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MAINTENANCE COST ANALYSIS OF MECHANICAL COMPONENTS IN THE AGROCHEMICAL INDUSTRY

Sanjay Bajgotra, Sangam Sangral, Gurtej Singh, Sanjeev Gupta
Department of ME
GCET, Jammu
J&K, India

Abstract— **This study evaluates the total maintenance cost of mechanical components used in the agrochemical industry, focusing on identifying cost drivers, optimizing strategies, and analyzing performance factors. Key findings include differences in maintenance costs for 1000g and 500g Stock Keeping Units (SKUs) over three years from January 2021 to December 2023, highlighting significant trends in Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), and maintainability. The analysis integrates preventive, predictive, and corrective maintenance strategies, offering actionable insights to minimize costs and improve equipment reliability. This paper provides a framework for efficient resource allocation, reduced downtime, and enhanced operational efficiency.**

Keywords—**Maintenance cost, MTBF, MTTR, Availability**

I. INTRODUCTION

The agrochemical industry relies heavily on efficient machinery to maintain high productivity and operational reliability. However, the maintenance of these mechanical components often poses significant challenges, primarily in cost and downtime. Effective maintenance strategies are not just a necessity but a critical determinant of long-term operational success. Maintenance cost analysis offers organizations an opportunity to evaluate the financial implications of different maintenance strategies, enabling them to optimize their processes. This research focuses on examining maintenance strategies and their cost-effectiveness for pick-fill-seal machines used in packaging operations for 1000g and 500g Stock Keeping Units (SKUs). By analyzing both direct and indirect costs, this study aims to uncover actionable strategies that can be implemented to minimize downtime and improve machine reliability. Analyzing maintenance costs is essential for maximizing the effectiveness, dependability, and performance of mechanical components. Because unanticipated breakdowns can result in significant downtime and repair costs, industries devote a sizable amount of their operating budgets to maintenance [1]. Reactive, preventive, and predictive maintenance are the three primary categories of maintenance procedures, and each has a unique financial impact [2]. Preventive maintenance is planned to lessen the chance of breakdowns, while reactive maintenance fixes components immediately after they fail. By using AI and IoT technology, predictive maintenance may anticipate component failures and improve maintenance schedules, which lowers costs and prolongs asset life [3]. The philosophy of Total Productive Maintenance (TPM) is to maximize production equipment's total performance and guarantee its most effective use. The effectiveness of the equipment and staff involvement in maintenance are the major goals of this approach. Increasing productivity and determining the best price. The objective is to save expenses, shorten lead times, and improve product quality throughout the equipment lifecycle. Every employee must be dedicated to this philosophy, which is implemented at all organizational levels [4-6]. The TPM's guiding principle is to continuously seek the industrial system's optimal productivity to maximize its productive potential or get as close to zero process interruptions as feasible. The TPM approach is divided into two stages: the first is an analysis phase that primarily aims to increase the production apparatus's overall efficiency, and the second is an improvement phase that centers on the idea of self-maintenance, or the involvement of machine operators by entrusting them with the operation of their equipment [7-9]. By removing unscheduled equipment shutdowns and stoppages, waste from deteriorating machine performance decreased productivity from lowering machine speed, breaks or stops requested by inexperienced operators or a shortage of qualified staff, and lost time when starting the equipment after a planned shutdown or not, TPM aims to achieve 100% availability of production equipment for production [10]. There are several benefits to implementing TPM, including increased productivity from removing outages, micro-shutdowns, and pace loss, higher quality from increased equipment stability, and an increase in delivery rate from a simpler timetable. A decrease in the amount of work in progress (WIP) accumulated at the locations designated for this purpose to make up for machine failures, and ultimately, may result in increased employee satisfaction through higher

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output, greater responsibility and participation, and more challenging assignments [11].

The purpose of this study is to increase a key production line's availability by using the Total Productive Maintenance methodology, MTBF, MTTR, Availability, maintainability, and RPM analysis. The primary issues are found, and attempts have been made to improve the system reliability in the industry. The primary objectives of my current research work are to identify the key cost drivers and optimize maintenance strategies for mechanical components. Compare maintenance approaches (reactive, preventive, and predictive) to determine the most cost-effective strategy. Analyze reliability and failure patterns of components to reduce unplanned downtime. Propose actionable steps to enhance operational efficiency. Evaluate cost trends and provide detailed recommendations for 1000g and 500g SKUs.

