PERFORMANCE EFFICIENCY ANALYSIS OF WATER TUBE BOILER MACHINE USING INPUT-OUTPUT METHOD AND FAILURE MODE EFFECT AND ANALYSIS

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ABSTRACT

The objective of this study is to evaluate the efficiency of boiler machine performance at PT Wilmar Nabati Indonesia through the application of the Input-Output method and Failure Mode and Effect Analysis (FMEA). The input-output method is employed to calculate the efficiency of boiler performance, based on fuel consumption data and steam production flow. Meanwhile, FMEA was employed to identify and evaluate potential failures in various boiler equipment and to ascertain the severity, recurrence, and detection values associated with operational risks. The findings revealed a notable decline in boiler machine efficiency, with some days exhibiting values below the critical threshold of 76.22%. This decline is indicated by various factors, including poor fuel quality, temperature and pressure setting errors, and potential damage to boiler components. In order to address these issues, this study recommends a thorough audit of the boiler system, the implementation of stricter monitoring procedures, and the development of a boiler machine maintenance plan. With a better understanding of the factors affecting efficiency, it is hoped that the company can improve the performance of the boiler machine and prevent further damage.

Keywords: Operations Management, Water Tube Boiler Engine, Failure Mode and Effect Analysis (FMEA), Input-Output Method, Engine Reliability.

1 INTRODUCTION

The boiler machine is one of the vital components in the industry that functions to produce steam needed in various production processes. The efficiency of boiler machine performance is very important to ensure that the energy used in the process of converting fuel into steam can be maximized [1]. Therefore, the analysis of boiler machine performance efficiency becomes very relevant in improving overall efficiency through the operation and technical inspection of the boiler machine.

This research project is concerned with the boiler machine utilized at PT Wilmar Nabati Indonesia, which serves as the primary source of steam in the production process at the palm oil processing plant. A boiler machine, also known as a steam boiler, is a device that serves as a primary source of steam generation. It is designed to heat water or other liquids, producing steam that is subsequently utilized in various production processes. Given the pivotal function of boiler machines in guaranteeing the seamless production process and operational stability of industrial facilities, which directly impact overall efficiency and productivity [1]. The boiler machine is designed to operate continuously for 24 hours per day over a two-week period. Given the continuous operation of these machines, the calculation of efficiency is of great importance [2].

In this context, boiler machine performance efficiency is not merely a performance indicator; rather, it is a pivotal factor that determines the sustainability of the production process [3]. However, this study identified a significant issue, namely a decline in boiler machine performance efficiency that can potentially disrupt the production process. Initial observations indicate that some boiler equipment has been damaged and that there is a lack of adequate operating procedures. These include instances of boiler machines working outside the standard 24 hours per month and the absence of boiler machine performance calculations. This raises an urgent need to understand the factors that cause the decline in performance.

In light of the existing issues, it is crucial to assess the performance of the boiler machine in order to gain insight into its current state and to identify potential issues before they lead to malfunctions and subsequent damage [4]. The objective of this study is to evaluate the efficiency of the boiler machine before the onset of failures or damage, with the aim of proposing improvements to enhance the overall performance of the boiler machine system. This approach is expected to enhance operational efficiency and mitigate the risk of more significant damage in the future. In order to achieve these objectives, this research employs the input-output method and the Failure Mode, Effect, and Analysis (FMEA) approach. The input-output method was employed to calculate boiler efficiency based on operational data collected over a 30-day period. Additionally, FMEA was utilized to identify and analyze potential failures that could occur in the boiler machinery. This approach enabled the researchers to conduct a comprehensive analysis of the boiler machine performance.

This study is not solely concerned with the outcomes of boiler machine performance; it also aims to elucidate the consequences of damage to boiler machine equipment, which can ultimately diminish the efficiency of the boiler machine itself. The efficiency and performance of a boiler are significantly affected by a number of factors, including the operational conditions and maintenance procedures employed [5]. The evaluation of boiler efficiency facilitates the identification of potential areas for improvement, thereby enhancing operational performance and reducing operational costs and environmental impacts associated with fuel use [2]. It is anticipated that this study will make a significant contribution to enhancing the operational performance of boiler machines and provide invaluable insights for the industry in the effective management and maintenance of boiler machines.

In conclusion, this research employs an analytical approach that integrates input-output and FMEA methods for the evaluation of boiler machinery performance. This approach offers a novel perspective on the efficiency of boiler performance and the impact of damage to the production process. It is therefore anticipated that this research will provide a valuable reference point for future studies and make a substantial contribution to the development of optimal practices for the management of boiler machines in industry.

