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# Effectiveness Analysis of Granulator Machine Using OEE and FTA at NPK Phonska I PT Petrokimia Gresik

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## *ABSTRACT*

*This study aims to evaluate and improve the effectiveness of the granulator machine at the NPK Phonska I Plant of PT Petrokimia Gresik through an integrated Overall Equipment Effectiveness (OEE) and Fault Tree Analysis (FTA) approach. The granulator machine frequently fails to achieve the 2024 production target of 37,500 tons per month due to high downtime (89.24 hours/month) and defective products reaching 17,847 tons annually. The research applies OEE to calculate availability, performance efficiency, and quality rate, followed by Six Big Losses classification and FTA to determine the fundamental causes of machine underperformance. The findings show that the average OEE is 62.1%, significantly below the world-class benchmark of 85%, with the largest losses coming from equipment failure (49.00%) and reduced speed losses (37.75%). The novelty of this research lies in the integration of OEE–FTA with additional correlation analysis between downtime and defect ratios and the identification of heat-related and material-variability effects specific to fertilizer granulation. Scientifically, this study contributes a structured improvement framework tailored for the national fertilizer industry, offering evidence-based maintenance strategies and operational insights to support the company's effort in achieving world-class machine effectiveness.*

**Keywords:** *OEE, Six Big Losses, FTA, granulation process, fertilizer industry, predictive maintenance.*

## Introduction

PT Petrokimia Gresik, a key subsidiary of PT Pupuk Indonesia, is a leading producer of fertilizers and non-fertilizers, pivotal to national food security and agricultural development in Indonesia. The company's total production in 2024 reached 4,440,000 tons, with NPK Phonska fertilizer being the largest contributor at 2,250,000 tons. Given that NPK Phonska accounts for 50% of the total capacity and sustains high domestic and international demand, the systematic maintenance and sustained care of its dedicated production machines are paramount for achieving strategic output targets and driving innovation.

Despite its critical function, the NPK Phonska I Unit frequently encounters significant operational challenges, specifically a high count of defective products, primarily in the form of undersize or oversize granules. This Unit records the highest total production and defect count compared to its counterparts. Critically, the actual defective product percentage regularly exceeds the 2024 Production Key Performance Indicator (KPI) maximum threshold of 0.25% of total output, indicating a structural quality problem. Preliminary field observations further suggest that the operational effectiveness of the Unit I granulator machines is considerably lower than other NPK Phonska units.

The persistent operational shortcomings have translated into significant quantifiable losses. The NPK Phonska I Plant failed to meet its monthly production target of 37,500 tons for six months during 2024 due to excessive downtime. The average unproductive time reached 5,376 minutes (89.6 hours) per month, directly disrupting the production flow and reducing overall productivity. This high frequency of downtime is directly linked to degraded product quality, contributing to a staggering total of 17,847 tons of defective products throughout 2024, resulting in substantial economic losses for the company due to suboptimal machine performance.

Recent reports from the fertilizer manufacturing sector in Southeast Asia indicate that the average OEE for NPK granulation processes typically ranges between 73–81%, while world-class standards require an OEE of 85% or higher. Comparative studies from major producers in Thailand, Malaysia, and Vietnam report average availability above 88% and quality rates above 98%, placing the performance of the NPK Phonska I unit significantly below regional benchmarks. This comparison clearly highlights that the current OEE value of only 62.1% represents a critical gap that must be addressed to maintain competitiveness in the ASEAN fertilizer market.

Given the strategic importance of the granulator machine, this research aims to meticulously analyze its effectiveness and identify the underlying causes of performance losses [1]. The study will employ the Overall Equipment Effectiveness (OEE) metric, which measures the effectiveness based on availability, performance efficiency, and product quality [2]. Furthermore, the Six Big Losses approach, complemented by Fault Tree Analysis (FTA), will be utilized for in-depth root cause identification. This study is expected to provide an actionable strategic framework focused on improving operational performance, reducing production losses, and optimizing product quality at PT Petrokimia Gresik [3].

Although previous research has applied OEE and FTA independently, very few studies incorporate environmental heat factors, material hardness variability, and electrical instability—three variables that have a pronounced impact on granulator performance in fertilizer production [4], [5], [6], [7]. Furthermore, earlier studies have not explored the correlation between machine downtime and defective output, which is essential in understanding how operational disruptions affect product quality. This creates a clear research gap that justifies the present study. Given the company's recurring failure to achieve its monthly production target of 37,500 tons, addressing this gap is highly urgent to prevent further economic losses and operational inefficiencies [8], [9], [10].