II. METHODOLOGY

The methodology used in this study is a combination of the MTBF, MTTR, and FMEA approach, which is more significant than the previous studies. The research process used for analyzing the Maintenance cost of Mechanical components in the Agrochemical Industry is illustrated in Fig.1**.** The first step is issue identification, which assists in identifying the biggest maintenance expense issues. The next step is problem formulation, where direction is established by precisely defining the goals, parameters, and advantages of the research. To ensure that the research builds on earlier work, a literature review is carried out to obtain insights from past studies. The foundation for analysis is provided by the maintenance logs, downtime reports, and cost analysis data that are gathered during the data collection phase. Data processing involves classifying the gathered information, calculating important reliability measures like Mean Time Between Failure (MTBF) and Mean Time to Repair (MTTR), and evaluating risks using the Failure Mode and Effects Analysis (FMEA). These results are interpreted during the analysis and discussion phase, which also finds important insights and patterns. The study concludes by summarizing the main conclusions and offering suggestions for methods to reduce maintenance expenses. A comprehensive and iterative research process is ensured by the flowchart's integration of feedback loops between processes, which permit improvement, reassessment, and validation.

A. Data Collection Process –

Data was collected over three years (2021-2023) from pick-fill-seal machines for 1000g and 500g SKUs in an agrochemical plant, as shown in Fig. 2. Parameters included:

- Operating time (hours/day)
- Downtime (planned and unplanned)
- Maintenance costs (preventive, corrective, labor, parts, and overhead) Controlled trials compared the effectiveness of predictive vs preventive maintenance. Predictive maintenance utilized IOT sensors and data analytics, while preventive maintenance relied on regular schedules.

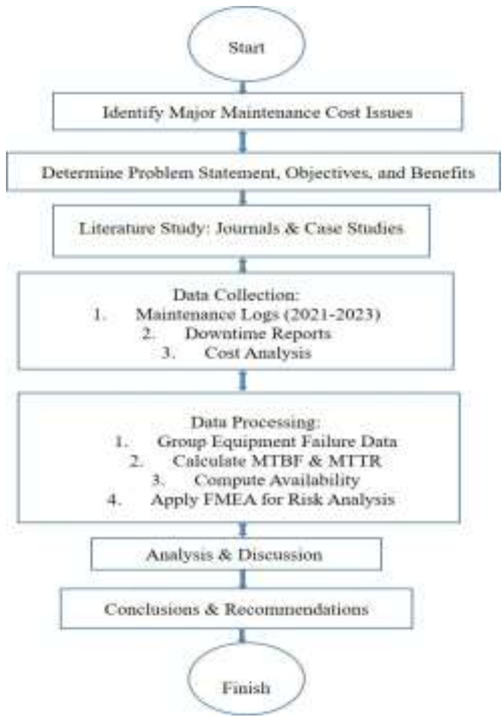

Fig. 1. Research Flow Process Chart

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On the basis of such considerations, the algorithm uses a different color image multiplied by the weighting coefficients of different ways to solve the visual distortion, and by embedding the watermark, wavelet coefficients of many ways, enhance the robustness of the watermark.

Mean Time Between Failures (MTBF): It is a key reliability metric used to measure the average time between failures of a system or component during operation. It is commonly used in maintenance and quality assurance to estimate the reliability and predict the lifespan of equipment or a system.

MTBF = Total Operation Time/No. of Failures

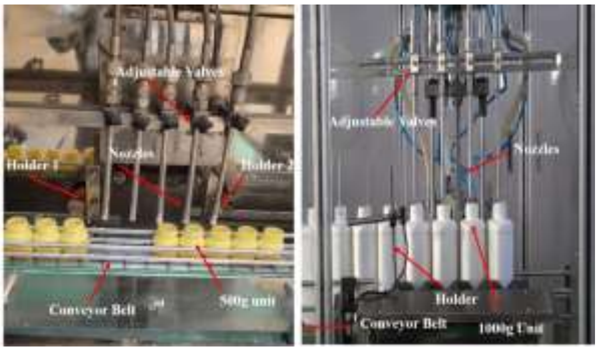

Fig. 2. Pick Fill Seal Machine used in the Agrochemical Industry for 500g and 1000g SKU

Mean Time to Repair (MTTR): It is a maintenance metric that measures the average time required to repair a system or component and restore it to full operational functionality after a failure. It is a key indicator of the efficiency of the repair process [12].

