE can be ensured by minimizing 16 types of Kobetsu Kaizen (KK) losses which are directly or indirectly responsible for availability, performance rate, as well as quality rate of equipment.

1.1 JSPL-Raigarh & SAF Plant

Jindal Steel & Power Limited (JSPL)-Raigarh, an integrated steel plant with a production capacity of 3.6 MTPA (million tonnes per annum), is the fastest growing steel plant in the country. The organization with strong core values has a vision to be a globally admired organization with sustainable development. JSPL has coal-based sponge iron plant of 1.4 MTPA with captive waste heat recovery boilers and fluidized bed boilers that account for a total production of 340 MW of power. State-of-the-art technology has been used for ferro-alloy making through sub-merged arc furnace (SAF), coke making, sinter making and hot metal production through blast furnace route.

As far as finished products are concerned, JSPL possesses 1.0 MTPA Plate Mill, 0.75 MTPA Rail Mill and 0.6 MTPA Beam and Structural Mill to produce a variety of sizes of beams, rails, channels, plates, coils, etc.

Installed capacity of the various production units of JSPL-Raigarh is tabulated in Table-1.

Production Units	Capacity, MTPA
Coal Based DRI Plant	1.32
Blast Furnace	1.6
Steel Melting Shop (SMS)	3.6
Rail Mill	0.75
Plate Mill	1
Beam and Structural Mill	0.6
Sinter Plant	2.5
Coke Oven	0.8
SAF (Submersed Arc Furnace)	0.06

Table-1: Installed capacity of Plants at JSPL-Raigarh

SAF is a ferro alloy plant which produces ferro alloys for captive consumption of JSPL-Raigarh. SAF produce different types of ferro alloys for steel melting shops. Ferroalloys are added in steel to improve its mechanical properties like tensile strength, ductility, fatigue strength and corrosion resistance, etc. Additionally, these are used for several other tasks like steel refining, de-oxidation, control of non-metallic inclusions and precipitates in steel. Fig. 1 shows an overview of SAF processing at JSPL-Raigarh.

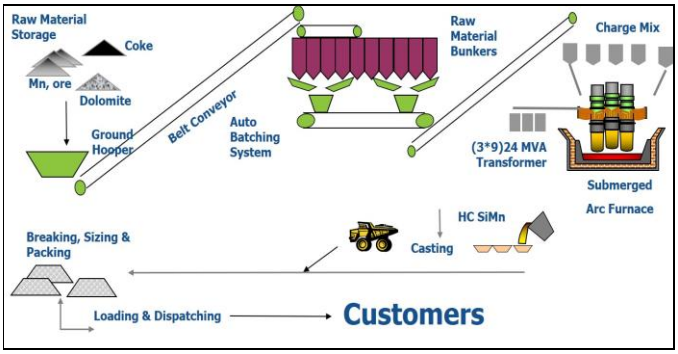

Fig. 1: An overview of SAF at JSPL-Raigarh.

At present, most of the departments of JSPL-Raigarh practise TPM methodology to eliminate the identified losses. The Organization has about 34 different departments which include manufacturing and services departments. SAF, a ferro alloys producing plant, of JSPL-Raigarh has been chosen for the study.

2. LITERATURE REVIEW

The OEE can be improved using various methodologies like TPM, Work study, etc. The Work Study improves setup time and adjustment time. The term 'work study' includes method study and work measurement. Whereas TPM is using Eight Pillars to improve OEE.

Ashok Kumar A. has suggested in their study, OEE is employed as a simple indicator, but it is still an effective method for analysing the efficiency of a single machine and an integrated system.

Pavan Kumar Malviya et. al. has suggested in their study, the implementation of OEE at a small enterprise through TPM methodology. To be successful and to achieve world class manufacturing, organizations must possess effective maintenance. OEE quantifies well working of manufacturing unit and performance to its designed capacity, during the periods when it is scheduled to run frequent machine breakdowns, low plant availability, increased rejection is a great threat to increase operating cost and lower productivity.