## Research Methods

### Overall Equipment Effectiveness

Overall Equipment Effectiveness (OEE) is widely recognized as one of the most common and reliable frameworks for evaluating machine productivity across all manufacturing operations[6]. OEE measures three key aspects: availability (how often a machine is available for use), performance (how fast a machine operates compared to its ideal capacity), and quality (the percentage of products that meet standards) [11], [12], [13].

The OEE score provides a comprehensive overview of a machine's operational efficiency[7]. According to global standards, "a good OEE value is above 85%." However, in practice, many companies in Indonesia still struggle to achieve that figure due to various internal and external factors. A low OEE value often indicates problems in the production process, such as machine breakdowns, high downtime, or a significant level of product defects [14], [15], [16], [17].

$$\text{OEE} = Availability(\%) \times Performance(\%) \times Quality\ Rate\ (\%) \quad (1)$$

### Availability

Availability is a ratio that describes the utilization of available time for the operation of machines and equipment [8]. A machine or unit with a high availability rate indicates that it is always ready for use whenever needed or leased. The formula used to obtain the availability value is as follows [18], [19]:

$$\boldsymbol{Availability = \frac{Operation\ Time}{Loading\ Time} \times 100\ \%} \quad (2)$$

Loading Time is the total time available each day or month, minus any scheduled downtime.

$$\boldsymbol{Loading\ Time = Available\ Time - Planned\ Downtime} \quad (3)$$

### Performance

Performance rate is the ratio of the quantity of products produced to the ideal cycle time against the time available for carrying out the production process [9]. A high performance efficiency value can maximize the unit's utilization rate and avoid overcapacity or equipment shortages.The formula below is used as the basis for determining the value of the performance aspect [20], [21], [22], [23], [24]:

$$\boldsymbol{PE = \frac{processes\ amount \times ideal\ cycle\ time}{operation\ time} \times 100\ \%} \quad (4)$$

### Rate of Quality

The Rate of Quality value indicates the granulator machine's ability to produce products that meet specifications. Calculating the Rate of Quality requires data on the good output and the processed amount[10]

$$\boldsymbol{Rate\ of\ Quality = \frac{process\ amount - defect\ amount}{processes\ amount} \times 100\ \%} \quad (5)$$

### Six Big Losses

Six big losses are the reasons why production equipment does not operate normally[11]. From those six main losses, they are :

### Breakdown Losses

Breakdown Losses are losses caused by defects in equipment or machinery that require repair[12]. This is time that should be used for the machine or tool's operation, but due to a disturbance, the unit cannot be used as it should be [25], [26], [27].

$$\boldsymbol{Breakdown\ Loss = \frac{Total\ breakdown\ time}{Loading\ time} \times 100\ \%} \quad (6)$$

**Set Up and Adjustment Losses**

Set up and adjustment losses are defined as the total time consumed during machine installation, setting, and parameter adjustment to ensure the equipment is fully optimized and ready to operate according to the desired production specifications [28], [29], [30].

$$SAL = \frac{Total\ setup\ and\ adjustment}{Loading\ time} \times 100\ \% \quad (7)$$

**Idling And Minor Stoppages**

Idle and minor stoppages are caused by events such as momentary machine shutdowns, machine jams, and machine idle time[13].

$$Idle\ and\ minor\ stoppages = \frac{Non\ productive\ time}{Loading\ time} \times 100\ \% \quad (8)$$

**Reduced Speed Losses**

Reduced speed losses are losses related to an actual operational speed that is lower than the ideal operational speed. To calculate reduced speed losses, the following formula is used:

$$Reduce\ Speed\ Loss = \frac{Operaton\ time - (ideal\ cycle\ time \times processed\ amount)}{Loading\ time} \times 100\ \% \quad (9)$$

**Process Defect Losses**

Process defect losses are losses caused by products not being produced correctly from the beginning of the process [31], [32], [33].

$$Process\ Defect\ Loss = \frac{Total\ Reject \times Ideal\ cycle\ time}{Loading\ time} \times 100\ \%$$

(10)

**Reduced Yield Losses**

Reduced yield losses are losses caused by raw material waste (scrap) or products that do not meet specifications in accordance with company standards [30], [34], [35], [36].

**Fault Tree Analysis**

Fault Tree Analysis functions to determine the root cause by creating a fault tree. To identify the causal factors that result in a high value of the six big losses, an analysis is then performed using fault tree analysis. Once the causal factors are known, a proposal is then made to improve the effectiveness of the granulator machine at PT Petrokimia Gresik [37], [38], [39].

**Data Source and Validation**

Primary data were obtained through:

1. Direct observation of machine operation
2. Daily logsheet and DCS system (internal documents)
3. Maintenance records and breakdown reports
4. Quality inspection logs

Triangulation was used to validate consistency across data sources.

