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Analysis of Machine Effectiveness to Minimize Six Big Losses in the Palm Oil Industry

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Abstract
PT XYZ is oil industry that processes CPO from oil palm, with a daily production target of 1,000 tons and a flow rate of 41.67 tons per hour. However, in 2019, the actual flow rate fell short of expectations. This study aims to improve equipment effectiveness in the refinery division through enhanced machine maintenance. Using the OEE method, the study identifies machines with the lowest effectiveness for priority improvement. Analysis of these machines, integrating OEE, FMEA, and TPM, reveals that the Niagara filter machine has the lowest effectiveness. The OEE value is 82.14%, primarily due to breakdown losses and idling minor & stoppage losses. Based on the highest RPN values, three improvement proposals are suggested. Such as routine field checking on every shift, scheduling system for maintenance processes, and training operators about how to always ensure and control the pressure when operating the machine. So, this improvement expected to raise the OEE more to 84.16%.

INTRODUCTION

PT XYZ is a company that processes crude palm oil (CPO) derived from oil palms. CPO is oil produced by processing oil palm fruits, which is further refined to produce derivative products (Mustafa, 2022). These derivative products include cooking oil, margarine, cocoa butter, soap base, and other raw materials as per consumer demand. One of the departments playing a crucial role in this production process is the Refinery Division. This division processes CPO into semi-finished oil, known as Refined, Bleached, and Deodorized Palm Oil (RBDPO). The division adheres to specific quality standards based on consumer requests. One factor contributing to the failure to achieve the target quality specifications of the refined oil is the influence of the quality of the CPO used in production.

The production target for the Refinery Division at PT XYZ is 1,000 tons per day, with a flow rate of approximately 41.67 tons per hour. However, in 2019, the average actual flow rate did not meet the expected target. One of the contributing factors was the substandard quality of the CPO or out-of-spec material. A significant amount of out-of-spec oil can increase both production costs and time (Ginting & Ulkhaq, 2018). When CPO is of poor quality, re-filtration processes are required to achieve the desired quality standards. This results in prolonged processing times, often leading to failure to reach the production targets. Production disruptions due to equipment failures are another cause of the low actual flow rate. Machine breakdowns can occur due to insufficient routine maintenance. Machinery is a critical factor influencing production processes and the quality of the final product (Suhartini, 2020). Therefore, improvements in machine maintenance are necessary to enhance equipment effectiveness in the refinery division.

Based on previous studies, related issues to equipment effectiveness, especially in Palm Oil Industry can be measured using the Overall Equipment Effectiveness (OEE) method. This has been applied in measuring the performance of ripple mill machines (Siregar & Rizkiansyah, 2022; Syarifuddin et al., 2023), CPO processing machines (Saputra et al., 2020), and screw press machines (Wardani, 2018), among others. According to Garza-Reyes (2015), it can optimize equipment performance systematically by setting performance targets through balanced availability, performance, and quality improvements.

This study focuses on measuring the overall machine effectiveness of the refinery division, particularly in the refinery plant. This research offers several novelties compared to previous studies. First, it measures the overall machine effectiveness across the production line using the OEE method to identify the machines with the lowest effectiveness, which will be prioritized for improvement. Machines with the lowest effectiveness will be further analyzed to determine the root causes. Second, the study integrates the OEE method with Failure Mode and Effects Analysis (FMEA) to identify the highest-priority solutions. Third, the proposed design will be linked to the concept of Total Productive Maintenance (TPM). As a result, this research aims to enhance machine effectiveness in the Refinery plant and support the achievement of the company's production targets.

METHOD

This research was conducted at PT XYZ, specifically in the refinery plant. The data used in this study are secondary data from January to December 2019 and primary data from interviews with key stakeholders of PT XYZ. This research used the OEE method to analyze machine effectiveness. Figure 1 shows the research methodology and the output of each study stage.