Mohammed Asif Mulla et. al. has mentioned in their study and they have implemented TPM and 5S techniques to improve the availability, performance and quality of the machines. Though TPM, 5S technique, design of multi-fixture was focused, the availability and performance were improved significantly by minimizing the equipment deterioration and failure.

M. Vivek Prabhu et. al. has stated that an OEE is an important performance measure for effectiveness of any equipment. Careful analysis is required to know the effect of various components. Their study indicates that OEE will be significantly improved if focus is given on performance rate improvement.

Amit Kumar Gupta et. al. has mentioned in their study the effectiveness and implementation of TPM programme in an automobile manufacturing organization. Through the case study of implementing TPM in an automobile manufacturing organization, the increase in efficiency and productivity of machines in terms of OEE are discussed.

3. METHODOLOGY

For this case study, SAF, a ferro alloys manufacturing plant at JSPL-Raigarh has been selected. The objectives of this study were:

1. To find out the Kobetsu Kaizen losses in the plant.
2. Why-why analysis to find root cause.
3. Perform Kaizen for eliminating root cause.
4. Improve OPE of the plant by implementation of above steps.

The above objectives of the plant need to be fulfilled. The below flowchart (Fig-2) shows the overall methodology adopted for study.

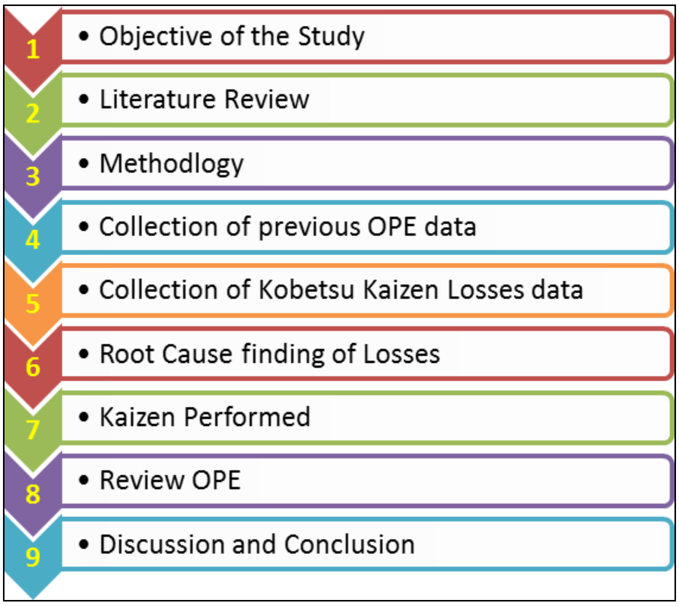

Fig -2 : Methodology of study

4. TPM PILLARS

Most modern improvement programme have two common goals—reduce wastes and increase efficiency. TPM is a lean manufacturing program that can help businesses to achieve these goals. It is built on eight pillars that focus on improving efficiency and reducing wastes. TPM is a Japanese concept for maintaining plants and equipment in healthy condition. The goal of the TPM is to markedly increase production and at the same time it increases employees' morale and job satisfaction. The main aims are:

- Establishing a corporate culture that will maximize production system effectiveness.
- Organizing a "Genba-Genbutsu" system to prevent losses and achieve such "reduction-to-zero" targets as "Zero-Defects" and "Zero-Breakdowns" in the entire production system life cycle.
- Involving all functions of an organization including production, development, sales and management.
- Involving every member of an organization, from top management to front-line operators.
- Achieving Zero Losses through the activities of overlapping small groups.

TPM is founded on eight pillars. Each pillar works together to form a program that improves productivity by involving the entire workforce. The eight pillars of TPM and its activities is shown in Fig. 3.

Fig -3 : TPM and its pillars

4.1 Kobetsu Kaizen (Focused Improvement) Pillar

This pillar of TPM guides about implementing all the technical approaches in a rational way to reduce all the losses of a plant to zero level.

As one of the pillars of TPM, Kobetsu Kaizen (KK) pursues efficient equipment, worker, material and energy utilization, that is, extremes of productivity and aims at achieving substantial effects. Kobetsu Kaizen activities try to thoroughly eliminate 16 major losses. The basis of these activities is to enhance and demonstrate the technological, analytical and Kaizen powers of the worker engaged in them.