MTTR = Total Downtime for Repairs/No. of Repairs

B. Failure Mode and Effect Analysis (FMEA) & Risk Priority Number (RPN)–

According to managerial viewpoints, Failure Mode and Effects Analysis (FMEA) will be used to determine and put into practice preventative or corrective measures to lower the risk of failure and improve the product's quality and reliability. The Risk Priority Number (RPN) is a representation of the risk that emerged and could lead to failure. In FMEA, this phrase refers to a numerical value that indicates the degree of failure risk [13].

RPN= Occurrence*Detection*Severity

Maintainability: It is a metric that measures the ease and efficiency of maintaining a system, equipment, or product and also represents the percentage of time a system is available for operation and maintenance compared to the total operating time [14].

Maintainability= $\mathbf{e}^{(-MTTR/Total\ Operating\ Time)}$

Availability: It refers to the ability of a system, component, or resource to be accessible and operational when required. It is commonly expressed as a percentage, representing the proportion of time a system is functional compared to the total time needed.

Availability= Operating Time/Sum Operating Time

III. RESULTS AND DISCUSSION

The maintenance cost trends for 1000g and 500g SKUs show cost variations due to operational phases, predictive maintenance, and equipment reliability, as shown in Fig.3. While the 1000g SKU had a higher average cost (₹2, 08,101) than the 500g SKU (₹1, 84,000), both maintained availability above 96%. Fluctuations in MTBF and MTTR reflect the impact of maintenance strategies on cost efficiency and system performance.

a) For 1000g SKU:
- Average maintenance cost: ₹2 08,101 over three years.
- Average availability factor: 96.114%.
- Significant MTBF improvements were observed after implementing predictive maintenance.

b) For 500g SKU:
- Average maintenance cost: ₹1 84,000 over three years.
- Average availability factor: 96.089%.
- Lower unplanned downtime compared to 1000g SKU.

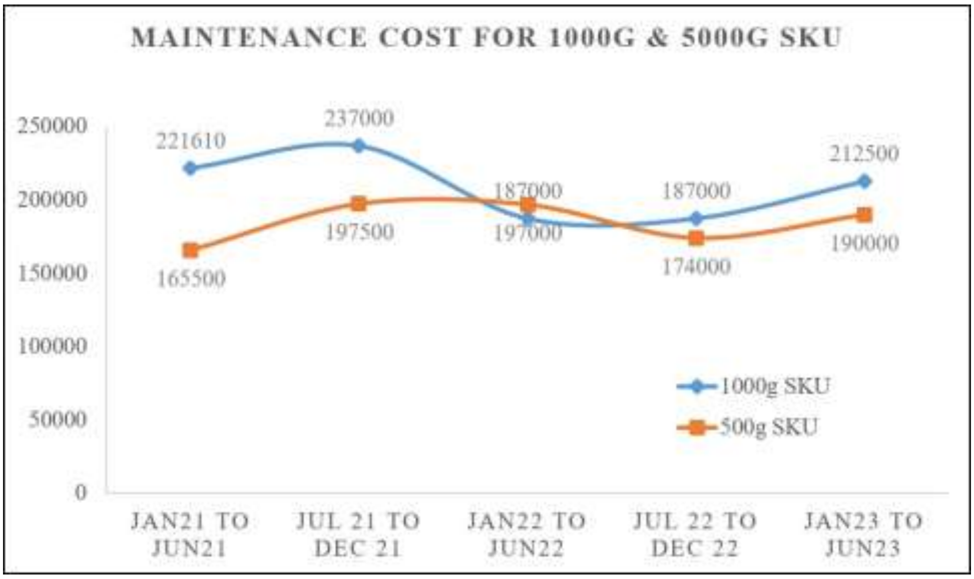

Fig.3 Maintenance cost for 1000g & 500g for the Period of 2021 to 2023

- A 6% increase in costs during the initial operational phase (2021).
- A 21% decrease in costs during 2022 due to fewer failures and smoother operations.
- An 8% increase in costs during 2023 attributed to extended operational hours.

