JOURNAL OF TROPICAL AGRO-ENVIRONMENTAL
VOL. 1 NOMOR 1 TAHUN 2025
Hal: 18 – 40
Keman, A. M., & Mardesci, H. (2025)

ENERGY SCANNING IN A PALM OIL MILL

Asri Manius Keman*, Hermiza Mardesci

Magister Ilmu Pertanian Sekolah Pascasarjana Universitas Lancang Kuning
Pekanbaru - Indonesia

** asrimaniuskeman61@gmail.com*

ABSTRACT

This study analyzes energy scanning at the PTPN-IV Pabatu Palm Oil Mill to evaluate the efficiency and sustainability of energy use in palm oil processing. Field observations were conducted to assess key energy components, including water, steam, heat, electricity, and boiler fuel derived from fiber and shell. The results show that feedwater quality significantly affects boiler performance, where proper treatment successfully reduced alkalinity, hardness, and silica to acceptable levels. However, the malfunction of deaerator instruments caused a decrease in feedwater temperature to 80 °C, leading to additional fuel consumption and energy losses. Analysis of superheated steam temperature demonstrated a positive correlation with boiler and turbine efficiency, where higher temperatures improved performance. Furthermore, the underutilization of shell fuel resulted in substantial financial losses, estimated at Rp. 344,190,000 per month. The findings highlight the importance of continuous monitoring, maintenance, and optimization of thermal parameters to strengthen energy balance, minimize losses, and enhance the sustainability of palm oil mill operations.

Keyword: Energy scanning, palm oil mill, boiler efficiency, turbine performance, feedwater quality, shell fuel utilization, sustainability.

Manuscript received: July 16, 2025; revised: July 27, 2025; accepted: July 28, 2025; date of publication: August 22, 2025

I. INTRODUCTION

Palm oil is a key commodity in Indonesia’s plantation sector and plays a strategic role in national economic development. As the world's largest plantation crop, oil palm covers approximately 16.38 million hectares in Indonesia, supported by around 1,200 processing mills. As Indonesia’s primary export commodity, palm oil contributes significantly to foreign exchange earnings, job creation, and community welfare. Consequently, palm oil mills play a central role in meeting global demand for palm-based products, while also serving as a catalyst for rural economic growth.

Efficient and sustainable energy use is essential in supporting the continuous operation of palm oil mills. Energy is primarily used to generate steam through fuel combustion, which then powers turbines and other critical processing operations. To optimize performance and ensure the sustainability of crude palm oil (CPO) and palm kernel production, palm oil mills must maintain continuous, balanced operations. One method of achieving this is through energy scanning, which allows for assessment of energy performance and identification of energy imbalances, thereby enabling prioritization of corrective actions and uncovering opportunities to enhance added value.

Palm oil mills typically fall into three operational categories: (1) mills supported entirely by their own plantations, (2) mills partnered with smallholder farmers, and (3) independent mills reliant on purchased FFB (fresh fruit bunches) from external sources. Regardless of the operational model, performance optimization remains critical. Implementing an energy balance analysis is essential to increase efficiency and identify potential energy savings, particularly from biomass sources such as palm kernel shells and fibers. Effective energy management not only improves production capacity but also supports environmental and industrial sustainability by minimizing waste and reducing operational costs.

Modern palm oil mills are equipped with sophisticated machinery to ensure efficient processing and high-quality output. These mills typically include comprehensive waste management systems to reduce the environmental footprint of production. The standard processing flow includes several key stations: (1) Raw Material Selection, (2) Weighing, (3) Sorting, (4) Boiling, (5) Pressing, (6) Clarification, (7) Empty Bunch Handling, (8) Storage Tank, (9) Kernel Processing, (10) Water Treatment, (11) Power Plant, (12) Steam Boiler, and (13) Effluent Treatment.

To further enhance operational efficiency, the adoption of digital technologies and information systems is increasingly recommended. The integration of Internet of Things (IoT) technologies and enterprise resource planning (ERP) systems allows real-time data processing, accurate monitoring of energy consumption, production rates, and equipment performance. Predictive maintenance using data analytics can reduce maintenance costs by up to 20%, minimize downtime by 30%, and generate energy savings of up to 15%. Furthermore, IoT-enhanced systems have been shown to improve demand forecast accuracy by 25% and reduce production errors to just 0.001%. Despite challenges such as high initial investment costs and cybersecurity risks, these innovations offer long-term competitive advantages in quality control, operational efficiency, and sustainable resource management (Zulfadlillah et al., 2024).

However, palm oil mills still face several operational challenges. These include limited human resource capacity, inadequate electrical equipment and maintenance systems, and inconsistent utilization of biomass waste, such as palm kernel shells and fibers, as renewable energy sources. The company's commitment to adopting sustainable fuel alternatives remains a key factor in overcoming these barriers (Suprianto & Nusantara, 2024).