The main aim of KK Pillar is to reduce all 16 chronic losses of a plant to zero level. These 16 chronicle losses are divided into 3 main categories as given below:

A. Losses that impede equipment efficiency

S. No.	Loss	Description
1	Failure losses – Breakdown loss	Losses due to failures. Types of failures include sporadic function stopping failures and function-reduction failures in which the function of the equipment drops below normal levels.
2	Setup/adjustment losses	Stoppage losses that accompany setup changeovers.
3	Cutting blade and Jig change loss	Stoppage losses caused by changing the cutting blade due to breakage or caused by changing the cutting blade when the service life of the grinding stone, cutter or bite.
4	Startup loss	When starting production, the losses that arise until equipment start-up, running-in and production processing conditions stabilize.
5	Minor stoppage/ Idling loss	Losses that occur when the equipment temporarily stops or idles due to sensor actuation or jamming of the work.
6	Speed loss – operating at low speeds	Losses due to actual operating speed falling below the designed speed of the equipment.
7	Defect/ rework loss	Losses due to defect and reworking.
8	Scheduled downtime / Shutdown loss	Losses that arise from planned equipment stoppages at the production planning level in order to perform periodic inspections and statutory inspection.

B. Losses that impede Human work efficiency

9	Management loss	Waiting losses that are caused by management, such as waiting for materials, tools, instructions, repair of breakdowns, etc.
10	Operating/ Motion loss	Manhour losses arising from differences in skills involved in setup and adjustment work, cutting blade change work, etc.
11	Line organization loss	Idle time losses when waiting for multiple processes or platforms.
12	Logistic / Distribution loss	Distribution man-hour losses due to transport of materials, processed products and dollies.
13	Measurement and adjustment loss	Work losses from frequent measurement and adjustment in order to prevent the occurrence and outflow of quality defects.

C. Losses that impede Production resources

14	Energy loss	Losses due to ineffective utilization of input energy (electric, gas, fuel oil, etc.) in processing.
15	Die, Jig and tool breakage loss	Financial losses (expenses incurred in production, regarding renitriding, etc.) which occur with production or repairs of dies, jigs and tools due to aging beyond services life or breakage.
16	Yield loss	Material losses due to differences in the weight of the input materials and the weight of the quality products.

4.1.1 Prioritization of Losses

Prioritizing of losses should be done on the basis of :

- ✓ Analyse the losses that affect OEE
- ✓ No. of occurrence and time losses
- ✓ Type of losses (sporadic or chronic)

Wastes must be eliminated from machine, tool and processes. TPM team leaders generally take turns monitoring and collecting data from work areas to identify waste. To make data easier to collect and understand, divide process elements into groups.

The following sample groups are often used to identify process waste:

- Equipment losses include downtime, speed, and quality. Common downtime losses are from machine and tool set-up, adjustments, and breakdowns. Speed losses typically relate to idling or unnecessary speed reductions. Quality losses are often the result of operator or process errors.
- Manpower losses are generally caused by poor cleaning, failing to monitor machines and tools, or waiting for materials, instructions, or quality approval.
- Material losses are associated with yield, energy, and material quality.

TPM is a process designed to improve OEE / OPE through comprehensive maintenance. The OEE formula helps facilities more clearly to follow machine and tool performance trends. In OEE, data percentages for availability, performance, and quality are used to provide a single score.

4.1.2 What is OEE?

Global performance evaluation is the most important in the field of continuous improving of the performance of manufacturing / production process. OEE is one of the performance evaluation methods that are most common and popular in the production / manufacturing industries. OEE plays a vital role where performance and quality of the product are of importance to the organization. The OEE is intended at minimizing the breakdowns, increasing performance and quality rate and thus improving the effectiveness of the machine/system. The availability of the machine, performance rate of the machine and quality rate of the products are considered as main parameters for maximizing the OEE of a manufacturing system. It is found that poor performance rate contributes more than availability and quality rate.

OEE is the measure of an asset's performance compared to its full potential. It quantifies the utilization of manufacturing resources – specifically physical assets, time, and materials – during production to indicate any gaps between actual and ideal performance.