From Fig.4, it is observed that in the value of Mean Time Between Failure, there is a 42% increase from Jan 21 to Dec 21 and a 50% decrease from Jul 21 to Jun 22 due to the negligence of the staff during monitoring. There is a 12% increase from Jan 22 to Dec 22 and a 28% increase from Jul 22 to Jun 23 due to the smooth functioning of the Pick Fill Seal Machine as per the guidelines of the maintenance.

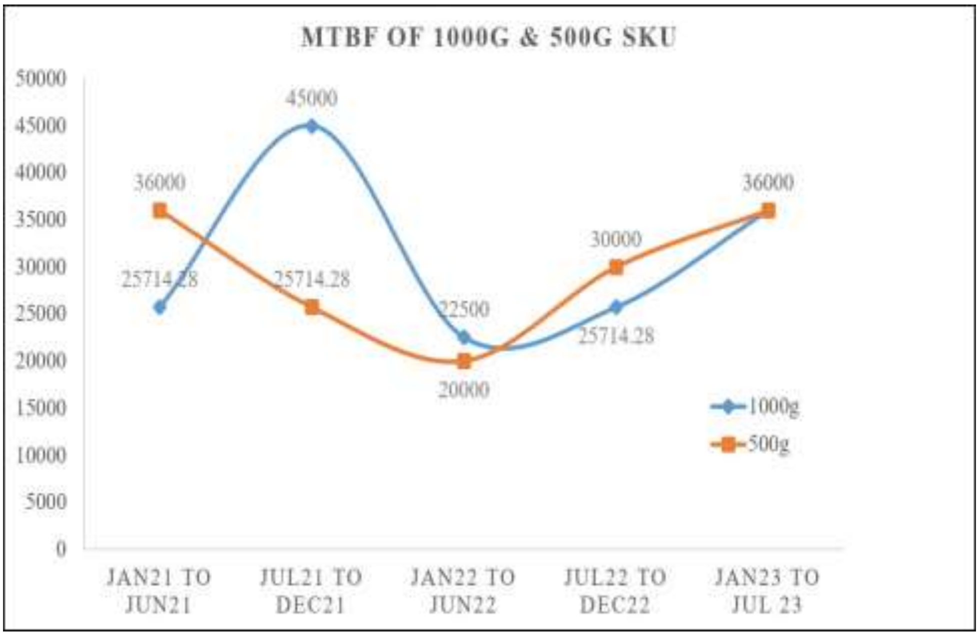

Fig.4 Mean Time Between Failures of 1000g & 500g for the period of 2021 to 2023

In the case of 500g, it is observed that in the value of Mean Time Between Failure, there is 28% decrease from Jan 21 to Dec 21, 22% decrease from Jul 21 to Jun 22, 33% increase from Jan 22 to Dec 22 and 16% increase from Jul 22 to Jun 23. The MTBF initially decreases due to early failures (infant mortality) and continues decreasing as weak components fail.

It then increases as the system stabilizes and defects are eliminated, followed by another increase due to effective maintenance or improved reliability in the later phase. This trend aligns with the bathtub curve failure pattern.