2 LITERATURE REVIEW

Table 1 Literature Review

No	Author	Title	Research Objective	Conclusion
1	Fadli et al., (2020)	Analysis of Instrumentation System and Boiler Reliability with Fault Tree Analysis (FTA) and Failure Mode and Effect Analysis (FMEA)	Analyze the cause of water delay to the steam drum caused by high temperature in the boiler machine and its impact on boiler reliability during its operational life.	Reduced boiler reliability during its operational period due to significant equipment damage [4].
2	Aprilia and Hardjono, (2021)	Determining Boiler Efficiency Using the Direct Method at PT X Lumajang	Determine the efficiency of boiler performance by overcoming the limitations of data on steam flow, and provide recommendations for	It is recommended to equip each station with various instrumentation tools, such as steam flow meters, temperature gauges, and flow meters, for

No	Author	Title	Research Objective	Conclusion
			equipping the station with appropriate instrumentation.	boiler performance evaluation [8]
3	Azmia et al., (2021)	Calculation of Fuel Requirements in Boiler with Fiber and Palm Shell Composition Variations at PT Domas Agrointiprima	Calculating optimal fuel consumption to improve boiler performance efficiency by considering variations in fuel composition.	The study results indicate optimal fuel consumption in the combustion chamber to improve boiler efficiency [18].
4	Sukania and Wijaya, (2023)	Analysis of Production Machine Maintenance System Using FMEA Method at PT. X	Analyze the external and internal factors that affect boiler efficiency, and reduce waste in the use of fuel.	The analysis identified two external and internal factors affecting boiler efficiency: fuel moisture and damaged boiler components [20]

3 RESEARCH METHODS

It is of paramount importance to pay close attention to boiler machines, which are indispensable components in industrial operations, in order to guarantee their optimal functionality and dependability. In light of the pivotal role that boilers play in the production process, this study is designed to analyze the efficiency performance of boiler machines at PT Wilmar Nabati Indonesia. A systematic methodology was employed to identify the factors impeding boiler performance and to develop solutions that could enhance operational efficiency [1]. The following figure depicts the research flowchart. This is illustrated in Figure 1.

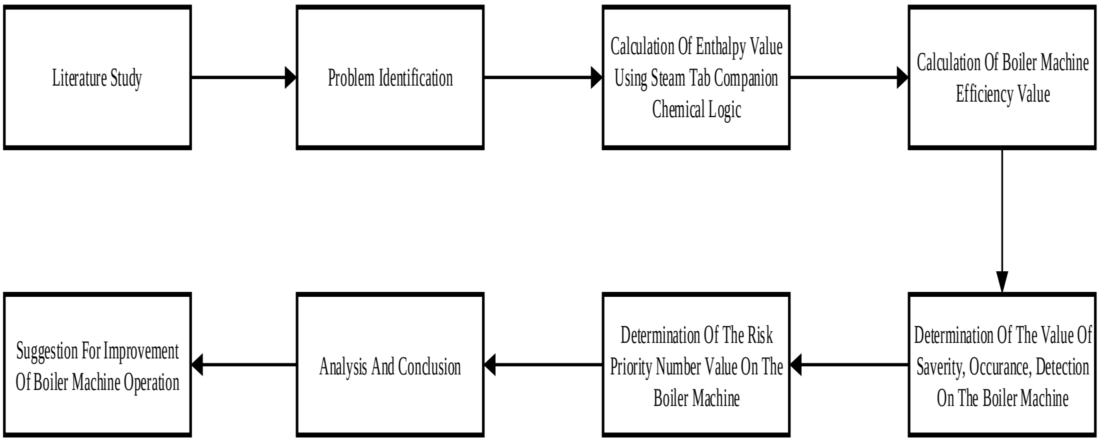

Figure 1. Flowchart of Research

The In the initial phase of this research, a comprehensive literature review is conducted to identify pertinent concepts, theories, and findings that align with the research objectives. In this process, academic sources and industry standards related to boiler machine performance, boiler machine efficiency calculation methods, and the application of Failure Mode and Effect Analysis (FMEA) are employed. The objective of this literature review is to establish a robust theoretical basis and to evaluate the findings of previous research in comparison with those of the present study [6]. The initial stage of this research involved the identification of problems. Through direct observation and a review of historical data, various issues affecting the performance of boiler machines at PT. The company Wilmar Nabati Indonesia was identified and subjected to analysis. The findings of this phase facilitate a comprehensive grasp of the underlying causes of diminished boiler machine performance efficiency and the concomitant risks inherent to boiler machine operations.

3.1 Input-Output Methods

The input-output method is employed for the calculation of boiler efficiency. This process entails the calculation of enthalpy values, which are obtained through the use of Chemical Logic's Steam Tab Companion software. This software refers to the steam table in order to ascertain the values of both the steam enthalpy (h3) and the water enthalpy (h1) within the boiler machine system [7]. This calculation is crucial for analyzing the energy balance of the boiler machine system and determining its thermal efficiency. Upon inputting parameters such as steam pressure, temperature, and steam flow rate, the software generates enthalpy values that are employed in the calculation of the overall efficiency of the boiler machine [8]. At this juncture, the boiler machine efficiency calculation is performed using the input-output approach. The enthalpy value obtained from the preceding calculation is employed to ascertain the thermal efficiency of the boiler, taking into account the energy input in the form of fuel and the energy output in the form of steam. This efficiency reflects the extent to which fuel energy is converted into heat energy in the form of steam [9]. Boiler efficiency can be calculated directly using the following formula:

$$\text{Boiler Efficiency } (\eta\beta) = \frac{\text{Heat in}}{\text{Heat of Steam Formation}}$$

$$\text{Boiler Efficiency } (\eta\beta) = \frac{\text{Ws x (h3-h1) x 24 h/day}}{\text{Wf x LHV}}$$