II. METHODOLOGY

This research employed a direct field observation method conducted over a short period to assess energy management efficiency at a palm oil mill. The study specifically examined the performance and control of various energy components, including:

- Water energy (m^3/hour)
- Steam energy (kg steam/hour)
- Heat energy (enthalpy in kcal/kg)
- Electrical energy (kWh)
- Boiler fuel energy from fiber and shell (kg/hour)
- Fuel calorific value (kcal/kg fuel)

3.1 Research Site and Timing

The observation was conducted on November 26, 2024, at the Pabatu Palm Oil Mill, operated by PTPN-IV Regional 2, located in Deli Serdang Regency, North Sumatra Province. This specific site was selected in coordination with the PTPN-IV PalmCo Plantation Sub-Holding, considering the plant's status as an idle-capacity facility, providing a unique opportunity to assess energy performance under underutilized conditions. The research was also supported academically by the ITSI Medan Educational Institute, which specializes in vocational education for the palm oil industry.

3.2 Tools and Materials

The research involved several tools and components, including; feed water system, water tube boiler, steam turbine, sterilizer, screw press, shell and fiber (as boiler fuel), material balance data, and steam table calculator.

3.3 Research Procedure

The research procedures involved direct data collection and observation of the mill's key energy-generating and energy-consuming components. Although the observed data were not entirely constant, variations across operational hours were relatively small. The methodology consisted of the following steps:

a. Field Observation

Conducted direct observation of each stage of the energy conversion process to collect data relevant to energy performance. This included; Water Treatment Plant, Boiler Unit, Steam Turbine, Sterilizer, Screw Press, Fuel usage (shell and fiber), and Overall material balance. Key parameters observed were pressure, temperature, heat capacity, and electrical output to understand the interrelationship among process units.

b. Fuel Energy Analysis

Calculated the calorific value of palm kernel shell and fiber fuel, measured the quantity of fuel input into the boiler, and determined the fuel ratio (shell to fiber) used for combustion.

c. Steam and Feed Water Analysis

Measured the feed water capacity, steam temperature, and steam output volume, followed by computation and discussion of thermal energy conversion efficiency based on these parameters.

III. RESULT AND DISCUSSION

The energy balance in a palm oil mill represents the equilibrium between various energy sources essential for the processing operations, including water, steam, heat, electricity, and boiler fuel. Among these, boiler water quality plays a crucial role in ensuring the safe and efficient generation of steam, which is the main driver of mechanical and thermal processes within the mill. To prevent scale formation, corrosion, and operational inefficiencies, boiler feedwater must meet strict quality parameters, namely pH, alkalinity, hardness, total dissolved solids (TDS), and silica, as stated in the findings of Husnawati et al., (2022) at PT. Beurata Subur Persada.

3.1 Data Collection (Verification and Validation) from Stations and Laboratory Results

3.1.1 Water Treatment Plant

In alignment with this reference, direct observations and measurements were conducted at the Water Treatment Plant of PTPN-IV Pabatu Palm Oil Mill to assess boiler feedwater quality. The water treatment system at this facility involves two main stages: (1) physical and chemical pretreatment (reservoirs, clarifiers, sedimentation tank, sand filters, and tower tanks), and (2) chemical conditioning, including cation-anion exchange and deaeration.The results of the feedwater quality analysis are presented in the Table 1.

Table 1. Boiler Feedwater Quality Parameters at Different Stages of Water Treatment

No	Parameter	Unit	After Sand Filter		After Anion Cation		Feed Tank		Information
			Real	Norm	Real	Norm	Real	Norm	
1	Turbidity	NTU	-	Max 1	-	-	-	-	Broken tool
2	pH	-	5.2	Max 6	7.52	7.5-9.5	8.51	7.5-9.5	
3	Tot. Alkalinity	Ppm	57.6	10	-	-	0	-	
4	Tot. Harness	Ppm	54.8	Min	0	Trace	0	Trace	
5	TDS	Ppm	55.6	Min	69	10-40	69	Max 100	
6	Silica	Ppm	12.5	Min	NA	Max 5	0	Max 5	

The feedwater quality for boiler operation was further assessed at three critical stages of the water treatment process: after sand filtration, after ion exchange (anion-cation), and at the feed tank prior to entering the boiler. The evaluation focused on six parameters: turbidity, pH, total alkalinity, total hardness, total dissolved solids (TDS), and silica. The results are discussed below:

a. Turbidity

Turbidity data could not be obtained due to a malfunctioning measurement instrument. However, based on industry standards, turbidity after sand filtration should not exceed 1 NTU to prevent fouling and scaling in downstream equipment. Proper instrument maintenance is crucial to ensure complete monitoring.

b. pH

The pH value improved significantly across the treatment stages, from 5.2 after sand filtration (acidic) to 7.52 after ion exchange, and finally 8.51 at the feed tank. The final pH falls within the ideal range (7.5–9.5), ensuring that the water is slightly alkaline. This is optimal for boiler operations as it minimizes the risk of corrosion in the steam generation system.

c. Total Alkalinity

Alkalinity decreased from 57.6 ppm at the initial stage to 0 ppm in the feed tank. This reduction is desirable, as high alkalinity can lead to the formation of carbonates and bicarbonates, which may cause scaling and foaming in the boiler. The complete removal at the final stage indicates effective chemical conditioning.

d. Total Hardness

Hardness dropped from 54.8 ppm after sand filtration to trace levels after ion exchange and remained trace in the feed tank. This shows that the ion exchange system effectively removed calcium and magnesium ions, preventing scale buildup and enhancing heat transfer efficiency in the boiler.

e. Total Dissolved Solids (TDS)

The TDS level remained constant at 69 ppm from the anion-cation process to the feed tank. Although slightly above the desired range of 10–40 ppm for ultra-pure boiler water, it is still within the maximum acceptable limit (100 ppm). Continuous monitoring is recommended to ensure TDS levels remain stable, as excessive TDS may cause carryover of impurities with the steam.

f. Silica

Silica content showed a significant decrease, from 12.5 ppm after sand filtration to 0 ppm at the feed tank. Silica must be minimized to avoid the formation of hard, glassy scale on turbine blades and boiler tubes. The final value complies with the maximum recommended limit of 5 ppm, indicating that silica removal processes are functioning effectively.