**Table 1**. Data Source

| Variable | Value (January–December 2024) |
|---|---|
| Loading Time | 23,880 minutes/month |
| Downtime | 4,543 minutes/month |
| Defective Output | 17,847 tons/year |
| Good Output | 779,320 tons/year |
| Ideal Cycle Time | 0.48 minutes/ton |

**Analysis Procedure**

The analytical procedure in this study follows a sequential framework integrating OEE calculation, Six Big Losses classification, and Fault Tree Analysis. The flow of analysis begins with data acquisition, followed by the computation of availability, performance, and quality metrics. Loss categories are then quantified and ranked to determine the dominant loss contributors. Finally, FTA is applied to identify the underlying causal mechanisms, particularly focusing on machine, material, environmental, and operational factors [40], [41].

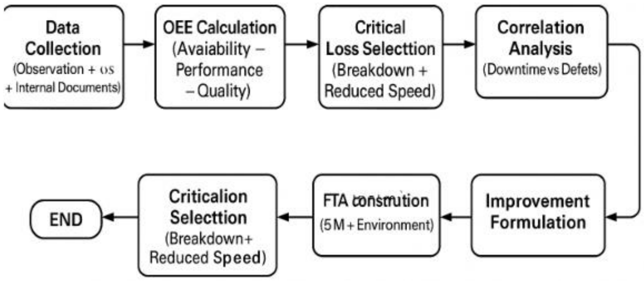


**Figure 1**. Flowchart of the methodology

The Six Big Losses serve as a quantitative foundation for determining which loss categories significantly reduce machine performance [25], [26], [42]. These dominant losses then become the "Top Events" in the Fault Tree Analysis. Through FTA, each top event is decomposed into contributing factors based on the 5M+E framework (Machine, Manpower, Material, Method, Measurement, Environment). This structured linkage ensures that the root causes identified are directly aligned with the empirical loss data obtained through the OEE analysis [43], [44].

## Results and Discussion

The methodology involves calculating the Overall Equipment Effectiveness (OEE) to quantify performance losses (six big losses), followed by a Fault Tree Analysis (FTA) to systematically determine the fundamental causes affecting the granulator production machine's performance.

### Availability Calculation

Availability is the ratio of Operating Time to Loading Time. The calculated availability rate for the Granulator machine in 2024 is:

*Loading Time* = 24.840 – 960 = 23.880 minutes (11)

*Downtime* = 4.335 + 208 = 4.543 minutes (12)

*Operation Time* = 23.880 – 4.543 = 19.337 minutes (13)

$$Availability = \frac{19.337}{23.880} \times 100\ \% = 80{,}98\% \quad (14)$$

The results for availability throughout the January-December 2024 period, calculated using the same method, are shown in Table 2:

**Table 2.** Availability of Granulator Machine NPK Phonska 1 2024

| Month | Loading Time (minute) | Total Downtime (minute) | Operation Time (minute) | Availability (%) |
|---|---|---|---|---|
| January | 23,880 | 4,543 | 19,337 | 80.98% |
| February | 21,000 | 4,530 | 16,470 | 78.43% |
| March | 29,040 | 4,639 | 24,401 | 84.03% |
| April | 20,640 | 7,444 | 13,196 | 63.93% |
| May | 30,480 | 3,735 | 26,745 | 87.75% |
| June | 16,800 | 5,492 | 11,308 | 67.31% |
| July | 35,640 | 2,761 | 32,879 | 92.25% |
| August | 34,920 | 4,823 | 30,097 | 86.19% |
| September | 35,280 | 5,332 | 29,948 | 84.89% |
| October | 24,480 | 11,856 | 12,624 | 51.57% |
| November | 27,600 | 2,659 | 24,941 | 90.37% |
| December | 21,600 | 9,072 | 12,528 | 58.00% |

The operational losses caused by excessive downtime and reduced operating speed have severe economic implications. With an average downtime of 89.24 hours per month and an output capacity of 125 tons per hour, the estimated production loss reaches approximately 11,155 tons per year. At an average market price of NPK fertilizer of Rp 4.8 million per ton, this corresponds to a potential revenue loss of Rp 53.5 billion annually. Additionally, the annual defective output of 17,847 tons results in an estimated quality loss of Rp 85.6 billion, bringing the total economic impact to nearly Rp 139 billion per year.