Description:

Ws = Steam production capacity (kg/day)
Wf = Fuel consumption (Kg/day)
h3 = Steam enthalpy (kj/kg)
h1 = Enthalpy of boiler feed/fill water (kj/kg)
LHV = Low heating value (kj/kg)

3.2 Failure Mode Effect and Analysis (FMEA)

In the application of FMEA, an analysis is conducted to evaluate potential failures in the boiler system using three main parameters: The severity (S), occurrence (O), and detection (D) of potential failures in some boiler machine equipment are evaluated [10]. The data utilized in this assessment are derived from the responses to a questionnaire that solicits information pertaining to operational and maintenance activities. It is of paramount importance to ascertain the value of each of these parameters in order to gain insight into the level of risk associated with each potential failure that may occur [11].

The term severity (S) is used to describe the level of impact that would be caused by a failure. This assessment is conducted by assigning a value on a specific scale, where higher values indicate a more significant impact on boiler operations [4]. For example, a failure that has the potential to cause significant damage to equipment or disrupt production processes would be assigned a high severity value. By understanding the severity of each potential failure, the management team is able to prioritize the corrective actions that are necessary to mitigate the risk [12].

The occurrence parameter (O) is utilized to assess the frequency with which a failure occurs. This assessment is based on an analysis of historical data and previous operational experience. A higher occurrence value indicates an increased probability of failure under specific operational conditions. By analyzing previous maintenance and incident data, the team can identify patterns and trends that may be useful in forecasting the likelihood of future failures [12].

The detection parameter assesses the system's capacity to identify failures before they result in more extensive damage. This parameter is also evaluated on a specific scale, wherein lower values indicate superior detection capabilities. In the event that a failure can be promptly identified through the implementation of an efficacious monitoring system or inspection procedure, the associated detection value will be relatively low. Conversely, if the failure is difficult to detect, the detection value will be high, indicating that there is a greater risk of more serious damage occurring

[4]. Once the aforementioned three parameters have been assessed, the Risk Priority Number (RPN) is calculated using the following formula: *RPN = Severity × Occurance × Detection*

RPN offers a means of prioritizing the handling of potential failures, whereby higher values indicate the necessity for immediate corrective action. The RPN calculation is an effective tool for identifying the most critical areas for improvement, with the ultimate goal of enhancing the safety and operational efficiency of the boiler [13].

4 RESULTS AND DISCUSSIONS

This research employs input-output and FMEA (Failure Mode and Effect Analysis) methodologies to evaluate the performance and efficiency of boiler machines at PT Wilmar Nabati Indonesia. The data set comprises fuel consumption, steam pressure, feed water temperature, steam flow, and information pertaining to boiler maintenance.

4.1 Boiler Machine Performance Calculation Results

Prior to calculating boiler performance efficiency, it is essential to ascertain the enthalpy value, which is necessary to determine the energy involved in the process of converting fuel into steam [15]. The aforementioned enthalpy values are obtained through the utilisation of the Steam Tab Companion software, which facilitates the measurement of the specific enthalpy of steam at specified pressure and temperature conditions. An understanding of enthalpy is essential for the analysis of boiler performance, as enthalpy is a key parameter in determining the effectiveness of a boiler in converting energy from fuel to steam energy [1]. Once the values of steam and water enthalpies have been determined, the input and output energies required for efficiency analysis can be calculated. The following figures illustrate the steam enthalpy (h3) and feed water enthalpy (h1), respectively.

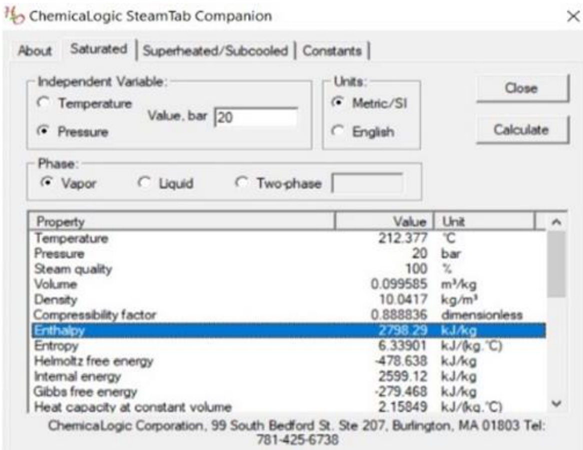

Figure 2. Steam Enthalpy (h3)

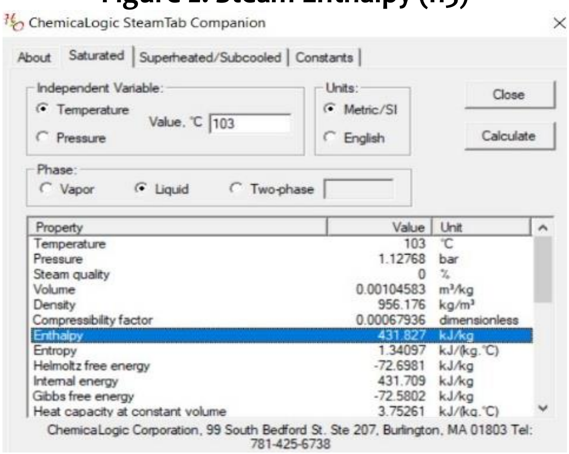

Figure 3. Feed Water Enthalpy (h1)

Following the retrieval of data pertaining to steam enthalpy (h3) and water enthalpy (h1) via the Steam Tab Companion software from Chemical Logic, the efficiency of the boiler machine's performance will be calculated using the input-output method. The data set encompasses a comprehensive range of operational scenarios, offering precise insights into the enthalpy fluctuations inherent to the boiler machine's operational cycle.