Today, OEE has become a common key performance indicator (KPI) and manufacturing best practice for determining the portion of the manufacturing process that is truly productive.

OEE is most commonly determined based on three underlying metrics:

- Availability (measures machine uptime)
- Performance (measures system speed)
- Quality (measures levels of defects)

The ability to calculate OEE is vital in any manufacturing process as it immediately shows up any losses. It offers valuable insights for systematic improvements. OEE remains the standard for eliminating waste and benchmarking production process with a view to continuously improving productivity.

OEE is expressed as mentioned below:

OEE = Availability x Performance rate x Quality rate

Availability :

The availability is the ratio of operating time to time available for operation i.e., loading time and covers all unscheduled/ unwanted stoppages of equipment

$$\text{Availability} = \frac{(\text{Loading time} - \text{Down time})}{\text{Loading time}} \times 100$$

Where,
Loading Time = Calendar time - Scheduled shutdown time

Performance Rate:

The performance rate which is an indicator of speed loss and minor stoppage & idling loss, basically reflects the utilization % of equipment against rated or designed speed

Performance Rate= Speed operating rate x Net operating rate

$$\text{Where, Speed operating rate} = \frac{\text{Standard cycle time}}{\text{Actual cycle time}}$$

and

$$\text{Net operating rate} = \frac{\text{Product unit processed} \times \text{Actual cycle time}}{\text{Loading time} - \text{Down time}}$$

Quality Rate:

The quality rate covers rework / defect loss because as per TPM definition, production means only quality production

$$\text{Quality rate} = \frac{\text{Product unit processed} - \text{Defect units}}{\text{Product unit processed}}$$

4.1.3 Losses & its relationship with OEE :

Availability mainly depends on:

- Shutdown loss
- Breakdown loss
- Cutting blade change loss
- Setup and Adjustment loss
- Startup loss

Performance rate depends on:

- Speed loss
- Minor stoppage / Idle loss

Quality rate depends on:

- Rejection and Rework loss

4.1.4 What is OPE (Overall Plant / Production Effectiveness)

OPE stands for Overall Plant / Production Effectiveness. The biggest difference between OPE and OEE is that OPE includes disconnected elements that may not be included in OEE calculations. This means that it includes activities like selective procedures and manual processes that don't include the machines themselves or may not apply to every product in a production run.

OPE will also commonly include planned downtime in the calculation. This is not usually calculated in OEE.

Typically, employees must collect the data for the OPE calculation manually as this is the point of the calculation. It captures processes that are not often easily measured by a sensor or machine and must have planned downtime inserted into the data.

OPE accounts for the full range of variables and steps that impact a manufacturing process. It's an end-to-end account of the value stream.

Crucially, OPE integrates machine data with an account of what happens around machines. It's a representation of human action as well as machine performance.

All the caveats about OEE also apply to OPE; however, OPE offers some additional benefits as a calculation to manufacturers that are accurately collecting and analyzing things like planned downtime and other manual processes. It simply provides some additional context.

5. CASE STUDY

5.1 Introduction

SAF is a ferro alloys plant which is one of the critical plants at JSPL-Raigarh. The main function of department is to produce ferro alloys for steel making process. The main product of SAF is "High carbon silico manganese". Ferro alloy is nothing but an alloy of iron with some element other than carbon and is used to physically introduce that element into molten metal, usually during steel manufacturing.

The ferro alloys making process is a reduction smelting operation. The reactants consist of metallic ores (Mn ores, FeMn slag) and a reducing agent, usually in the form of coke, charcoal, high- and low-volatility coal and fluxes like quartz, dolomite.

5.2 Data Collection and Discussion

The data collection for the study has been done for the period of January-June 2020. The data was collected for OPE during the period with availability, performance rate, quality rate (Table -2).