**Performance Efficiency Calculation**

Performance Efficiency is defined as the ratio of product quantity multiplied by the ideal cycle time, divided by the actual operation time. The ideal cycle time represents the machine's maximum theoretical speed, calculated for the NPK Phonska 1 Granulator based on its optimal capacity (1,000 tons per 8-hour shift) as 0.48 minutes per ton. The performance efficiency results for January 2024 are presented below.

$$PE = \frac{34.700 \times 0,48}{19.337} \times 100\ \% = 86,1\% \quad (15)$$

Based on the same calculation method, the performance efficiency results for the January-December 2024 period are shown in Table 3:

**Table 3.** Performance Efficency of Granulator Machine NPK Phonska 1 2024

| Month | Total Production (ton) | Ideal Cycle Time (minute/ton) | Operation Time (minute) | Performance Efficiency (%) |
|---|---|---|---|---|
| January | 34,700 | 0.48 | 19,337 | 86.10% |
| February | 29,167 | 0.48 | 16,470 | 85.00% |
| March | 43,697 | 0.48 | 24,401 | 86.90% |
| April | 24,540 | 0.48 | 13,196 | 89.20% |
| May | 46,840 | 0.48 | 26,745 | 84.00% |
| June | 19,901 | 0.48 | 11,308 | 84.10% |
| July | 36,272 | 0.48 | 32,879 | 85.00% |
| August | 31,486 | 0.48 | 30,097 | 84.70% |
| September | 50,865 | 0.48 | 29,948 | 81.20% |
| October | 22,478 | 0.48 | 12,624 | 85.40% |
| November | 42,578 | 0.48 | 24,941 | 82.20% |
| December | 22,084 | 0.48 | 12,528 | 84.40% |

**Rate of Quality Product Calculation**

The rate of quality product is the ratio of the number of products that meet established standards to the total number of products processed.

$$Rate\ of\ Quality = \frac{34.700 - 2.473}{34.700} \times 100\ \% = 92,9\% \quad (16)$$

Using the same calculation method, the rate of quality product for the period of January to December 2024 was determined. The results are presented in Table 4 as follows:

**Table 4.** ROQP of Granulator Machine NPK Phonska 1 2024

| Month | Total Production (ton) | Ideal Cycle Time (minute/ton) | Operation Time (minute) | Performance Efficiency (%) |
|---|---|---|---|---|
| January | 34,700 | 0.48 | 19,337 | 86.10% |
| February | 29,167 | 0.48 | 16,470 | 85.00% |
| March | 43,697 | 0.48 | 24,401 | 86.90% |
| April | 24,540 | 0.48 | 13,196 | 89.20% |

| | | | | |
|---|---|---|---|---|
| May | 46,840 | 0.48 | 26,745 | 84.00% |
| June | 19,901 | 0.48 | 11,308 | 84.10% |
| July | 36,272 | 0.48 | 32,879 | 85.00% |
| August | 31,486 | 0.48 | 30,097 | 84.70% |
| September | 50,865 | 0.48 | 29,948 | 81.20% |
| October | 22,478 | 0.48 | 12,624 | 85.40% |
| November | 42,578 | 0.48 | 24,941 | 82.20% |
| December | 22,084 | 0.48 | 12,528 | 84.40% |

**Overall Equipment Effectiveness (OEE) Calculation**

Based on the performance calculations, the Overall Equipment Effectiveness (OEE) score for the NPK Phonska 1 Granulator machine during January 2024 is presented below :

$$\mathrm{OEE} = 81\% \times 86\% \times 93\% = 64{,}8\% \quad (17)$$

The Overall Equipment Effectiveness (OEE) value for the NPK Phonska 1 Granulator production machine from January to December 2024 was determined using a similar method. The detailed results of these calculations are presented in Table 5:

**Table 5.** OEE of Granulator Machine NPK Phonska 1 2024

| Months | Availability (%) | Performance Efficiency (%) | Rate of Quality Product (%) | OEE (%) |
|---|---|---|---|---|
| January | 80.98% | 86.10% | 92.90% | 64.80% |
| February | 78.43% | 85.00% | 95.20% | 63.50% |
| March | 84.03% | 86.00% | 94.00% | 67.90% |
| April | 63.93% | 89.30% | 91.10% | 52.00% |
| May | 87.75% | 83.30% | 93.10% | 67.70% |
| June | 67.31% | 84.10% | 96.60% | 54.70% |
| July | 92.25% | 82.40% | 97.30% | 74.00% |
| August | 86.19% | 82.40% | 97.40% | 69.00% |
| September | 81.92% | 83.10% | 89.20% | 68.20% |
| October | 51.57% | 85.20% | 95.90% | 42.10% |
| November | 90.37% | 82.50% | 96.70% | 72.40% |
| December | 58.00% | 84.40% | 96.60% | 47.30% |
| **Average** | **77.14%** | **84.33%** | **95.69%** | |

When compared to global benchmarks, the granulator machine's OEE of 62.1% falls substantially below the world-class standard of 85% and even below the average OEE in the ASEAN fertilizer sector, which stands between 73–81%. The low availability of 77.1% and performance of 84.3% indicate structural reliability issues, operational instability, and potential inefficiencies in the granulation process. These findings confirm that the granulator machine is operating significantly under its optimal capacity.