Table 2 Steam Enthalpy And Feed Water Enthalpy

Day	Steam Enthalpy (kj/kg)	Feed Water Enthalpy (kj/kg)
1	2794	432
2	2797	427
3	2799	431
4	2798	436
5	2801	431
6	2797	427
7	2795	423
8	2798	431
9	2800	436
10	2794	423
11	2798	436
12	2801	436
13	2800	427
14	2800	423
15	2799	427
16	2802	431
17	2803	427
18	2803	436
19	2803	440
20	2803	431
21	2801	431
22	2802	431
23	2803	436
24	2803	423
25	2802	423
26	2802	431
27	2803	431
28	2803	440
29	2803	436
30	2803	436

The steam enthalpy value (h3) exhibited a range of 2794 to 2803 kJ/kg across the table. Such variation may be attributed to fluctuations in boiler operating parameters, including steam pressure and temperature. An increase in steam enthalpy values is indicative of operating conditions where the steam has a higher thermal energy content, which is typically generated at elevated pressures or temperatures [16]. The consistency in the steam enthalpy values within the range of 2800 kJ/kg to 2803 kJ/kg suggests that the boiler was operating under relatively stable conditions for the majority of the measurement period.

A review of the data pertaining to water enthalpy (h1) revealed a range of values between 423 and 440 kJ/kg. Such fluctuations may be attributed to alterations in the temperature of the feed water prior to its entry into the boiler. Lower water enthalpy values are typically associated with lower water temperatures, which can result in a reduction in heating efficiency due to the increased energy required for the conversion of water to steam. Conversely, higher values indicate that the water is already in a hotter condition before entering the boiler, which can increase heating efficiency [17].

The discrepancy between the steam and water enthalpies signifies the quantity of energy that the boiler expends in transforming water into steam. The efficiency of a boiler can be calculated by comparing the energy added (as measured through the enthalpy of steam and water) to the energy that enters in the form of fuel [9]. Furthermore, fluctuations in this data may indicate potential areas for improvement, such as feed water temperature stabilization or adjustments to the operating pressure to maintain the steam enthalpy value within the optimal range.

In sum, the data presented in the table provides a robust foundation for conducting an analysis of the thermal efficiency of the boiler. By noting the enthalpy variations that occur, operators can identify optimal operating conditions and implement strategies to improve boiler efficiency. Such strategies may include resetting operating parameters or implementing improvements in the feedwater heating system.

Once the enthalpy value has been obtained, the boiler performance efficiency calculation is performed using either the direct method or the input-output method. In this latter case, the fuel consumption data (input) is divided by the steam production flow data (output), which is taken from the boiler daily log shift [18]. The results of this calculation provide an overview of the performance efficiency of the boiler machine over the 30-day period from February 2 to March 2, 2023. Additionally, they assist in identifying potential issues that may affect the optimal performance of the boiler.

Boiler Engine Performance Efficiency Calculation Day 1

$$(\eta\beta) = \frac{29.000 \text{ kg/day} \times (2794 \text{ kj/kg} - 432 \text{ kj/kg}) \times 24 \text{ h/day}}{90.000 \text{ kg/day} \times 20289.472 \text{ kj/day}} \times 100\%$$

$$(\eta\beta) = \frac{1.643.952.000 \text{ kj/day}}{1.826.052.480 \text{ kj/day}} \times 100\%$$

$$(\eta\beta) = 90.02\%$$

Boiler Engine Performance Efficiency Calculation Day 2

$$(\eta\beta) = \frac{27.000 \text{ kg/day} \times (2797 \text{ kj/kg} - 427 \text{ kj/kg}) \times 24 \text{ h/day}}{75.000 \text{ kg/day} \times 20289.472 \text{ kj/day}} \times 100\%$$

$$(\eta\beta) = \frac{1.506.600.000 \text{ kj/day}}{1.521.710.400 \text{ kj/day}} \times 100\%$$

$$(\eta\beta) = 99.00\%$$

Boiler Engine Performance Efficiency Calculation Day 3

$$(\eta\beta) = \frac{27.000 \text{ kg/day} \times (2799 \text{ kj/kg} - 431 \text{ kj/kg}) \times 24 \text{ h/day}}{80.000 \text{ kg/day} \times 20289.472 \text{ kj/day}} \times 100\%$$

$$(\eta\beta) = \frac{1.534.464.000 \text{ kj/day}}{1.623.157.760 \text{ kj/day}} \times 100\%$$