The overall feedwater quality at the feed tank meets the operational standards required for efficient and safe boiler operation, with the exception of the missing turbidity data. Improvements in pH, hardness, alkalinity, and silica levels confirm the effectiveness of the water treatment system. These results are in line with the findings of Husnawati et al. (2022), who emphasized that maintaining optimal boiler water quality is essential to preventing energy loss, equipment degradation, and unscheduled maintenance in palm oil mill operations.

A deaerator is a device designed to minimize the oxygen content in boiler feedwater and to preheat the water to its boiling point before it enters the boiler drum. If the deaerator temperature falls below 98°C, the boiler is forced to compensate by heating the water within the drum using additional thermal energy, typically from fiber and shell fuel. This not only increases energy consumption but also contributes to waste. In the observed case, the deaerator's monitoring instruments (manometer and thermometer) were damaged, and the feedwater temperature was measured manually, yielding a result of only 80°C, below the standard operational range of 98–100°C. The deaerator can be seen in Figure 1. Meanwhile, the addition of boiler fuel can be seen in Figure 2.

As an essential part of the boiler feedwater system, the deaerator's primary function is to eliminate dissolved gases, particularly oxygen, to prevent corrosion in the boiler, especially in the tubes. Since the deaerator operates continuously, maintaining a stable water level is crucial to ensure consistent boiler operation. According to Ramadhan & Andika (2024), implementing a fuzzy logic control system for regulating the deaerator water level enhances performance and system stability. Their study at the Muara Karang Steam Power Plant demonstrated that such a control system effectively maintained the water level within the desired range, with a settling time (ts) of 302.337 seconds, rise time (tr) of 145.907 seconds, steady-state error (ess) of 0.4%, and a maximum overshoot of 1.329%.

Figure 1. Deaerator

Figure 2. The Addition of Boiler Fuel

3.1.2 Station Boiler

This steam generator heats water from 98–100°C into unsaturated steam using thermal energy, operating at a pressure of 18–21 kg/cm² and a temperature of 210–220°C. It is fueled by byproducts of palm oil mills, namely palm fiber (with a heating value of 2,710 kcal/kg) and palm shells (4,120 kcal/kg). The boiler used is a Takuma-brand water tube boiler, which produces superheated steam and operates by injecting water to generate saturated steam, with a steam capacity of 30 tons per hour. To evaluate energy performance, the boiler steam efficiency formula is applied. This formula provides a comprehensive assessment, taking into account feedwater, the steam output directly used in operations, and the thermal energy generated from burning fiber and shell fuels to convert water into steam. Boiler efficiency can be calculated using the following formula:

$$\eta = \frac{PU\ x\ (i.upl - i.am)}{BB\ x\ NP} x\ 100\%$$

Formula Description:
η = boiler efficiency (%)
PU = boiler steam production (kg/hour)
upl = superheated steam enthalpy (kcal/kg)
am = inlet water enthalpy (kcal/kg)
BB = fuel (kg/hour)
NP = combustion rate (kcal/kg)

Based on the boiler efficiency calculations, it is evident that superheated steam temperature plays a significant role in influencing boiler performance. For instance, at low, medium, and high superheated temperatures of 225.4°C, 232.9°C, and 245.9°C, the corresponding boiler efficiencies were recorded at 50.61%, 51.70%, and 51.78%, respectively. A similar trend was observed in the performance of the steam turbine, where the same incremental increase in superheated temperature resulted in turbine efficiencies of 14.08%, 15.69%, and 15.71%. These findings indicate a clear correlation: the higher the superheated temperature, the better the performance of both the boiler and the steam turbine. This conclusion aligns with the study conducted by Siswanto et al. (2023), which analyzed the effect of superheated steam temperature on boiler performance at PT. Perkebunan Nusantara VI PKS Aur Gading Batanghari Jambi. Measurement results at the Boiler Station on November 26, 2024, can be seen in Table 2.

Table 2. Measurement Results at the Boiler Station

Hours	Steam Output (kg/cm^2)	Flue Gas (°C)	Hours	Steam Output (kg/cm^2)	Flue Gas (°C)
07.00 – 08.00	20.2	240	19.00 – 20.00	20.8	258
08.00 – 09.00	20.4	235	20.00 – 21.00	21.1	254
09.00 – 10.00	20.6	250	21.00 – 22.00	20.6	256
10.00 – 11.00	20.2	253	22.00 – 23.00	20.8	260
11.00 – 12.00	20.5	255	23.00 – 24.00	21.1	258
12.00 – 13.00	20.7	260	00.00 – 01.00	20.6	263
13.00 – 14.00	20.2	259	01.00 – 02.00	21.4	260
14.00 – 15.00	20.5	258	02.00 – 03.00	20.8	263
15.00 – 16.00	20.4	259	03.00 – 04.00	20.8	266
16.00 – 17.00	20.7	260	04.00 – 05.00	21.1	264
17.00 – 18.00	20.2	262	05.00 – 06.00	21.4	268
18.00 – 19.00	20.6	260	06.00 – 07.00	21.3	267
12 Hours	**20,4**	**254,25**	**12 Hours**	**20,9**	**261,42**