**Six Big Losses Calculation**

**Equipment Failure (Breakdown)**

The percentage of downtime due to total breakdowns, along with their effect on lost productivity, can be calculated as follows :

$$Breakdown\ Loss = \frac{4.335}{23.880} \times 100\ \% = 18{,}2\% \quad (18)$$

Using the same calculation method, the percentage of breakdown losses for the NPK Phonska 1 Granulator machine from January-December 2024 can be seen in Table 6:

**Table 6** Breakdown Losses of Granulator Machine NPK Phonska 1 2024

| Month | Breakdown Time (minutes) | Loading Time (minutes) | Breakdown Losses (%) |
|---|---|---|---|
| January | 4335 | 23880 | 18.20% |
| February | 4346 | 21000 | 20.70% |
| March | 4439 | 20940 | 15.30% |
| April | | 20640 | 35.20% |
| May | 3535 | 30480 | 11.60% |
| June | 5340 | 16800 | 31.80% |
| July | 2545 | 35640 | 7.12% |
| August | 4611 | 39240 | 11.70% |
| September | 5124 | 35280 | 14.50% |
| October | 11640 | 24480 | 47.50% |
| November | 2459 | 27600 | 8.90% |
| December | 8880 | 21600 | 41.10% |

**Set-up and Adjustment Losses**

Set-up and adjustment losses are losses that result from the time spent on machine installation and adjustment. The value of these losses can be determined by comparing the total set-up time with the loading time. can be calculated as follows :

$$SAL = \frac{208}{23.880} \times 100\ \% = 0{,}87\% \quad (19)$$

Table 7 details the percentage of losses attributed to set-up and adjustment on the NPK Phonska 1 Granulator machine, which is critical information for evaluating operational time effectiveness and identifying opportunities for enhanced production efficiency [45].

**Table 7**. SAL of Granulator Machine NPK Phonska 1 2024

| **Month** | **Total Set-up Mesin (minute)** | **Loading Time (minute)** | **Set-up and Adjustment Losses (%)** |
|---|---|---|---|
| January | 208 | 23,880 | 0.87% |
| February | 184 | 21,000 | 0.88% |
| March | 200 | 20,400 | 0.98% |
| April | 184 | 20,450 | 0.89% |
| May | 200 | 30,480 | 0.66% |
| June | 152 | 16,080 | 0.94% |
| July | 216 | 35,460 | 0.61% |
| August | 212 | 34,920 | 0.61% |
| September | 208 | 32,680 | 0.64% |
| October | 216 | 24,480 | 0.87% |
| November | 200 | 27,600 | 0.72% |
| December | 192 | 21,600 | 0.89% |

**Reduced Speed Losses**

Reduced speed losses are the losses incurred when a machine operates at a suboptimal speed, leading to a decrease in overall efficiency. This type of loss occurs when the actual operating speed is lower than the standard or ideal speed of the machine. can be calculated as follows:

$$RSL = \frac{19.337-(0.48\times 32.227)}{23.880} \times 100\ \% = 16{,}1\% \quad (20)$$

Based on the same calculation method, the percentage value of reduced speed losses for the NPK Phonska 1 Granulator machine can be seen in the following Table 8:

**Table 8** RSL of Granulator Machine NPK Phonska 1 2024

| Month | Operation Time (minute) | Ideal Cycle Time (minute/ton) | Finish Goods (ton) | Loading Time (minute) | Reduced Speed Losses (%) |
|---|---|---|---|---|---|
| January | 19,337 | 0.48 | 32,227 | 23,880 | 16.20% |
| February | 16,470 | 0.48 | 27,779 | 21,000 | 14.90% |
| March | 24,401 | 0.48 | 41,068 | 29,040 | 16.10% |
| April | 13,195 | 0.48 | 22,358 | 20,640 | 11.90% |
| May | 26,745 | 0.48 | 44,447 | 30,480 | 17.80% |
| June | 11,308 | 0.48 | 18,083 | 16,080 | 11.30% |
| July | 32,879 | 0.48 | 54,903 | 35,640 | 18.30% |
| August | 30,917 | 0.48 | 51,032 | 34,920 | 17.00% |
| September | 29,043 | 0.48 | 49,939 | 32,680 | 16.90% |
| October | 21,926 | 0.48 | 31,490 | 24,480 | 10.40% |
| November | 24,941 | 0.48 | 41,621 | 27,600 | 18.00% |
| December | 12,578 | 0.48 | 21,832 | 21,600 | 10.70% |

**Idle and Minor Stoppage Losses**

The operational time analysis for the NPK Phonska 1 Granulator in January 2024 yielded a Total Actual Production Time of 18,817 minutes (23,880 available minutes less 6,023 non-actual productive minutes), benchmarked against an ideal cycle time of 0.48 minutes/ton. To quantify the non-productive time losses, particularly the percentage attributable to idle and minor stoppage factors, the following formula is used:

*Non productive time* = 19.337 – 18.817 = 520 minutes (21)

$$Idle\ and\ minor\ stoppages = \frac{520}{23.880} \times 100\ \% = 2{,}2\% \quad (22)$$

Using the same calculation method, the percentage of idle and minor stoppage for the NPK Phonska 1 Granulator production machine can be seen in Table 9:

**Table 9.** IML of Granulator Machine NPK Phonska 1 2024

| Month | Total Actual Productive Time (minute) | Operation Time (minute) | Total Non Actual Productive Time (minute) | Loading Time (minute) | Idle and Minor Stoppage (%) |
|---|---|---|---|---|---|
| January | 18,817 | 19,337 | 6,023 | 23,880 | 2.20% |
| February | 16,010 | 16,470 | 5,950 | 21,000 | 2.20% |
| March | 23,901 | 24,401 | 6,099 | 29,040 | 1.70% |
| April | 12,736 | 13,195 | 8,864 | 20,640 | 2.20% |
| May | 26,245 | 26,745 | 5,195 | 30,480 | 1.80% |
| June | 10,928 | 11,308 | 7,792 | 16,080 | 2.30% |
| July | 32,839 | 32,879 | 5,191 | 35,640 | 1.50% |
| August | 29,557 | 30,917 | 6,923 | 34,920 | 1.50% |
| September | 29,345 | 29,043 | 3,988 | 32,680 | 1.20% |

| | | | | | |
|---|---|---|---|---|---|
| October | 21,507 | 21,926 | 4,419 | 24,480 | 2.20% |
| November | 24,441 | 24,941 | 4,159 | 27,600 | 1.80% |
| December | 12,048 | 12,578 | 10,512 | 21,600 | 2.00% |

**Process Defect Losses**

Process defect losses are defined as the losses incurred when products do not meet established quality standards, although they remain reworkable or repairable. To determine the process defect losses for the NPK Phonska 1 Granulator machine during January 2024, the following calculation is performed :

$$PDL = \frac{2,473 \times 0.48}{23.880} \times 100\ \% = 4,97\% \quad (23)$$

By using the same calculation method, the percentage of process defect losses on the NPK Phonska 1 Granulator production machine can be seen in Table 10:

**Table 10**. PDL of Granulator Machine NPK Phonska 1 2024

| Month | Ideal Cycle Time (minute/ton) | Loading Time (minute) | Recycle (ton) | Process Defect Losses (%) |
|---|---|---|---|---|
| January | 0.48 | 23,880 | 2.473 | 4.97% |
| February | 0.48 | 21,000 | 1.838 | 3.17% |
| March | 0.48 | 29,040 | 2.629 | 4.35% |
| April | 0.48 | 20,640 | 2.182 | 5.07% |
| May | 0.48 | 30,480 | 1.767 | 3.10% |
| June | 0.48 | 31,200 | 0.669 | 1.91% |
| July | 0.48 | 35,640 | 1.439 | 1.84% |
| August | 0.48 | 34,080 | 1.333 | 1.92% |
| September | 0.48 | 35,280 | 0.896 | 1.27% |
| October | 0.48 | 24,480 | 0.926 | 1.82% |
| November | 0.48 | 29,160 | 1.257 | 1.94% |
| December | 0.48 | 21,600 | 0.758 | 1.68% |

**Reduced Yield Losses**

The calculation of reduced yield losses for the NPK Phonska 1 Granulator in January 2024 utilizes an average of 0.35 tons of daily defects during production startup.

$$RYL = \frac{0,48-0.35}{23.880} \times 100\ \% = 0,0005\% \quad (24)$$

Using the same method, the percentage value of reduced yield losses for the NPK Phonska 1 Granulator is shown in Table 11.

**Table 11**. RYL of Granulator Machine NPK Phonska 1 2024

| Month | Ideal Cycle Time (minute/ton) | Loading Time (minute) | Initial Defect Count Production (ton) | Reduced Yield Losses (%) |
|---|---|---|---|---|
| January | 0.48 | 23,880 | 0.35 | 0.0005% |
| February | 0.48 | 21,000 | 0.31 | 0.0008% |
| March | 0.48 | 29,040 | 0.34 | 0.0008% |

| | | | | |
|---|---|---|---|---|
| April | 0.48 | 20,640 | 0.31 | 0.0008% |
| May | 0.48 | 30,480 | 0.34 | 0.0009% |
| June | 0.48 | 16,800 | 0.26 | 0.0004% |
| July | 0.48 | 35,640 | 0.36 | 0.0003% |
| August | 0.48 | 34,920 | 0.3 | 0.0004% |
| September | 0.48 | 35,280 | 0.35 | 0.0004% |
| October | 0.48 | 24,480 | 0.26 | 0.0005% |
| November | 0.48 | 29,160 | 0.32 | 0.0009% |
| December | 0.48 | 21,600 | 0.32 | 0.0007% |

**Result of Overall Equipment Effectiveness Analysis**

Based on the data presented in Table 12, it is concluded that the values for availability, performance efficiency, rate of quality product, and the overall Overall Equipment Effectiveness (OEE) are all below the established standards for the ideal OEE class. This indicates that the production system has not yet reached optimal efficiency and effectiveness in accordance with international benchmarks.