Month	Availability (%)	Performance Rate (%)	Quality Rate (%)	OPE (%)
Jan-20	80.98	82.02	100	66.42

Feb-20	80.84	86.49	100	69.92
Mar-20	80.91	85.39	100	69.09
Apr-20	82.11	85.53	100	70.23
May-20	85.77	84.51	100	72.48
Jun-20	83.15	82.28	100	68.42

Table -2: Data collection before TPM implementation

In ferro alloys production, the quality rate is always 100% as there is an in-process inspection which guides the operations before the final production and ensures the product quality in terms of chemical analysis and size analysis before dispatching to the customer.

It is evident from the Table-2 that availability and performance rate is not consistent which resulted in lower OEE values which are well below the standard value of OEE in world (85%). An OEE score of 85% (with availability = 90%, Performance Rate = 95% and Quality Rate = 99%) is considered world class for discrete manufacturers. For many companies, it is a suitable long-term goal.

Losses in availability takes equipment failure (unplanned stops) and setup and adjustments (planned stops) into account, whereas performance loss takes idling and minor stops (small stops) and reduced speed (speed loss) into account. Data of the mentioned losses were collected and shown as month wise total losses in Chart-1. To understand these data, the breakup of total loss data into different types of losses has been plotted in Chart-2 whereas the % contribution of losses has been shown in Chart-3.

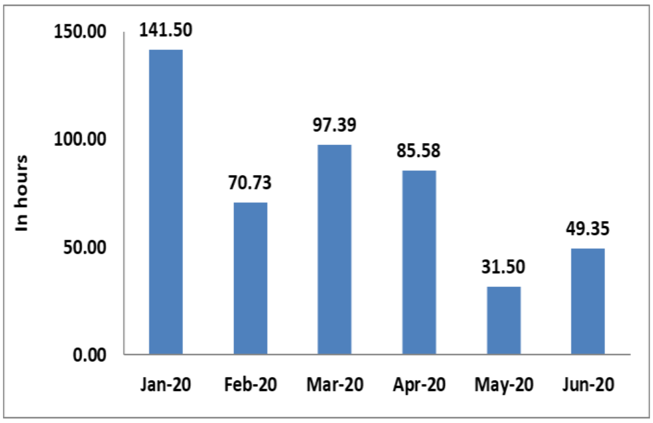

Chart -1: Total losses in hours (month wise)

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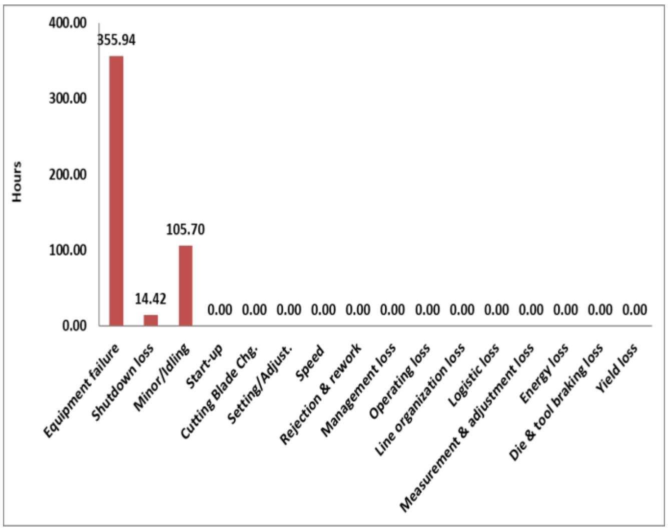

Chart -2: Breakup of total losses (losses type wise)

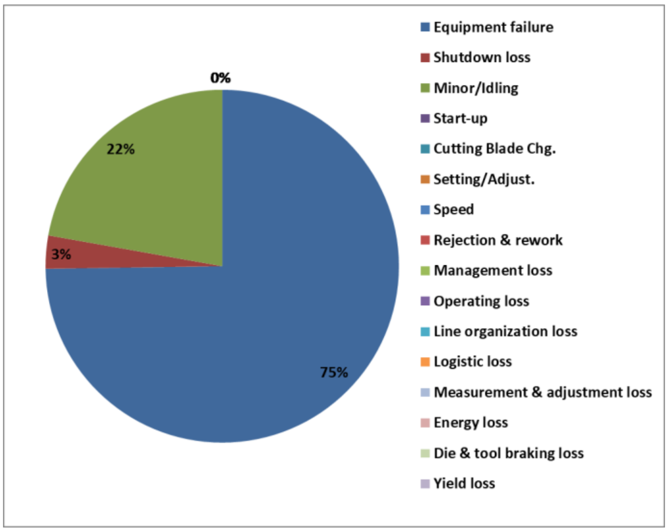

Chart -3: %age contribution of losses

It is very clear from Chart -2 & Chart -3 that equipment failure losses have very high contribution in overall / total losses and main reason for less OEE of the plant as the major contribution of equipment failure is about 75%.