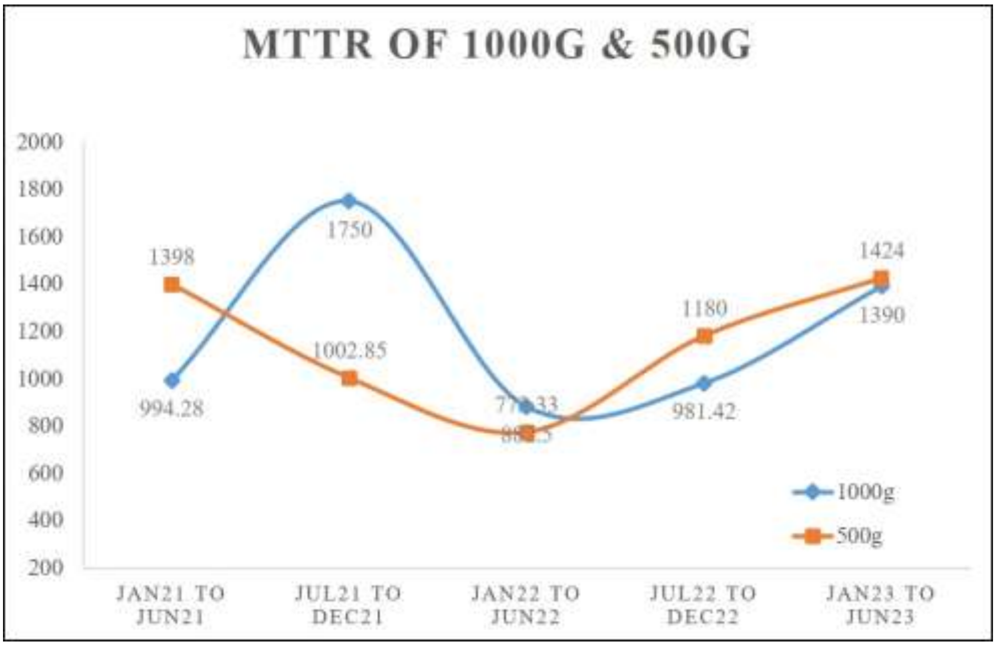

Fig.5 Mean Time To Repair of 1000g & 500g for the period of 2021 to 2023

From Fig.5, it is observed that there is a 43% increase from Jan 21 to Dec 21, a 49% decrease from Jul 21 to Jun 22, a 10% increase from Jan 22 to Dec 22, and a 29% increase from Jul 22 to Jun 23. In the case of Mean Time to Repair, there is a 28% decrease from Jan 21 to Dec 21, a 22% decrease from Jul 21 to Jun 22, a 34% increase from Jan 22 to Dec 22, and a 17% increase from Jul 22 to Jun 23. The overall maintenance cost and the variation in MTBF and MTTR calculated from January 2021 to June 2023 are shown in Table 1.

Period (From 2021-2023)	For 1000g TMC	For 500g TMC	For 1000g MTBF	For 500g MTBF	For 1000g MTTR	For 500g MTTR
Jan 21 To Jun 21	221610	165500	25714.28	36000	994.28	1398
Jul 21 To Dec 21	237000	197500	45000	25714.28	1750	1002.85
Jan 22 To Jun 22	187000	197000	22500	20000	882.5	773.33
Jul 22 To Dec 22	187000	174000	25714.28	30000	981.42	1180
Jan 23 To Jun 23	212500	190000	36000	36000	1390	1424

Table 1. Total Maintenance cost, MTBF & MTTR trends (respectively) for 1000g & 500g SKU (2021-2023).

IV.CONCLUSION

1. 1000g SKU had higher maintenance costs due to increased operational demands. 500g SKU exhibited lower maintenance costs, indicating better cost efficiency. Predictive maintenance significantly reduced maintenance expenses over time.
2. MTTR showed fluctuations, with a general improvement after implementing predictive maintenance. A significant decrease in MTTR was observed in 2022 due to proactive maintenance strategies. Reduced MTTR contributed to minimizing machine downtime and improving production efficiency.
3. MTBF improved over time, especially for the 1000g SKU, after maintenance strategies were optimized. Initial failures (infant mortality phase) led to a temporary decrease in MTBF, followed by stabilization. Effective maintenance interventions resulted in long-term reliability improvements.

From the result obtained in this research study, it is observed that in the case of 1000g SKU, the average performance factor is the same, but there is a significant change in the availability factor. In the case of 1000g SKU, there is almost a 4% reduction in the average availability factor as compared to 500g SKU, which might be due to the large production of the same material within the same period. The adoption of predictive maintenance technologies, combined with real-time monitoring and proactive measures, offers a pathway to enhanced machine reliability and efficiency. Future research should focus on leveraging advanced analytics and machine learning to refine maintenance models further and address industry-specific challenges.

In conclusion, a robust maintenance framework not only ensures the longevity of mechanical components but also contributes significantly to the profitability and sustainability of industrial operations. Implement predictive maintenance using IOT for real-time monitoring and maintain an optimized spare parts inventory to minimize downtime. Also, conduct regular training sessions for maintenance staff on advanced techniques.

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