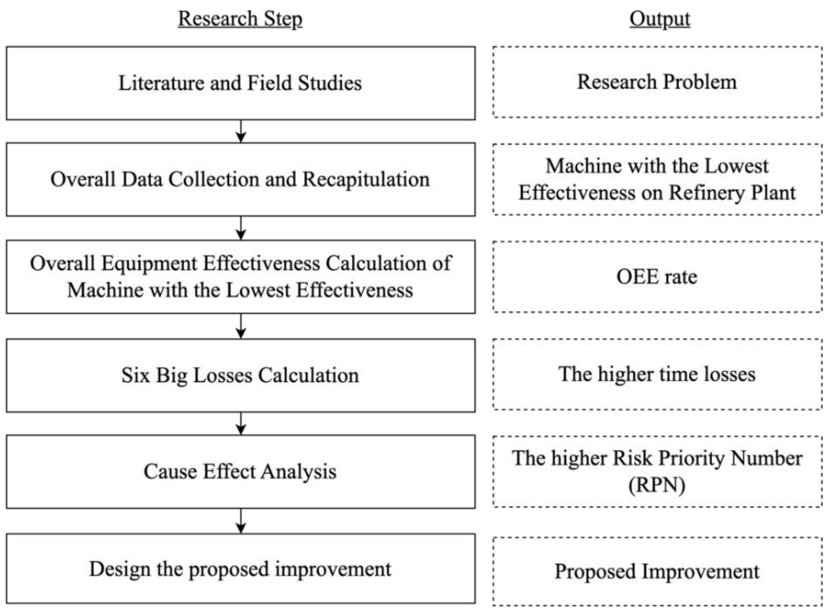

Figure 1. Research Method

Literature Review and Field Studies
The study begins with literature reviews and field observations. These provide theoretical insights and practical knowledge about machinery performance in the palm oil industry. Based on these initial findings, the research problem was then defined.

Overall Data Collection and Recapitulation
Secondary data was collected from production records, maintenance logs, and operational reports. Based on this data, the machine with the lowest effectiveness was identified and became the main object of analysis.

Overall Equipment Effectiveness Calculation of the Machine
The main object was evaluated using the OEE method. OEE was a set of metrics introduced by Seiichi Nakajima to evaluate machinery performance in a manufacturing environment (Seiichi, 1988). This metric was valuable for diagnosing issues and comparing production efficiency across different industries. Initially, OEE was developed as a core component of TPM and later became the foundation for various other industrial optimization techniques (Womak et al., 1990). OEE can be calculated by measuring the

availability of the machine or equipment, the efficiency of the process performance, and the product quality rate (Diniaty & Susanto, 2017; Widyantoro et al., 2020). This step provided the machine's OEE rate. The world-class percentage standard for OEE was determined based on the Japan Institute of Plant Maintenance or JIPM (Seiichi, 1988). The minimum standard values are set as follows: 90% for the availability rate, 95% for the performance rate, 99% for the quality rate, and 85% for the OEE rate.

Six Big Losses Calculation

The Six Big Losses framework was applied to classify efficiency losses. There were six big losses: equipment failure losses, setup and adjustment losses, idle and minor stoppage losses, reduced speed losses, defect losses, and reduced yield (Seiichi, 1988). The output of this stage was to determine which losses have the highest value and become the basis for improvement priorities.

Cause Effect Analysis

The highest time losses were used as a basis for cause-effect analysis, which was used to find the root causes of inefficiencies. Then, every failure was calculated using the FMEA, especially on the Risk Priority Number (RPN), to identify the ranks based on severity, occurrence, and detection.

Design the Proposed Improvement

Based on the analysis, an improvement plan was designed. The proposed solution aimed to reduce losses, increase efficiency, and improve the OEE score.