5.3 Analysis of problem and developing solution:

Kobestu Kaizen (Focused improvement) was used to elevate performance and availability of the plant by aligning the correct method to the correct scenario. From the analysis done by the authors, it was found that losses in performance and availability are the causes of low OEE. The losses in performance are going to be solved by addressing minor stoppages, reduced speed and idling. Similarly, losses in availability are to be solved by addressing losses in equipment failure, set-up and adjustment.

Performance takes three losses into account which are idling, minor stoppages and reduced speed. Hence the approach will be to use focused improvement to address the causes of these losses. Availability takes equipment failure and setup & adjustment losses into account. Likewise, the focused improvement is going to be used to address the causes of these losses.

Below is few major kaizens and best practices adopted as solutions to minimize / eliminate these losses.

Problem 1: Due to high temperatures in the furnace, stainless steel pressure rings got cracked frequently and resulting water leakages.

The Why-why analysis:
1. Why the Pressure ring water leakage occurs?
- Due to heavy heat radiation, the SS ring got cracked and leaked.
2. Why the heat radiation is high?
- Due to over rating of furnace and high ash coal usage the heat radiation is high at the furnace top and SS rings are not protected from radiation.
3. Why the pressure rings are not protected from heat?
- The pressure ring can be protected from heat radiation by covering with an insulation material.

Kaizen performed:
Kaizen Theme: To minimize the furnace delay due to water leakages in pressure ring.
Idea: By insulating the pressure ring with anchors and castable.
Countermeasure / Solution: Water leakages can be minimized by insulating the pressure ring with anchors and castable. By this the direct heat radiation can be minimized. So castable provided on pressure ring as shown in Fig-4.

Fig -4 : Before and After

Problem 2: Due to heat radiation the hydraulic pipeline was frequently failing.

The Why-why analysis:
1. Why temperatures of hydraulic power pack getting high?
Answer: Due to heating of hydraulic line from heat radiation of chimney.
2. Why hydraulic line getting heat from chimney heat radiation?
Answer: Due to lack of a heat shield in between chimney and hydraulic pipeline.
3. Why heat shield was not there?
Answer: Because earlier temperature was low in furnace due to good quality of raw materials (coal), therefore no need of heat shield at that time.

Kaizen performed:
Kaizen Theme: Provision of heat shield between hydraulic pipelines to chimney to avoid heat radiation.
Idea: Arrangement of a heat shield to protect hydraulic pipeline from chimneys heat radiation.
Countermeasure/ Solution: A heat shield of glass wool materials prepared and fixed in between chimney and hydraulic line to protect hydraulic line from heat radiation of chimney as shown in Fig-5.

Fig -5: Before and After

Apart from the mentioned kaizens, several other kaizens had been performed and many best practices have been adopted to eliminate / minimized the losses.

5.4 Result & Discussion:

After problem analysis and successfully implementation of all solutions in form of Kaizens and best practices adopted, again data of OPE and losses are collected for 6 moths (July 2020 to December 2020) as shown in Table-3.

Month	Availability (%)	Performance Rate (%)	Quality Rate (%)	OPE (%)
Jul-20	94.12	91.60	100	*86.21*
Aug-20	95.32	90.55	100	*86.31*
Sep-20	93.73	93.26	100	*87.41*
Oct-20	94.77	93.09	100	*88.22*
Nov-20	97.63	91.05	100	*88.89*
Dec-20	96.54	94.89	100	*91.60*

Table-3: Data collection after implementation

It is evident from the Table-3 that availability and performance rate is now consistent which resulted in higher OEE values which are well above the standard value of OEE in world (85%).