Data Source: Boiler St Journal Report

Input Data — Units: MKS

Steam Pressure: 20.72 kg/c

Result		
Saturated Steam Temperature	215.67	°C
Latent Heat of Steam	448.153	kca
Specific Enthalpy of Saturated Steam	668.814	kca
Specific Enthalpy of Saturated Water	220.661	kca
Specific Volume of Saturated Steam	0.093481	m³/
Specific Volume of Saturated Water	0.001182	m³/

Figure 3. Calculator: Saturated Steam Table by Pressure

The validation of the boiler superheater temperature was conducted using indicator parameters, which showed a value of 500°F (~260°C). At this temperature, the steam output was converted into saturated steam by injecting water into the main steam pipe leading to the steam turbine. The average working pressure of the boiler was measured at 20.72 kg/cm², which, based on the saturated steam table, corresponds to a steam temperature of approximately 215.67°C. This value is close to the steam turbine's overload threshold of 216°C, with a corresponding saturated steam enthalpy of 668.81 kcal/kg.

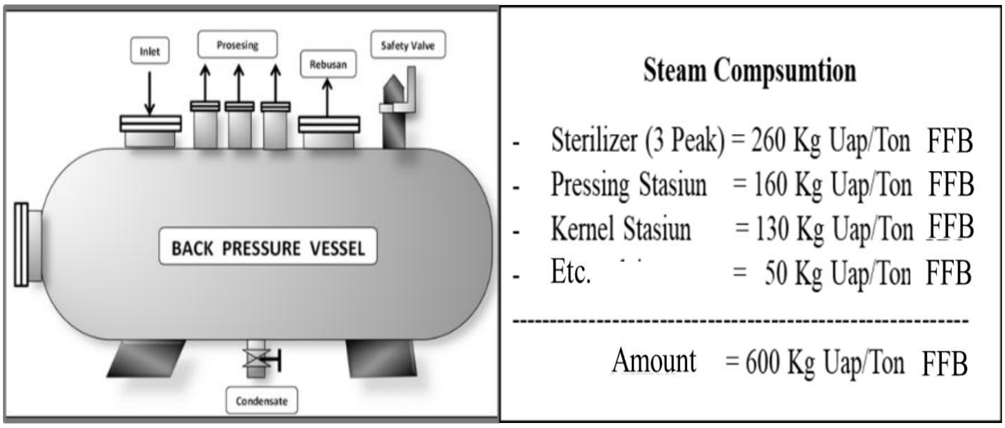
The results of the boiler efficiency calculation indicated that the superheated steam temperature significantly influences boiler performance. When the superheated temperatures were set to 225.4°C, 232.9°C, and 245.9°C (categorized as low, medium, and high levels), the resulting boiler efficiencies were 50.61%, 51.70%, and 51.78%, respectively. Similarly, steam turbine efficiency also increased with higher superheated temperatures, reaching 14.08%, 15.69%, and 15.71% at the same temperature levels. These findings suggest a strong positive correlation between superheated steam temperature and the overall performance of both the boiler and the steam turbine.

This analysis aligns with the findings of Siswanto et al. (2023), who studied the effect of superheated steam temperature on boiler and turbine efficiency at PT. Perkebunan Nusantara VI's palm oil mill in Aur Gading, Batanghari, Jambi. Their research demonstrated that increasing the superheater temperature improves thermal efficiency and operational performance, particularly in industrial steam generation and utilization systems, confirming the importance of thermal parameter optimization in energy-intensive processes.

3.1.3 Power Plant

The power plant functions as an electricity generation station comprising a steam turbine as the primary power generator, utilizing steam from the boiler to drive an alternator for electricity production. In addition, a generator set (genset) serves as an auxiliary unit primarily used for plant start-up. The steam turbine system consists of three well-maintained units, manufactured by Alen KKK, Shinko, and Drasser Rand, operating with saturated steam (wet steam). Each unit has a power output of 800 kW, a rotational speed of 1,500 rpm, and an output voltage of 380 volts. These operational parameters contrast significantly with those of a superheater-type boiler, which produces dry steam. Therefore, water injection into the main steam pipeline is required to adjust the steam temperature to saturated conditions suitable for steam turbine operation, with a working pressure of 20.72 kg/cm² and a saturated steam temperature of 215.67°C.

The steam turbine also produces exhaust steam, which is directed into a pressure vessel known as the Back Pressure Vessel (BPV). The BPV operates at a pressure of 2.56 kg/cm² and a working temperature of 135.63°C, based on average indicator measurements. The exhaust steam from the BPV is further utilized in processing operations, with steam consumption distributed as shown in Figure 4.