$$(\eta\beta) = 94.53\%$$

Boiler Engine Performance Efficiency Calculation Day 4

$$(\eta\beta) = \frac{27.000 \text{ kg/day} \times (2362 \text{ kj/kg} - 436 \text{ kj/kg}) \times 24 \text{ h/day}}{76.000 \text{ kg/day} \times 20289.472 \text{ kj/day}} \times 100\%$$

$$(\eta\beta) = \frac{1.530.567.000 \text{ kj/day}}{1.541.999.872 \text{ kj/day}} \times 100\%$$

$$(\eta\beta) = 99.25\%$$

Boiler Engine Performance Efficiency Calculation Day 5

$$(\eta\beta) = \frac{25.000 \text{ kg/day} \times (2801 \text{ kj/kg} - 431 \text{ kj/kg}) \times 24 \text{ h/day}}{77.000 \text{ kg/day} \times 20289.472 \text{ kj/day}} \times 100\%$$

$$(\eta\beta) = \frac{1.422.000.000 \text{ kj/day}}{1.556.289.344 \text{ kj/day}} \times 100\%$$

$$(\eta\beta) = 91.02\%$$

Once the calculation of boiler machine performance efficiency has been completed, the results are then summarized and presented in tabular form. The tabular format was selected for its capacity to present the data in a more transparent and structured manner, thereby facilitating further analysis. The table presents a variety of significant parameters, along with the resulting efficiency value derived from the calculation. The utilization of this table facilitates a more efficient data interpretation process, enables the identification of potential patterns or discrepancies, and supports decision-making related to the enhancement and optimization of boiler machine performance.

Table 3 Boiler Efficiency Calculation Results

Day	Steam Flow (ton/day)	Fuel Consumption (ton/day)	Efficiency
1	29	90	90.02%
2	27	75	99.00%
3	27	80	94.53%
4	27	76	99.25%
5	25	77	91.02%
6	27	77	98.30%
7	24	70	96.19%
8	27	87	86.89%
9	29	90	90.10%
10	28	107	73.39%
11	27	101	74.69%
12	28	80	97.91%
13	28	90	87.32%
14	27	80	94.89%
15	26	77	94.74%
16	28	92	85.35%
17	29	96	84.90%
18	29	100	81.19%
19	31	108	80.23%
20	25	95	73.83%
21	26	110	66.26%
22	27	93	81.42%
23	29	96	84.57%
24	28	87	90.60%
25	27	77	98.67%
26	28	92	85.35%
27	28	95	82.69%
28	31	103	84.12%
29	32	97	92.36%
30	30	99	84.84%

The analysis of boiler machine performance efficiency over a 30-day period from February 2 to March 2, 2023, revealed several noteworthy issues that require prompt attention. During the monitoring period, there were several instances where the efficiency of the boiler machine fell significantly below the critical threshold of 76.22%, indicating a serious issue that requires immediate attention. On the tenth day, the boiler efficiency exhibited a pronounced decline, reaching 73.39%. This decline suggests the presence of an underlying fault that is impeding the boiler machine's optimal performance. A comparable decline was observed on day 11, with an efficiency of 74.69%, indicating that the issue that manifested on the previous day had not been entirely rectified. Additionally, critical periods were observed on days 20 and 21, with efficiency levels reaching 73.83% and 66.26%, respectively, representing the lowest values recorded during this monitoring period. This indicates that there is a problem with the boiler machine components or operational disturbances that affect the overall performance.