Data of the mentioned losses were again collected for the period of next 6 months (after implementation of KK Kaizens, etc.) as month wise total losses in Chart-4. The comparative data (before and after implementation of TPM philosophy successfully) of total losses, monthly avg. losses, total losses in 6 months (loss wise) as well as % OEE has been depicted in Charts 4-8 respectively.

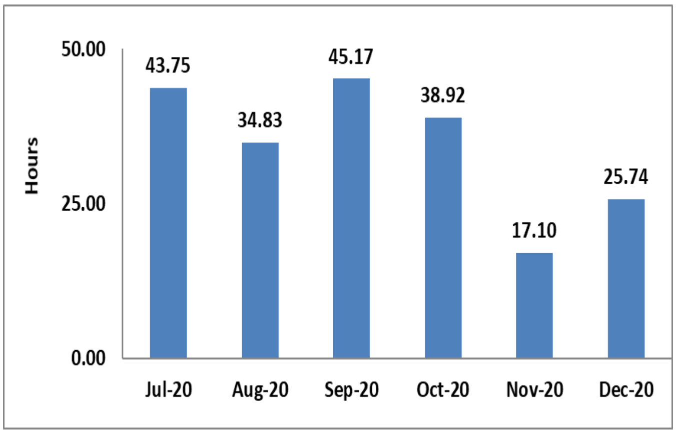

Chart -4: Total losses in hours (month wise)

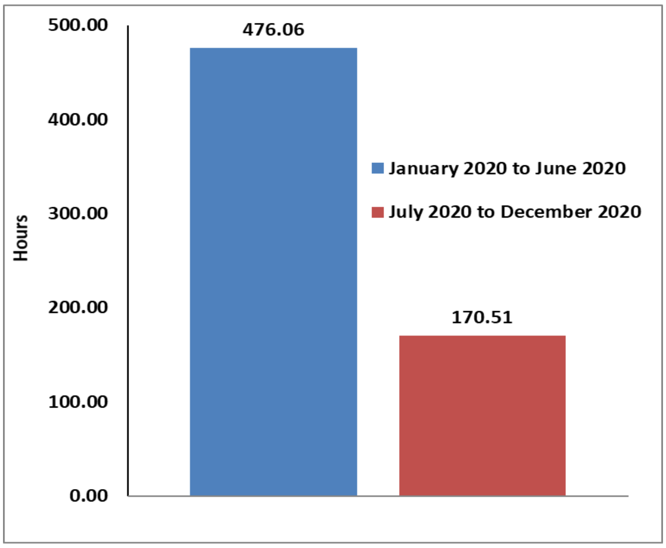

Chart -5: Total losses (Before and After)

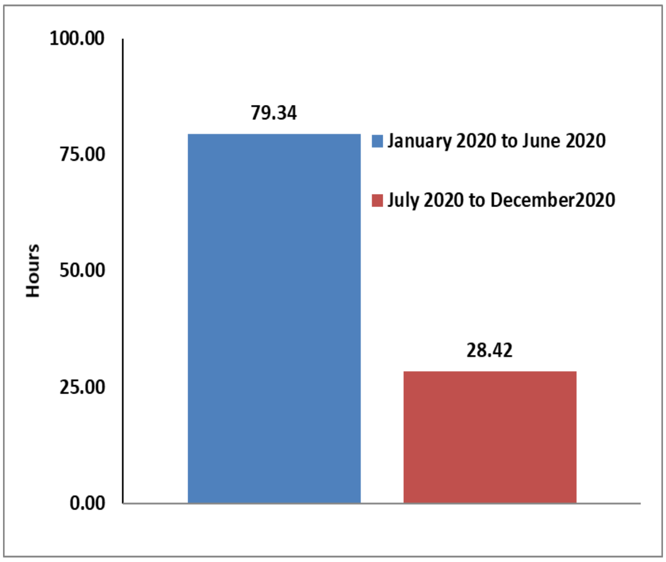

Chart-6: Monthly avg. losses (Before and after)