RESULTS AND DISCUSSION

Overall Data Collection and Recapitulation

Figure 2 illustrates the series of machines in the refinery process at PT XYZ. The process results in a semi-finished oil or RBDPO that fulfills specifications and is ready to be processed

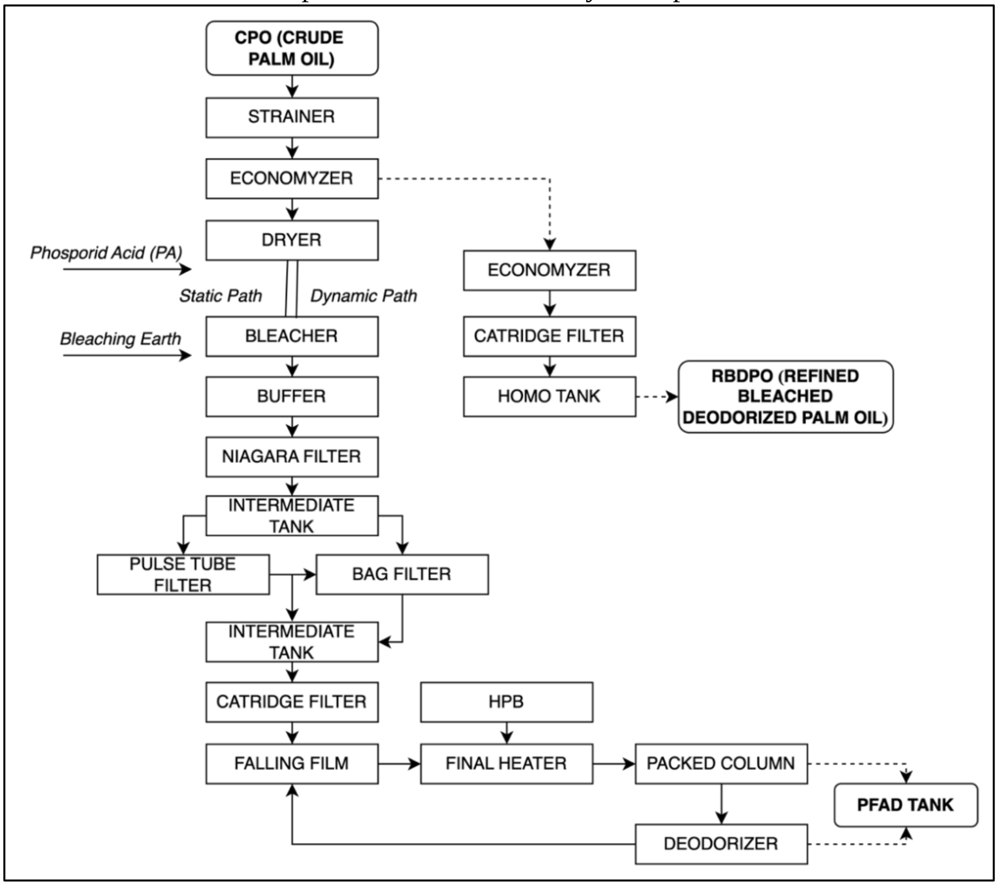

Figure 2. Refinery Process

The refinery process involves interconnected machines and can be classified into three main methods, such as degumming, bleaching, and deodorizing stages, based on Figure 2.

a. Degumming

CPO is stored in a tank and pumped into a strainer. The strainer filters out impurities such as palm fiber residues and plastic contaminants that may have entered the oil during transportation from the plantation to the storage tank. Next, the CPO is directed to an economizer, where its temperature is increased from 40-45°C to 70-80°C through a heat exchange process with RBDPO, which has a temperature of approximately 130°C. However, if the tank is empty and no RBDPO is available, the CPO temperature is raised using a Plate Heat Exchanger (PHE) heater. This temperature increase facilitates the evaporation of moisture content in the oil.