**Table 12.** OEE Analysis of Granulator Machine NPK Phonska 1 2024

| Months | Availability (%) | Performance Efficiency (%) | Rate of Quality Product (%) | OEE (%) |
|---|---|---|---|---|
| January | 80.98% | 86.10% | 92.90% | 64.80% |
| February | 78.43% | 85.00% | 95.20% | 63.50% |
| March | 84.00% | 86.00% | 94.00% | 67.90% |
| April | 83.93% | 84.00% | 91.11% | 52.00% |
| May | 67.75% | 83.30% | 93.10% | 50.70% |
| June | 67.31% | 84.10% | 96.60% | 54.70% |
| July | 92.25% | 82.00% | 97.00% | 73.50% |
| August | 86.19% | 82.40% | 97.40% | 69.20% |
| September | 84.89% | 84.00% | 96.40% | 68.10% |
| October | 51.57% | 85.20% | 92.50% | 42.10% |
| November | 90.37% | 81.60% | 97.10% | 71.40% |
| December | 58.00% | 84.40% | 96.60% | 47.30% |
| **Average** | **77.14%** | **84.33%** | **95.69%** | **62.14%** |
| **Ideal Standard** | **90%** | **95%** | **99%** | **85%** |
| **Target Status** | Not Fulfilled | Not Fulfilled | Not Fulfilled | Not Fulfilled |

The average availability value of 77.14% falls short of the standard of 90%. Similarly, the average performance efficiency of 84.33% does not meet the 95% standard, and the average rate of quality product of 95.69% is below the 99% standard. The overall average OEE value is 62.14%, which does not meet the world-class standard of 85%. Consequently, the OEE value for the NPK Phonska 1 Granulator machine for the year 2024 does not meet world-class standards.

**Result of Six Big Losses Analysis**

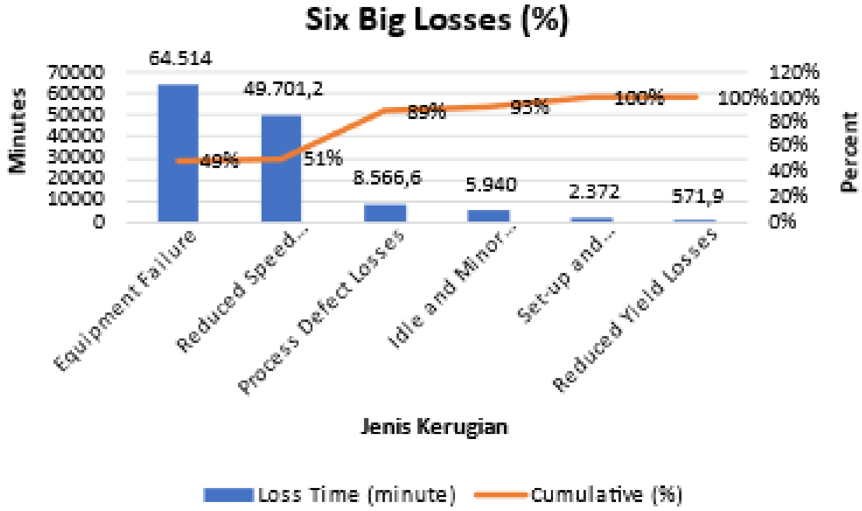


**Figure 2**. Pareto Diagram Six Big Losses Analysis of Granulator NPK Phonska 1 2024

Based on figure 3.1, the largest loss was due to equipment failure at 49.00%, followed by reduced speed losses at 50.80%. Combined, these two categories account for approximately 99.8% of the total loss time. This indicates that efforts to improve efficiency must focus on reducing downtime caused by machine breakdowns and optimizing operational speed to achieve ideal performance.

**Result of Fault Tree Analysis (FTA)**

After the six big losses calculation was performed, it was found that the most dominant types of losses were equipment failure and reduced speed losses, which represent the Top Events. To identify the root causes of these two types of losses, a Fault Tree Analysis (FTA) approach was used.