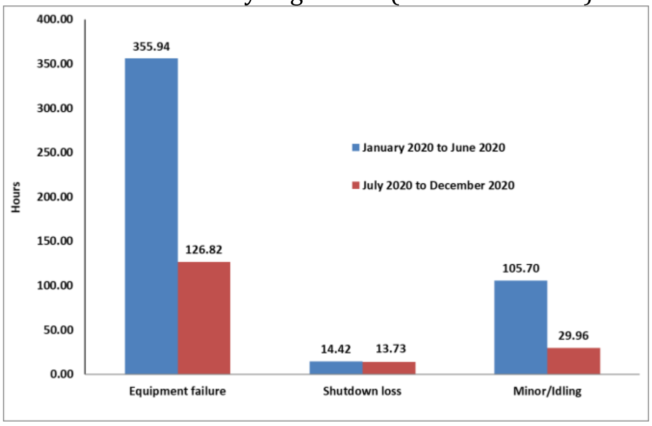

Chart-7: Losses in 6 months (loss wise)

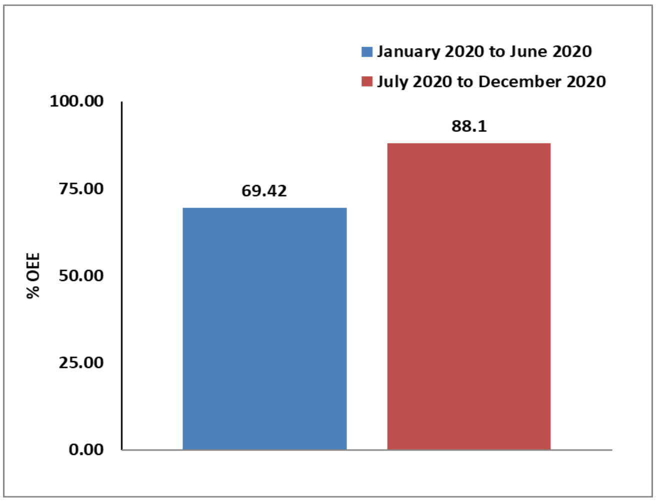

Chart-8: %OEE (Before and After)

It is evident from these charts that after detailed analysis of losses, after implementation of several kaizens and best practices adopted under the focused improvement (KK Pillar) all types of losses have been decreased drastically. However, some more attention are required to make these losses zero which is the ultimate goal of TPM.

It is clear from the charts that losses have been decreased up to 170.52 hour from the previous level of 476.06 hours. Whereas monthly avg. losses have been reduced up to a level of 28.42 hours from previous 79.34 hours. During these 6 months, equipment failure loss is decreased from 355.94 hours to 126.82 hours in 6 months. There are increases in availability and performance rate as the OPE has been increased by 29.6% and reached to a level of 88.1% (earlier it was 69.42%).

6. CONCLUSIONS

- The successful improvement of OEE depends on the elimination of 16 types of losses through Kobestu Kaizen (focussed improvement). The key factors for this implementation are workers involvement and top management support.
- To improve productivity, it is essential to improve the performance of the manufacturing systems. The desired production output is achieved through high equipment availability, which is influenced by equipment reliability and maintainability.
- OEE is a structured continuous improvement process that strives to optimize production effectiveness by identifying and eliminating losses associated with equipment and production efficiency throughout the production system life cycle through active team-based involvement of employees across all levels of the operational hierarchy by performing kaizens and adoptions of best practices.
- The average value of OPE of SAF Plant was 69.43% with an availability of 82-83%, performance rate 82-86%, and quality rate 100%. OPE values of the plant was below the standard OEE value in the world, which is 85%. The main factor influencing the low OEE value is the equipment failure with a percentage of 75%. Other factors that cause losses are 22% (idle and minor stoppage) and 3% (shutdown losses).
- After the detailed analysis of losses, considering suitable corrective actions in form of focused improvement kaizens and adoption of best practices would eliminate / stop the losses and increase OPE / OEE drastically.
- It is expected that this study would help people to visualize and understand the losses elimination and would help the industries more productive.

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