The CPO then enters the dryer to remove the moisture. Water vapor in the oil tends to bind easily with bleaching earth (BE). The more BE is consumed in binding with moisture, reducing its primary function of absorbing gums and clarifying the oil color. After drying, the CPO is pumped into the bleacher through two possible pathways: dynamic and static. The dynamic path contains a rotating rotor system, which facilitates the mixing of Phosphoric Acid (PA) at an 85% concentration and a 0.05% dosage at 3000 rpm. This high-speed mixing ensures a homogeneous and thorough blending of PA with oil. In contrast, the static pathway is used when the dynamic pathway malfunctions or when processing high-quality CPO.

b. Bleaching

Bleaching is crucial in removing unwanted impurities, such as gums, metals, color pigments, and phosphatides. These impurities, which were previously bound during the degumming process, are eliminated by adding BE in the bleacher. After adding BE, the Degummed Bleached Palm Oil (DBPO) flows into a buffer tank, allowing sufficient reaction time for BE to absorb gums and other impurities from the degumming stage. The DBPO is then directed to the Niagara filter, where several interdependent processes occur. First, the filter is filled with DBPO from the buffer tank. Then, DBPO circulates between the buffer and the Niagara filter until it reaches clarity. The separation process follows, where DBPO passes through filter leaf sheets while BE particles are retained in the filter. The next step involves draining the oil from the Niagara filter back into the buffer with the assistance of steam.

Additionally, the BE is dried using steam, known as heel removal, before the system undergoes pressure reduction (decompression). The final step involves cake discharge or disposing of the BE, which requires opening a valve and activating a vibrator to shake the filter leaf. This ensures the BE falls into a designated disposal area. Special handling is required since BE is classified as hazardous waste (B3 waste).

c. Deodorizing

After bleaching, the DBPO is temporarily stored in the intermediate tank before proceeding to deodorization. This stage is crucial for eliminating unwanted odors, free fatty acids (FFA), and volatile compounds that can affect the quality of the refined oil. First, DBPO is pumped through a pulse tube and bag filter, removing any remaining fine particles and impurities to ensure a cleaner final product. The filtered DBPO is then directed to another intermediate tank before entering the deodorization unit. Before deodorization, the oil undergoes further filtration through a cartridge filter to ensure purity. The falling film heat exchanger and final heater gradually raise the temperature to the required deodorization level, ensuring efficient removal of odor compounds.

Second, the pre-heated oil enters the packed column and is subjected to a vacuum steam distillation process. Inside the deodorizer, high-temperature steam (200-260°C) is injected under vacuum conditions to strip off volatile impurities, including free fatty acids (FFA), ketones, aldehydes, and peroxides, which are responsible for undesirable odors and flavors. The stripped impurities and free fatty acids are collected separately as by-products, while the purified oil progresses toward the final storage. The deodorized oil is divided into two significant products. The primary product stored in the RBDPO tank is used for food processing, cosmetics, and industrial applications. The second product is PFAD, which is collected in the PFAD tank and is commonly used in soap production, animal feed, and biodiesel manufacturing.

All refinery processes were generated by direct observation and interviews with relevant parties. Figure 3 shows the effectiveness of all machine performance in the refinery plant. The differences in machine effectiveness are not significantly noticeable. However, the lowest effectiveness percentage was observed in the Niagara filter machine, which has a value of 91.62%, slightly lower than the overall machine average of 92.77%. Therefore, this study focuses on analyzing the effectiveness of the Niagara filter machine in the refinery plant, which plays a crucial role in the filtration process. The refinery process involves three Niagara filter machines that operate in an integrated manner.