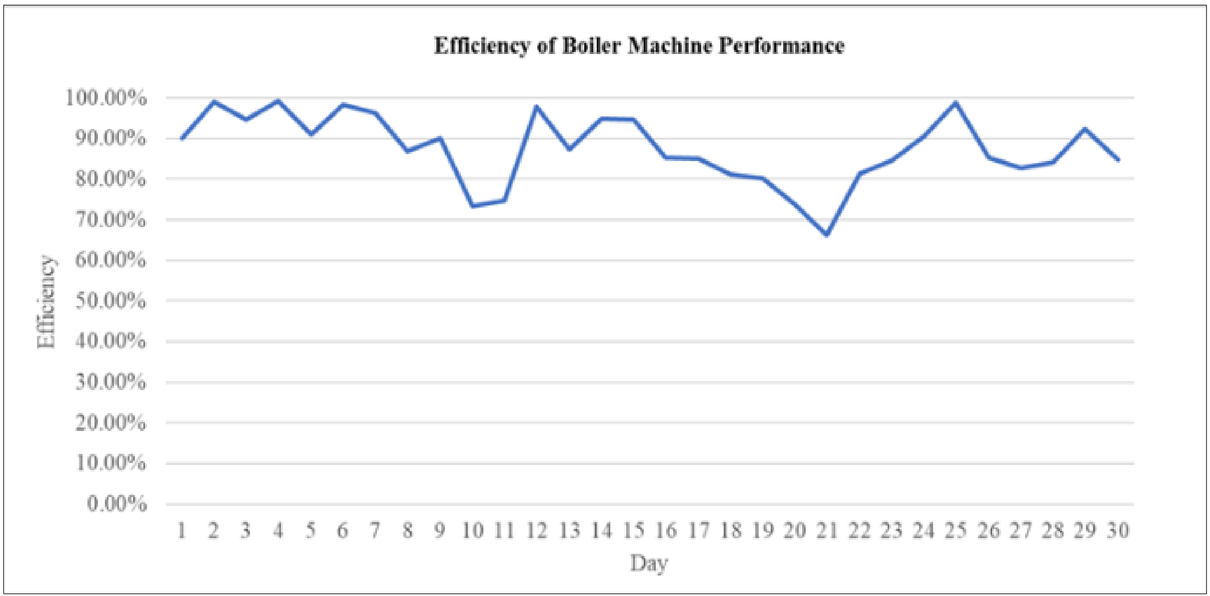

Figure 4. Analysis of boiler machine performance

A decline in boiler machine performance efficiency to below 76.22% is indicative of a significant underlying issue within the system. This decline in efficiency may be attributed to a multitude of factors, including technical issues with the boiler machine components or alterations in operational parameters [6]. Moreover, these issues not only impact operational efficiency but also have the potential to cause further damage if not addressed promptly [2]. It is therefore crucial to conduct regular evaluations and maintenance procedures in order to guarantee that the boiler machine is operating at its optimal level and to prevent significant losses.

Some of the main factors that lead to a decrease in boiler efficiency can be grouped into three categories: fuel quality, fluctuations in temperature and pressure settings, and non-optimization of maintenance procedures. Low fuel quality, for example, can result in incomplete combustion, resulting in less energy being produced than expected. In such cases, possible solutions include selecting a higher quality fuel or using a fuel mixture that improves the efficiency of the combustion process.

In addition, unstable temperature and pressure fluctuations are one of the significant factors that affect the decrease in boiler efficiency. This instability often arises from inappropriate settings of operating parameters or sudden changes in operational conditions. To address this issue, improvements to the temperature and pressure control system can be made to ensure a faster and adaptive response to changing operational conditions. Thus, temperature and pressure variations that can reduce efficiency will be minimized, so that the boiler can work more stably and efficiently.

Non-optimization in maintenance procedures is also a major contributor in the decline of boiler efficiency. Maintenance carried out irregularly increases the risk of component damage which can have an impact on the overall performance of the machine. Therefore, the implementation of periodic preventive maintenance is highly recommended. In addition, setting stricter maintenance schedules and increasing training for operators in aspects of boiler maintenance and operation are important steps that need to be considered to maintain boiler efficiency.

4.2 Failure Mode Effect and Analysis (FMEA) Calculation Results

At this juncture, a failure mode and effects analysis (FMEA) is conducted to identify potential failure modes in the operation of the boiler machine. The three variables subjected to analysis are severity, occurrence, and detection. The data is obtained from a variety of sources, including maintenance records, questionnaires, and interviews with employees at the boiler station.

Table 2 Steam Enthalpy And Feed Water Enthalpy

No	Type of damage	S	O	D	RPN
1	Boiler Pipe Leaks	5	6	8	240
2	Conecting Fuel Conveyor Regardless	4	5	7	140
3	Vibrating Fuel Fan Blower	5	4	6	120
4	Broken ID Fan Shift Bearing Block	4	5	7	140
5	Broken Blowdown Faucet	4	3	6	72
6	Fuel Fan Bearing Broken	5	4	9	180
7	Broken ID Fan Blower Ducting	5	4	7	140
8	Vibrating Elmot IDF Bearings	4	3	5	60
9	Clogged Distribution Conveyor	5	4	7	140
10	Clogged Boiler Fuel Funnel	4	3	6	72
11	Corrosion of Boiler Pendulum Inlet Plate	4	3	7	84

The results of the FMEA questionnaire calculation indicate that the most severe damage, reaching a severity level of 5, encompasses leaking boiler pipes, vibrating fuel fan blowers, damaged fuel fan shaft bearings, damaged ID fan blower ducting, and clogged distribution conveyors. These damages have a considerable impact on the efficiency and operation of the boiler, necessitating immediate attention [10]. Furthermore, while severity 4 failures, such as disconnected fuel conveyor connections and damaged ID fan shaft bearing blocks, are not as impactful as severity 5 failure modes, they nevertheless require close monitoring due to their potential to develop into more serious problems if not addressed [19].

The occurrence analysis indicates that the most prevalent failure mode is that of leaking boiler pipes, with an occurrence rate of 6. This underscores the necessity for meticulous attention to boiler pipe maintenance through regular inspections and, when necessary, material replacement [20]. Additionally, other malfunctions, such as disconnected fuel conveyor connections and broken ID fan shaft bearing blocks, have an occurrence rate of 5, which also necessitates a comprehensive evaluation. Meanwhile, malfunctions such as vibrating fuel fan blowers and clogged distribution conveyors have been identified as occurring at level 4, indicating the necessity for regular maintenance in order to reduce the frequency of these failures.

In the detection analysis, it was determined that the defects with the highest detection difficulty level include broken fuel fan shaft bearings (detection level 9), followed by leaking boiler pipes (detection level 8) and vibrating IDF motor bearings (detection level 7). Malfunctions such as disconnected fuel conveyor joints and rusted boiler pendulum inlet plates, with a detection level of 7, indicate the necessity for meticulous inspection for the purpose of early detection. In contrast, defects with the lowest detection level, such as vibrating IDF motor bearings (detection level 5), can be identified with greater ease through visual inspection and the use of vibration detection devices.