Steam Compsumtion

- Sterilizer (3 Peak) = 260 Kg Uap/Ton FFB
- Pressing Stasiun = 160 Kg Uap/Ton FFB
- Kernel Stasiun = 130 Kg Uap/Ton FFB
- Etc. = 50 Kg Uap/Ton FFB

Amount = 600 Kg Uap/Ton FFB

Figure 4. Steam Compsumtion

Deposition in steam turbines is primarily caused by impurities such as chlorine (Cl), boron (B), silica (SiO_2), iron (Fe), calcium (Ca), magnesium (Mg), sulfate (SO_4), and total dissolved solids (TDS), while erosion results from solid particles carried by the steam that impact the turbine blades. These two phenomena significantly affect turbine performance by reducing isentropic efficiency by 0.0133%, increasing the turbine steam rate by 0.172 kg/kWh, raising the turbine heat rate by 125.585 kJ/kWh, and lowering the overall efficiency of the turbine-generator system by 2.3298%. To mitigate these adverse effects, regular maintenance is essential. Common procedures include sandblasting to remove deposits and applying stellite coatings to restore the eroded surfaces of turbine blades (Yuliyani et al., 2024). The measurement results of the Steam Turbine and Back Pressure Vessel (BPV) on November 26, 2024, are presented in Table 3.

Table 3. The measurement results of the Steam Turbine and Back Pressure Vessel (BPV)

Hours	Inlet Steam (kg/cm^2)	Amper (A)	**$cos\theta$**	BPV	
				kg/cm^2	ºC
07.30	19.00	800	0.95	2.5	135
08.00	19.00	800	0.95	2.0	130
08.30	19.00	800	0.95	2.0	130
09.00	19.00	800	0.95	3.0	140
09.30	19.00	800	0.95	3.0	140
10.00	19.00	800	0.95	2.0	130
10.30	19.00	800	0.95	2.0	130
11.00	19.00	800	0.95	3.0	140
11.30	19.00	800	0.95	3.0	140
12.00	19.00	800	0.95	2.0	130
12.30	19.00	800	0.95	2.0	130
13.00	19.00	800	0.95	2.0	130
13.30	19.00	800	0.96	3.0	140
14.00	19.00	800	0.95	3.0	140
14.30	19.00	800	0.95	2.0	130
15.00	19.00	800	0.95	3.0	140
15.30	19.00	800	0.96	2.0	130
16.00	19.00	800	0.96	3.0	140
16.30	19.00	840	0.96	2.0	130
17.00	19.00	760	0.95	3.0	140
17.30	19.00	760	0.95	3.0	140
18.00	18.00	800	0.95	3.0	140
18.30	19.00	840	0.95	3.0	140
19.00	19.00	840	0.95	3.0	140
12 hours	**18.88**	**808.33**	**0.95**	**2.56**	**135.63**

Data source: Power Plant Journal Report

The actual electrical power generated by a Steam Turbine Alternator is:

$$P = I\ x\ V\ x\ Cos\ \theta\ x\ \sqrt{3}$$

$$P = 808.33\ x\ 380\ x\ 0.95\ x\ 1.73 = 505.71\ kWh$$

3.1.4 Station Sterilizer

This pressure vessel is used for boiling fresh fruit bunches (FFB) of oil palm. It operates at a working pressure of 2.8–3.0 kg/cm^2 and a temperature range of 130–135°C. The standard boiling process follows a triple-peak system with a boiling limit of 90°C. The sterilizer unit is illustrated in Figure 5.

Figure 5. Sterilizer Unit and Loading TBS

The triple-peak sterilization system in palm oil mills is designed to ensure that steam effectively penetrates the inner parts of the fresh fruit bunches (FFB), which consist of both outer and inner fruits. This facilitates the detachment of loose fruits (brondolan) from the bunch, eases seed separation from the mesocarp, and allows for easier shell removal from the kernel. The success of FFB processing capacity begins with an optimized sterilization process, which is influenced by several operational parameters, including:

1. The number of sterilizer units used—for a capacity of 30 tons/hour, two sterilizer units are typically required;
2. The filling of FFB into lorries according to lorry volume (e.g., 2.5 tons/lorry);
3. The boiling time limit, from loading to door opening, which ideally follows the industry standard of 90 minutes per cycle; and
4. he availability of a standard number of 70 lorries for a 30-ton/hour mill, consisting of 20 units inside the sterilizer (2 vessels), 10 units in front (chain line), 20 units behind (loading ramp), 6 pushing units, and 4 units under daily repair.

The formula for calculating FFB processing capacity is as follows:

$$X = \frac{A\ x\ B\ x\ C}{Y} x\ 60\ minute$$

where **X** is the processing capacity (tons of FFB/hour), **A** is the number of lorries in use, **B** is the capacity per lorry (tons), **C** is the number of sterilizer units, and **Y** is the boiling cycle time (minutes).

In the triple-peak sterilization process, steam pressure is increased progressively: the first peak reaches up to 1.5 kg/cm², the second peak 2.5 kg/cm², and the third peak 2.8–3.0 kg/cm². This final peak is maintained for 40–45 minutes at a temperature of 125–130°C. After each peak, the pressure is rapidly reduced to 0 kg/cm² to create a thermal shock that enhances steam penetration into the fruit core. Meeting these operational parameters is critical for achieving consistent and sustainable FFB processing capacity. It also ensures that the energy balance in the palm oil mill is maintained for the subsequent stages of energy conversion. Triple peak and gap system theory with realization is illustrated in Figure 6.