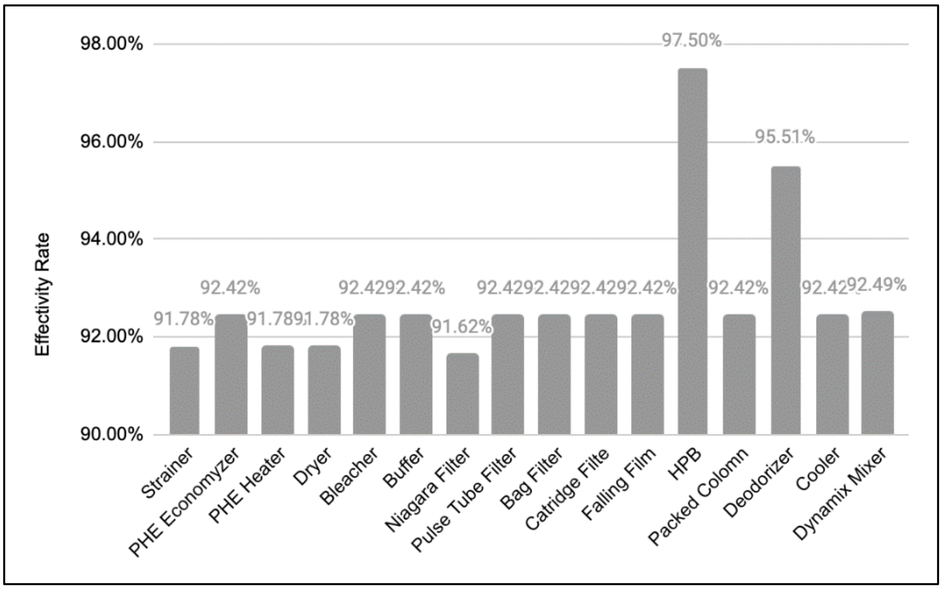

Figure 3. Effectivity Rate of Refinery Machine

OEE Calculation of the Machine with the Lowest Effectiveness

The Niagara filter machine has the lowest effectiveness percentage. Table 1 shows the data recapitulation of time and production activity from January to December 2019.

Table 1. Data Recapitulation

Period	Planned Downtime (hours)	Setup time (hours)	Breakdown time (hours)	Availability Time (hours)	Production Total ('000 tons)
Jan-19	0	0	75	25.3	744
Feb-19	0	0.25	55.5	23.6	672
Mar-19	0	0.75	50.75	26.4	744
Apr-19	0	0.25	83.5	26.1	720
Apr-19	144	0.25	90	20.3	744
Jun-19	96	0.25	42	9.9	384
Jul-19	0	0.25	21	28.5	744
Aug-19	0	0	14	29.4	744
Sep-19	0	0.25	32	25	720
Oct-19	571	0.25	69	3.5	744
Nov-19	0	0	76	24.8	720
Dec-19	0	0.75	37	26.7	744

The calculation of OEE is the result of multiplying the availability rate, performance rate, and quality rate. The OEE calculation results are used to determine the machine's effectiveness. Table 2 summarizes the data from the calculations and the OEE values graph.

Table 2. OEE Calculation

Period	*Availability Rate*	*Performance Rate*	*Quality Rate*	*OEE Rate*
Jan-19	90%	90.61%	100%	81.47%
Feb-19	92%	92.09%	100%	84.45%
Mar-19	93%	91.42%	100%	85.10%
Apr-19	88%	98.60%	100%	87.13%
Mei-19	85%	95.71%	100%	81.31%

Period	*Availability Rate*	*Performance Rate*	*Quality Rate*	*OEE Rate*
Jun-19	85%	96.45%	100%	82.30%
Jul-19	97%	94.56%	100%	91.86%
Agt-19	98%	96.60%	100%	94.79%
Sep-19	96^	86.97%	100%	83.07%
Okt-19	60%	81.08%	100%	48.63%
Nov-19	89%	92.29%	100%	82.55%
Des-19	95%	90.90%	100%	86.29%
Average rate	**88%**	**92.27%**	**100%**	**82.41%**
Standard JIPM	(≥ 90%)	(≥ 95%)	(≥ 99%)	(≥ 85%)
Interpretation	*Unsuitable*	*Unsuitable*	*Suitable*	*Unsuitable*

Based on the average OEE analysis in 2019, the OEE value was below the JIPM standard. This was due to the availability and performance rates unsuitable for the expected standards. The availability rate, which fell below the JIPM standard, was affected by several loss factors, including breakdown losses and setup & adjustment losses. Meanwhile, the performance rates unsuitable for the JIPM standard were impacted by reduced speed losses and idling and minor stoppage losses. The quality rates, however, achieved 100%, indicating that it met the JIPM standard (≥ 99%). This is because there was no rework or scrap in the oil; if it did not meet the established criteria, it would be downgraded to a lower quality and reprocessed in the subsequent fractionation stage.