The Failure Mode and Effect Analysis (FMEA) revealed several primary risks that could potentially impact the boiler's performance. These include pipe boiler leakage, blower bearing damage, and fuel distribution conveyor blockage. Each risk is assigned a distinct Risk Priority Number (RPN), which indicates the necessity for specific mitigation actions.

For instance, a pipe boiler leak, with the highest RPN value of 240, necessitates immediate attention due to the potential for significant energy loss and disruption to production. The proposed practical solution is to conduct routine inspections of the boiler pipes and, if necessary, replace the material to reduce the potential for leakage. Furthermore, damage to the blower bearings also possesses a high RPN value (180), which can result in operational disruption due to vibration. To prevent this, a more rigorous maintenance and replacement schedule for the bearings is required.

Furthermore, the implementation of an early detection system for potential damage, such as that observed in the fuel conveyor joints or boiler inlet plates, is of significant importance. The implementation of a more effective early detection method would entail the use of vibration detection and visual inspection tools on a regular basis. The implementation of these mitigation measures, based on the results of the FMEA, is expected to maintain boiler operation efficiency, enhance machine reliability, and mitigate the risk of unplanned downtime.

The implementation of these measures enables the company to maintain optimal boiler efficiency, mitigate further damage, and support overall production process efficiency. A deeper understanding of the factors affecting efficiency allows companies to optimise the use of resources and reduce operational costs, thereby enhancing long-term productivity and profitability.

The combination of severity, occurrence, and detection indicates that damages with a very high RPN include leaking boiler pipes (RPN 240) and damaged fuel fan shaft bearings (RPN 180). These require immediate action to avoid significant impacts. Damages with an RPN value of 140, such as a disconnected fuel conveyor connection and a broken ID fan shaft bearing block, are of medium severity and require regular monitoring. Meanwhile, failures with a lower RPN, such as a vibrating fuel fan blower (RPN 120) and corrosion of the boiler pendulum inlet plate (RPN 84), warrant attention but have a relatively minor impact. In conclusion, failure modes with high RPN should be the primary focus of mitigation efforts to ensure optimal boiler performance and reduce unexpected downtime.

5 CONCLUSIONS

The analysis of the performance efficiency of the boiler machine at PT Wilmar Nabati Indonesia yielded noteworthy findings. Over the course of a 30-day period, the boiler efficiency exhibited considerable variability, with some days registering values below the critical threshold of 76.22%. The boiler exhibited peak efficiency on the second day, reaching 99%. However, this was followed by a decline on day 21, with efficiency dropping to 66%. This decline was precipitated by a multitude of factors, including the use of suboptimal fuel quality and erroneous temperature and pressure settings, which collectively signified the presence of operational deficiencies that necessitated rectification.

A Failure Mode and Effect Analysis (FMEA) was conducted to identify potential failure modes and their associated effects in the boiler equipment. The risk priority number (RPN) for pipe leaks was 240, while fan damage was assigned an RPN of 180. These values indicated the necessity for immediate intervention. These findings underscore the necessity of proactive maintenance and more rigorous monitoring to forestall further damage and ensure that the boiler machinery is operating at optimal efficiency levels.

To address these issues, comprehensive remedial measures should be implemented. These include a thorough audit of the boiler system and the development of a plan for scheduling preventive maintenance on a regular basis. Additionally, training for operators is necessary to improve their understanding of boiler operation and maintenance, enabling them to detect problems early. The implementation of enhanced and responsive monitoring procedures has the potential to markedly enhance the performance of boiler machines, thereby reducing the risk of breakdowns and ultimately supporting the smooth functioning of the production process. A more profound comprehension of the elements influencing efficiency enables organizations to optimize the utilization of resources and curtail operational expenses, thus enhancing productivity and long-term profitability.

REFERENCES

[1] A. Syahwal et al., "Analisa Kinerja Boiler Type N-750 Takuma Menggunakan Metode Berbasis Komputasi," 2022.

[2] M. Haikal and I. R. Setiawan, "Jurnal Pendidikan Teknik Mesin Undiksha Analisis Pengaruh Uap Boiler Pipa Api Kapasitas 6 Ton Pada Proses Produksi V-Belt di PT Bando Indonesia Analysis of

the Effect of 6 Ton Capacity Fire Pipe Boiler Steam on the V-Belt Production Process In PT Bando Indonesia," Analisis Pengaruh Uap, 2023.

[3] Badaruddin Soomro, Muhammad Irfan, Bilal Waseem, Sumaira Nosheen, Abdul Karim Aziz, and Hamza Butt, "Failure investigation into the boiler tubes of power plant," International Journal of Science and Research Archive, vol. 2, no. 2, pp. 028–036, May 2021, doi: 10.30574/ijsra.2021.2.2.0048.

[4] E. L. Jurnal and P.-I. Sains, "Analisa Sistem Instrumentasi dan Keandalan Boiler dengan Metode Fault Tree ANALYSIS (FTA) dan Metode Failure Mode And Effect Analysis (FMEA)," vol. 2, no. 2, pp. 2527–6336, 2020.