According to Novriska et al. (2024), in a study conducted at PT. XYZ, a palm oil mill in North Sumatra, the FFB boiling process is carried out at approximately 135°C and 2.0 kg/cm² for 70–80 minutes using a vertical sterilizer with a capacity of 14 tons/hour. The study demonstrated that steam pressure and temperature play a crucial role in the efficiency of the sterilization process, directly affecting both the quality and quantity of crude palm oil (CPO) produced. The researchers applied a quantitative approach to evaluate heat consumption in the vertical sterilizer, emphasizing the importance of optimizing steam utilization in palm oil processing.

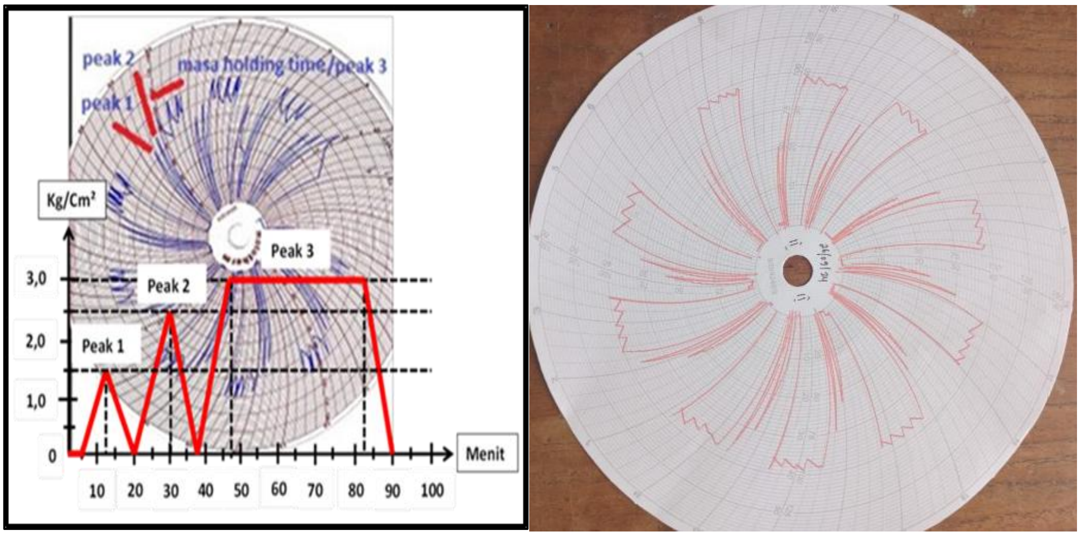


Figure 6. Triple Peak and Gap System Theory with Realization

Validation of Processing Capacity Based on the Availability of Lorries:

With 70 lorries available, the sterilization process, including loading fresh fruit bunches (FFB) into the lorries, pushing them into the sterilizer, and closing both the front and rear sterilizer doors, can be completed within the standard 90-minute cycle time. Consequently, a 45-minute interval between the operations of two sterilizer units is sufficient to ensure the continuous and uninterrupted circulation of the process at full processing capacity.

$$Capacity = \frac{2\ unit\ x\ 10\ lories\ x\ 2.5\ ton\ x\ 60\ minute}{90\ minute}$$

$$Capacity = \frac{3000}{90} = 33.33\ ton/hours$$

$$Limit\ Interval = \frac{90}{2} = 45\ minute$$

If only 48 lorries are available and the boiling time is limited to 90 minutes per cycle, the process circulation cannot be maintained continuously, resulting in a disruption to the processing flow. Even if the boiling time is extended to 110 minutes per cycle, the reduced number of lorries still limits the overall throughput, causing the achieved processing capacity to fall below 30 tons per hour.

$$Capacity = \frac{2\ unit\ x\ 10\ lorries\ x\ 2.5\ ton\ x\ 60\ minute}{110\ minute}$$

$$Capacity = \frac{3000}{110} = 27{,}273\ ton/hours$$

$$Limit\ Intervals = \frac{110}{3} = 55\ minute$$

For safety considerations related to processing capacity, three sterilizer units are utilized to achieve a throughput exceeding 30 tons per hour. However, this approach may lead to increased losses of condensate water and potentially disrupt established operational discipline and routines.

$$Capacity = \frac{3\ unit\ x\ 10\ lorries\ x\ 2.5\ ton\ x\ 60\ minute}{135\ minute}$$

$$Capacity = \frac{4500}{135} = 33.33\ ton/hours$$

$$Limit\ Intervals = \frac{135}{3} = 45\ minute$$

3.1.5 Screw Press Station

This station comprises a digester and a screw press. The digester functions to crush the boiled fruit flesh (loose fruits) using a steam jacket maintained at 70–80°C and operates at a speed of 24 rpm. Through the rotation of its long and short arms, the digester effectively separates the mesocarp from the kernels. The mass exiting the digester is then processed by the screw press, which operates at a working pressure of 40–50 bar. During this stage, approximately 20% water is added to dilute the fresh fruit bunches (FFB), and the temperature is maintained at 80–90°C to facilitate the separation of oil from the pulp and kernels. The digester and screw press are shown in Figure 7.