Six Big Losses Calculation

The total time losses on the Niagara Filter Refinery machine amounted to 1,154.73 hours. Based on the Pareto concept, 80% of the causes should be prioritized for improvement. Therefore, a more in-depth analysis is needed for breakdown losses, idling, and minor stoppage losses. Table 3 shows the comparison of Niagara filter time losses.

Table 3. Time Losses Comparison

Six Big Losses	Time Losses (hours)	Losses	Cumulative Losses
Breakdown Losses	645.75	55.92%	55.92%
Idling Minor & Stoppages Losses	317.21	27.47%	83.39%
Reduced Speed Losses	180.52	15.63%	99.02%
Setup & Adjustment Losses	11.25	0.97%	100.00%
Rework Losses	0	0.00%	100.00%
Yield/Scrap Losses	0	0.00%	100.00%

Breakdown losses refer to losses caused by equipment failure, rendering it unusable for production. In the filtration process of the Niagara filter machine, breakdown losses occur due to incomplete filtration of the oil. It is caused by dirt that cannot be removed from the filter leaf component. As a result, the Niagara filter machine must be disassembled to clean the filter leaf. Additionally, breakdown losses are caused by power supply drops from the utility company (PLN) and damage to other machine components that disrupt the operation of the Niagara filter machine. Examples include failures in the vacuum deodorizer, HPB errors, leaks in the economizer, pump line damage, and process recirculation.

Idling minor and stoppage losses refer to equipment downtime due to temporary issues, such as intermittent operation, jamming, or idle machines. In the filtration process of the Niagara filter in the refinery-fractionation plant, minor idling and stoppage losses occur when the Niagara filter machine is idle during transitions after completing a series of processes. These processes include all bleaching processes.

Cause Effect Analysis

The cause-and-effect analysis was divided into categories: man, machine, method, material, and environment. The results were then mapped using FMEA to identify which factors are most likely to cause the low OEE values in the Niagara Filter Refinery machine. Factors with higher risk were further investigated to determine the root causes, allowing the company to minimize time losses and improve overall performance. Table 4 shows the cause-and-effect analysis and calculates results with FMEA analysis to identify the higher RPN.

Table 4. FMEA Analysis

Factor	Potential Failure Effect	Potential Failure Causes	S	O	Detection Mode	D	RPN	%RPN
Man	Incorrect Operator Settings	Performing other activities	5	8	*Visual check*	2	80	2%
		Drowsiness	7	5	*Visual check*	2	70	2%
		Laziness to read instructions	3	6	*Visual check*	4	72	2%
		Instruction with foreign language	4	4	*Visual check*	5	80	2%
	Errors in Repairs	Lack of coordination between mechanics and operators	8	6	*Function check*	6	288	8%
Machine	Bottlenecks	Insufficient routine maintenance	9	8	*Visual & function check*	6	432	12%
	Machine Idling	Machine operates with unpredictable time standards	6	7	*Function check*	7	294	8%
	Frequent Machine Disassembly	Faulty vibrator	9	4	*Visual & function check*	6	216	6%
		Inappropriate bleaching earth concentration	8	6	*Visual & function check*	5	240	6%
		Low filter quality	7	5	*Function check*	6	210	6%
		Incorrect pressure settings	9	9	*Function check*	5	405	11%
Material	Decreased Flowrate	Problems in the previous process	8	6	*Function check*	7	336	9%
		Poor quality of raw materials	8	7	*Function check*	7	392	11%
Method	Inaccurate Machine Condition Checks Using PC	Discrepancies between PC information and actual conditions	8	8	*Visual & function check*	7	448	12%
	Ineffective checklist	Different perceptions to fill the checklist between user	6	7	*Function check*	7	294	2%
Environment	Lack of Power for PC	Power outage from State Electricity Company (SEC)	9	5	*Visual check*	2	90	2%

Based on the 15 potential failure causes, three potential failure modes have the highest RPN. First, the failure mode is related to discrepancies between PC information and actual conditions due to the significant impact of such discrepancies, such as oil leakage caused by an inadequately sealed tank, despite the PC indicating that the tank is closed. Second, the failure mode of insufficient routine maintenance, which, if neglected, can lead to damage requiring repairs and reduced production availability. Third, the failure mode is related to incorrect pressure settings, which can result in torn filter leaves and incomplete oil filtration, affecting the quality of the oil.