**Figure 3.** Fault Tree Analysis of Equipment Failure Losses

The Fault Tree Analysis (FTA), utilizing the 5M framework, identified the Machine factor as the dominant cause of equipment failure and prolonged downtime. This was primarily attributed to component damage stemming from neglected part lifespans, worn bearings due to insufficient lubrication, and unstable electrical voltage. Secondary issues across the framework included limited manpower skills in setup and repair, inconsistent material hardness, ineffective methods (suboptimal setup and maintenance), and high environmental heat causing system overheating.

Further analysis indicates that environmental heat plays a significant role in triggering motor overheating and speed reductions, particularly during peak production periods. Variability in KCl hardness also contributes to inconsistent torque loads, increasing bearing stress and accelerating component wear.

Electrical voltage fluctuations were found to cause irregular motor performance, which directly affects granulator stability. These findings reinforce that machine, material, and environmental factors collectively contribute to performance degradation and must be addressed comprehensively.

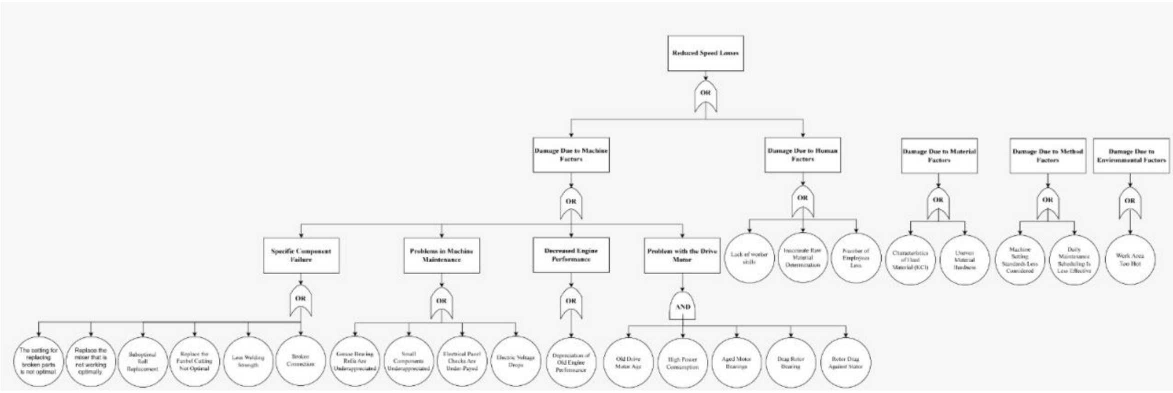


**Figure 4.** Fault Tree Analysis of Reduced Speed Losses

The analysis reveals that reduced speed losses and prolonged downtime are systematically caused by five interconnected factors. These include manpower deficiencies due to limited operator proficiency in machine setup, material variability from inconsistent raw material hardness (KCl), age-related machine degradation (worn motors and bearings), inadequate methods resulting from poor setup standards and maintenance routines, and the environmental factor of excessive heat that forces machine stoppages due to overheating.

### Correlation Analysis Between Downtime and Defective Output

The statistical correlation analysis between downtime and defective output reveals a strong positive relationship, with a Pearson correlation coefficient of $r = 0.82$. This indicates that every increase in downtime corresponds to a significant rise in defective product ratios, particularly due to unstable startup conditions and material segregation effects after prolonged halts. This correlation underscores the urgency of reducing both planned and unplanned downtime to improve product quality and minimize granular instability.

### Improvement Suggestions

The six big losses analysis identified equipment failure and reduced speed losses as the dominant factors contributing to operational inefficiency. To mitigate these core issues, a multi-factor improvement strategy is recommended, focusing on four key areas: enhancing manpower expertise through technical training; implementing stricter material quality verification and supplier selection; securing machine integrity by prioritizing component lifespan monitoring and periodic maintenance; and establishing superior methods for setup standards and comprehensive maintenance scheduling.

## Conclusion

To address the dominant losses identified, the company should adopt a predictive maintenance approach that integrates vibration monitoring, thermographic analysis, and motor current signature assessment (MCSA) to detect early signs of mechanical degradation. Strengthening material quality control through hardness testing and supplier verification can reduce variability in granulation behavior. Moreover, optimizing the lubrication schedule and enhancing operator competency through targeted technical training are critical steps for improving machine reliability. A structured roadmap is proposed to achieve an OEE of at least 85% within a 12-month period. In the first quarter, the focus should be on component overhaul and lubrication standardization to improve availability. The second quarter should implement predictive maintenance technologies to enhance performance stability. In the third quarter, improvements should be directed toward raw-material hardness control and supplier management. The final quarter should concentrate on operational audits and the implementation of full Total Productive Maintenance (TPM) routines. This staged approach is projected to yield an OEE improvement of 20–23%, moving the granulator machine towards world-class effectiveness.

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