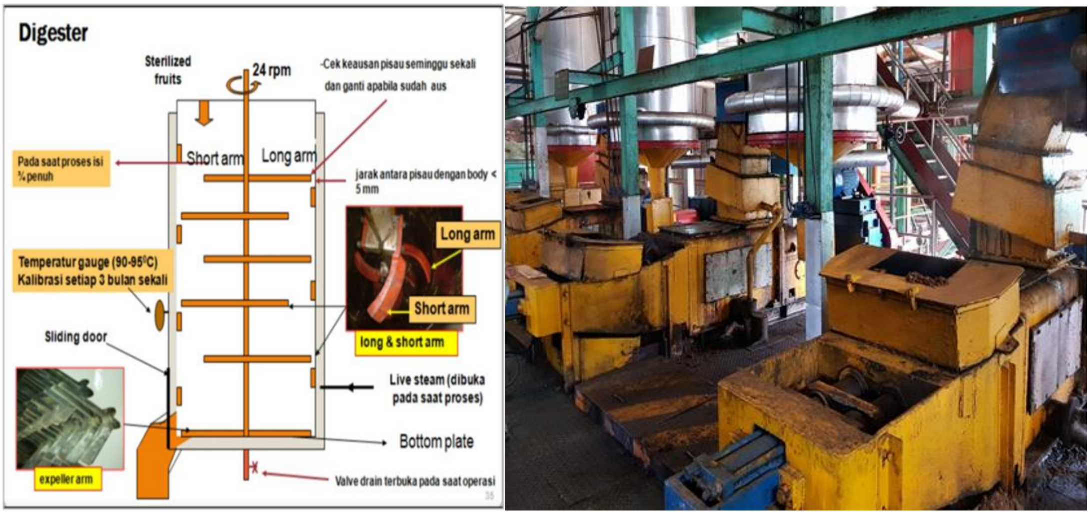


Figure 7. The Digester and Screw Press

Three sets of digesters and screw presses (Apindo brand, type LP-17), with a capacity of 15–17 tons of fresh fruit bunches (FFB) per hour are available at the facility. All units are in good operational condition and are capable of supporting a total processing capacity of 30 tons of FFB per hour. However, a significant issue arises with one of the most critical machines in crude palm oil (CPO) and kernel production: the screw press, which functions as the primary separator of oil, kernels, and fiber. The performance and effectiveness of this machine were evaluated using the Overall Equipment Effectiveness (OEE) method, which considers three key components: availability, performance, and quality. According to a study by (Arsil et al., 2024), although the quality rate reached 100%, the availability was only 89% and performance was significantly low at 49%. This resulted in a poor overall OEE score, indicating low machine effectiveness. The primary cause was extended downtime during production, which negatively impacted production targets and led to delays in processing FFB, thereby increasing the risk of fruit spoilage.

3.1.6 Kernel Station

The Kernel Station is responsible for processing palm kernels, producing kernels as the main product along with fiber and shell as byproducts. The fibers are immediately directed to the fiber cyclone to be used as boiler fuel. Kernels are transported via a nut transport fan into a nut hopper, where they are prepared for processing in a ripple mill with a capacity of 4 tons per hour. The ripple mill operates at an efficiency of 98.2%.

Following this, kernel separation occurs at LTDS I, where the kernels are transferred to the kernel silo for a curing process lasting approximately 36 hours. Meanwhile, the shells and broken kernels are conveyed to LTDS II. Pure shells are then directed to the shell cyclone and utilized as boiler fuel. Remaining shell fragments are further processed in a hydrocyclone or clay bath to recover small-diameter kernels. Both fiber and shell byproducts are used to fuel the boiler, contributing to energy efficiency within the mill. Additionally, any excess shell material has the potential to be sold as a byproduct, thereby generating additional revenue for the company. Figure 8 illustrates the pneumatic system used for separating fiber from seeds and shell from kernel.

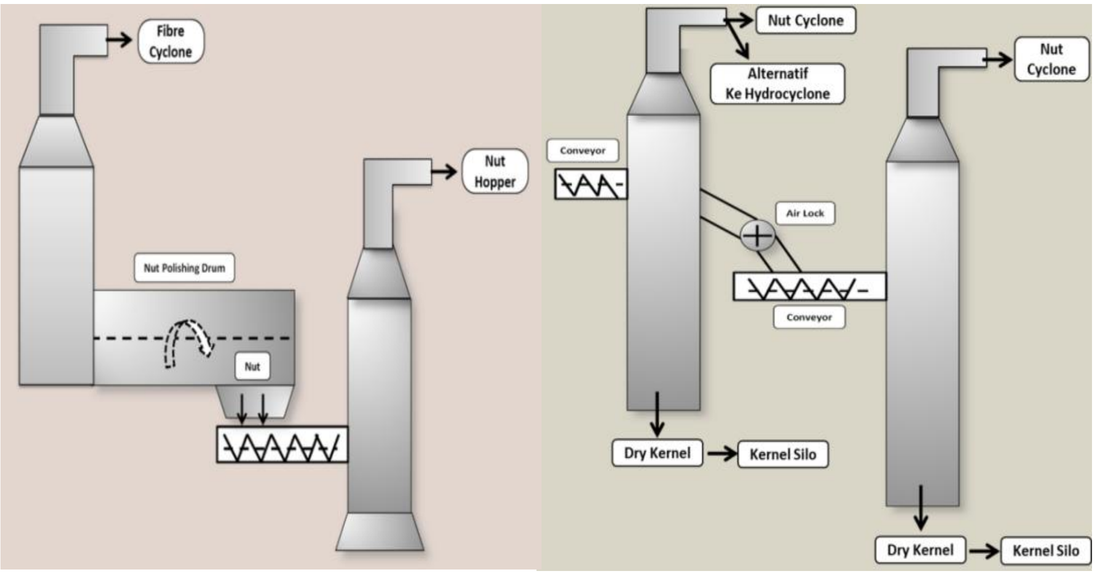


Figure 8. The Process of Separating Fiber from Seeds and Shell from Kernel Using a Pneumatic System