Design the Proposed Improvement

TPM has been used in several related studies to boost productivity through equipment maintenance procedures. These include the manufacturing industry research to reduce waste activity (Prabowo et al., 2018), MSE's case study (Pandey et al., 2019), designing the key metric for garment industries (Saha et al., 2017; Uddin et al., 2021), and many related cases. TPM aims to sustain and enhance product quality by maintaining tools and supplies, including machinery and equipment (Setiawan, 2021). The operator's involvement in the maintenance process is the primary distinction between TPM and other ideas. Autonomous maintenance, planned maintenance, quality maintenance, focused improvement, early equipment management, safety, health, and environment, and TPM in administration are the eight pillars of TPM (Dutta & Dutta, 2016). Three TPM pillars were implemented in this study to build the suggested improvement scenario, which was based on the top three potential failure causes. Table 5 shows the proposed improvement scenario based on TPM Pillars.

Table 5. Proposed Improvement Scenario

Potential Failure Causes	Proposed Improvement	TPM Concept
Discrepancies between PC information and actual conditions	Routine field checking on every shift	Autonomous maintenance
Insufficient routine maintenance	Scheduling system for maintenance processes	Planned Maintenance
Incorrect pressure settings	Training operators about how to always ensure and control the pressure when operating the machine	Education and training

a. Routine Field Checking on Every Shift

Field checking involves conducting rounds throughout the plant to inspect the operating condition of machinery. Operators often neglect to perform these checks routinely, except when abnormalities or malfunctions arise. Therefore, implementing regular field checking across all machines in the refinery plant can help reduce breakdown losses that hinder production. Field checking should be performed routinely at least twice per shift by operators. They are responsible for inspecting a series of machines and pipelines from the start to the end of the process, checking for leaks, monitoring oil levels in tanks through sight glasses, applying oil to vibrators and other machines when needed, and verifying flow rates and oil quality through the PC Operator. Field checking can also be facilitated by providing an appropriate checklist to streamline the operators' tasks and reporting to the foreman. The foreman is crucial in planning the repair process and preparing the necessary tools in coordination with the mechanical team.

This solution corresponds to the Autonomous Maintenance pillar of TPM, where operators are empowered to take responsibility for routine equipment maintenance. By conducting field checks during every shift, operators can proactively identify potential issues, such as early signs of wear or malfunction, before they escalate into significant problems. This practice not only extends the lifespan of equipment but also reduces unexpected breakdowns and ensures that machines operate at peak efficiency. This is consistent with the research Guritno & Cahyana (2021) where the implementation of autonomous maintenance aims to increase the knowledge, responsibility, and skills of production operators regarding machinery, thereby improving overall productivity.

b. Scheduling system for maintenance processes

In the Refinery plant, the scheduling and maintenance system has not been implemented routinely due to the continuous nature of the production process. For the Niagara filter machine specifically, similar challenges are faced—continuous production creates a culture of waiting until issues arise before disassembly is carried out, as well as the use of new components with unknown technical lifespans. Scheduling is essential for periodic maintenance, aligning with the machine's lifespan.

Periodic maintenance of the Niagara filter components includes cleaning the filter leaf, inspecting, and replacing other components as needed. The filter leaf and Niagara holding require regular cleaning to remove BE that adheres to the surface and disrupts the oil filtration process. This maintenance should be performed every 2-6 weeks for each Niagara filter machine, with disassembly scheduled weekly on a rotating basis to clean the filter leaves. However, if a filter leaf malfunctions, additional immediate disassembly is required. Table 6 shows the scheduling scenarios for checking and maintenance processes.