[5] D. Enggastiarti, D. Nofriansyah, A. Calam, P. Studi Sistem Informasi, S. Triguna Dharma, and S. Pakar Dempster Shafer, "Sistem Pakar Untuk Mendeteksi Kerusakan Pada Mesin Boiler Steam Kelapa Sawit Dengan Menggunakan Metode Dempster Shafer," Jurnal CyberTech, vol. 3, no. 3, pp. 438–444, 2020, [Online]. Available: https://ojs.trigunadharma.ac.id/

[6] S. Wilastari, P. Studi Teknika, P. I. Bumi Akpelni Semarang JlPawiyatan Luhur, and B. Duwur, "Faktor-Faktor Penyebab Menurunnya Kinerja Boiler Di PT. Papertech Indonesia," 2022. [Online]. Available: www.e-journal.akpelni.ac.id,

[7] A. J. Sihombing, "Productivity Analysis And Engineering Of Oil Palm Factory Productivity Process On Boiler Work Effectiveness At PTPN III PKS Sei Mangkei," 2021. [Online]. Available: www.iocscience.org/ejournal/index.php/JBT

[8] D. Aprilia, "Penentuan Efisiensi Boiler Dengan Menggunakan Metode Langsung Di PT X Lumajang," vol. 2021, no. 2, pp. 421–426, [Online]. Available: http://distilat.polinema.ac.id

[9] A. Suci Ningsih et al., "Efisiensi Termal Produksi Steam Ditinjau Dari Rasio Udara Bahan Bakar Solar Pada Cross Section Water Tube Boiler The Thermal Efficiency Of Steam Production In Terms Of Air Fuel Ratio Of Diesel In The Cross Section Water Tube Boiler," Jurnal Kinetika, vol. 12, no. 01, pp. 18–22, 2021, [Online]. Available: https://jurnal.polsri.ac.id/index.php/kimia/index

[10] A. Puspa Wirani, M. Janwar, and M. S. Wajdi, "Application Of The Fmea Method To Know The Factors Causing Weld Defects In The Boiler Fabrication Process," International Journal Of Social And Management Studies (IJOSMAS), vol. 2, no. 2, 2021.

[11] B. A. Nainggolan, L. Mei, and C. Wulandari, "Analisis Risiko Operasional Menggunakan Metode Fmea Di Cv. Gamarends Marine Supply Surabaya," 2021.

[12] A. Maya, F. Lubis, T. Hernawati, and S. Andri, "Analisis Nilai Efektivitas Unit High Pressure Boiler Kapasitas 50 Ton/Jampada Section Power Plant Dengan Metode Overall Equipment Effectiveness Di PT. Socimas, Kim I Medan".

[13] T. AlKautsar and A. Saputra, "Analysis of Boiler Start-Up Failure Risk with Grey FMEA and RCA Methods in Pt. PLTU Nagan Raya," Jurnal Inotera, vol. 7, no. 2, pp. 109–119, Sep. 2022,doi: 10.31572/Inotera.vol7.iss2.2022.id 181.

[14] G. Mohammad et al., "Analisis Kapabilitas Proses Mesin Tenon dan Mortise Produk Bangku Kebun Analysis Of Tenon and Mortise Machine Process Analysis Of Garden Bench Products," Metode Jurnal Teknik Industri, vol. 10, no. 1.

[15] H. Apriadi and S. Habiba, "Syahrir Habiba INNOVATIVE," Journal Of Social Science Research, vol. 4, pp. 4907–4918, 2024.

[16] R. Samosir and E. Kurniawan, "Analisa Efisiensi Isentropik Turbin Uap Pembangkit Listrik Tenaga Biomassa (PLTBM)."

[17] M. Hasudungan Baringbing and I. Nazaruddin Sinaga, "Analisis Efisiensi Water Tube Boiler Menggunakan Metode Langsung Di PT. Toba Pulp Lestari, Tbk Porsea-Sumatera UtarA," 2023.

[18] Azmia, P. N., Mirnandaulia, M., Fernandez, B. R., Marbun, N. V. M., Tarigan, E. R., & Hikmawan, O. (2023). Perhitungan Kebutuhan Bahan Bakar Pada Boiler Dengan Variasi Komposisi Fiber Dan Cangkang Kelapa Sawit Di PT. Domas Agrointi Prima. Jurnal Agroindustri, Agribisnis, dan Agroteknologi, 2(2), 14-19.

[19] A. Christine Sembiring, "Journal Knowledge Industrial Engineering Analysis of Boiler Machine Maintenance using The Reliability-Centered Maintenance Method," Journal Knowledge Industrial Engineering), vol. 11, no. 1, pp. 1–8, 2024, doi: 10.35891/jkie.

[20] I. W. S. Sukania and C. W. Wijaya, "Analisis Sistem Perawatan Mesin Produksi Menggunakan Metode FMEA di PT. X," Jurnal Energi Dan Manufaktur, vol. 15, no. 2, p. 103, May 2023, doi: 10.24843/jem.2022.v15.i02.p06.