Table 6. Scheduling scenarios for checking and maintenance processes

Niagara Filter Machine Component	Time Period
Filter leaf cleaning	Every 2 weeks*
O-ring replacement	During each cleaning
Niagara holding replacement	Every 6 months*
Mess filter leaf replacement	After two repairs
Pump inspection	Every 4 months*
Valve replacement	Every 6 months*
Bearing replacement	Every 6 months*
Rubber coupling replacement	Every 6 months*
Tank draining	Once a year

*It may vary depending on the technical lifespan of the components.

Tank draining maintenance is typically conducted by the company during a plant shutdown, usually during the Idul Fitri holiday. During this period, all operators disassemble and clean all machines and tanks, with operators even entering the tanks for thorough cleaning. However, tank draining can also be carried out twice a year, depending on operational requirements. A scheduling system that aligns with the Planned Maintenance pillar of TPM should be introduced. Planned maintenance focuses on creating a systematic schedule for maintenance tasks to prevent machine failure and reduce downtime. The maintenance team can ensure timely inspections, part replacements, and repairs by implementing a well-organized scheduling system, increasing equipment reliability and minimizing production interruptions. The purpose of the scheduled maintenance is also to lower production costs by reducing unplanned and unnecessary breakdowns caused by a lack of a systematic approach and to increase and maintain equipment availability (Kar, 2016).

c. Training Operators

The pressure limit set by the company for this process is 4 bar. If the pressure approaches this limit, it can cause the screen on the filter leaf to leak or tear, resulting in small particles in the oil not being filtered. This leads to the disassembly of the Niagara filter machine, increasing time losses. Therefore, pressure control must always be closely monitored. This can be addressed by routinely reminding operators through notes in the daily production instructions. Additionally, the section head should instill a sense of ownership among operators over the machines, encouraging them to operate the machine settings with careful attention to instructions and procedures. Thus, it is crucial to train operators always to ensure and control the pressure when operating the machine.

This solution aligns with the Education and Training pillar of TPM. This pillar aims to equip operators with the necessary knowledge and skills to maintain equipment effectively and safely. By providing targeted training on monitoring and controlling machine pressure, operators can ensure that machines operate within optimal parameters, reducing the likelihood of errors and enhancing overall productivity. Training also empowers operators to take more autonomy in handling routine maintenance tasks.

Based on the three proposed solutions and considering the continuous production system and similar improvements, breakdown losses are expected to be reduced by 16% (Zhang & Nakamura, 2005). As a result of these improvements, there will be an increase in the availability rate that meets JIPM standards, a reduction in percentage losses, an increase in total production, and an improvement in the OEE value of the Niagara filter machine in refinery plant, as follows on table 7.

Table 7. Comparing Value based on Proposed Improvement

Six Big Losses	Current Value before Improvement	Expected Value after Improvement (hours)
Breakdown Losses	645.75 hours	542.43 hours
Availability rate	89.04%	90.78%
%Losses	48.5%	44.17%
Production total	269427 ton	273733 ton
%OEE	82.41%	84.16%

CONCLUSION

The analysis of machine effectiveness at the refinery plant indicates that the Niagara filter machine has the lowest effectiveness. The effectiveness level or OEE rate of the Niagara filter machine in the filtration process at the Refinery Plant from January to December 2019 was 82.41%. Then, the availability, performance, and quality rates of 89.04%, 92.27%, and 100%, respectively. In terms of the six significant losses, the primary cause of the low effectiveness of the Niagara filter machine in the filtration process at the Refinery Plant was attributed to breakdown losses (55.92%), and idling minor & stoppages losses (27.47%). Based on the FMEA method, the leading causes of breakdown and idling minor & stoppage losses were discrepancies between machine information on the PC and actual conditions, lack of regular machine maintenance, and improper pressure settings. Improvement suggestions that can be implemented to enhance machine effectiveness include routine field checking, creating a scheduling system for machine maintenance processes, training operators to understand how to maintain pressure while operating the machine, and sorting raw materials based on the oil quality to be produced. These proposals were expected to increase the effectiveness to 84.16%.

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