A Ripple Mill is a palm oil seed-cracking machine designed to separate the shell from the kernel. It operates at an actual efficiency of 98.2%. The Ripple Mill functions by rotating the kernels using a rotor at a speed of 1,500 rpm. As the kernels collide with the stator wall, the impact causes the shell to break and detach from the kernel, enabling effective separation. The Ripple Mill is shown in Figure 9.

Figure 9. Ripple Mill

Hydrocyclones are generally considered more effective and efficient than clay baths for kernel and shell separation at the kernel station, primarily due to their higher operating speed and superior separation rate. However, the selection between hydrocyclones and clay baths depends on the specific process conditions and operational requirements of the mill. According to Zebua (2024), in a study on the maintenance analysis of sterilizer machines at PT. Perkebunan Nusantara IV Dolok Sinumbah Palm Oil Mill, process optimization, including the choice of separation technology, plays a critical role in maintaining overall equipment effectiveness (OEE) and improving production efficiency.

3.1.7 Material Balance

A material balance is a key indicator used to determine the composition of fresh oil palm fruit bunches (FFB) during processing, enabling the calculation of all resulting parameters based on their respective potentials. This material balance must be conducted annually to monitor changes in the composition of each batch of FFB processed at the mill and to assess processing yields, particularly in relation to the acceptance and evaluation of FFB raw materials purchased from third parties. The material balance is presented in Figure 10.

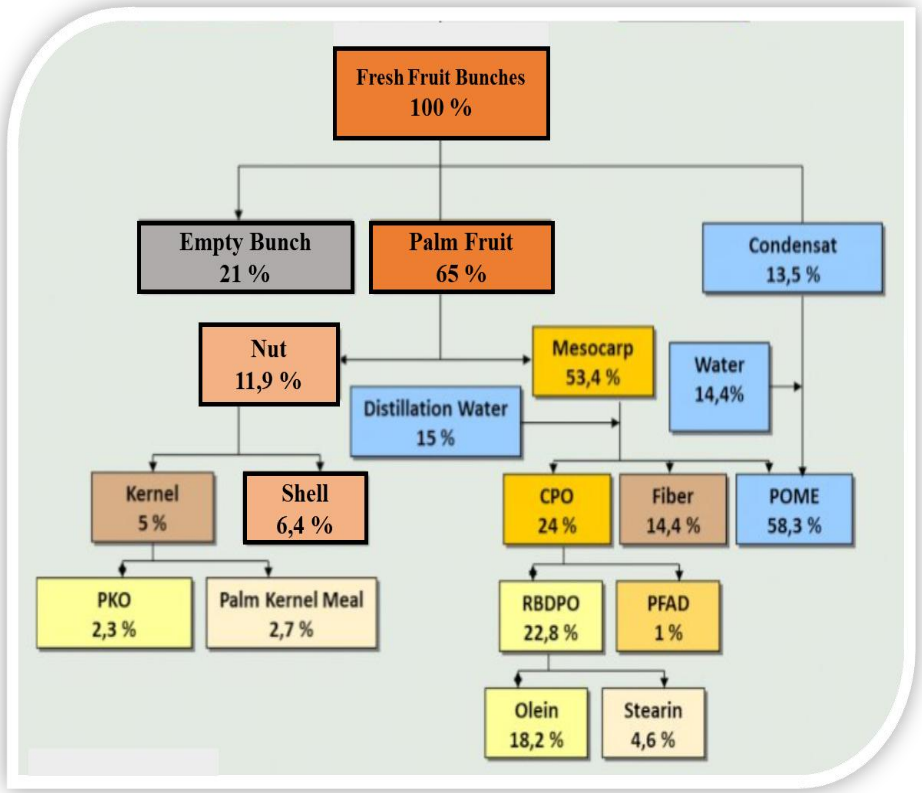


Figure 10. The Material Balance

Material balance is a fundamental calculation used to monitor the mass flow of materials involved in the processing of fresh fruit bunches (FFB) into final products, such as crude palm oil (CPO). This process accounts for all inputs and outputs, including waste and by-products, to evaluate operational efficiency, optimize yield, control product quality, and improve waste management. Additionally, material balance plays a crucial role in estimating the energy required to produce fiber and shell-based fuels, which is essential for determining the volume and calorific value of fuel needed to convert water into steam, thereby supporting the calculation of steam output.

The mass balance calculation in this study is based on a processing capacity of 30 tons per hour. From the total processed FFB, 68% (equivalent to 20,400 kg/hour) is directed to the loose fruit digester. This feedstock consists of six components: oil (8,213.04 kg/hour), water (956.76 kg/hour), kernel (807.84 kg/hour), shell (2,025.72 kg/hour), fiber (1,605.48 kg/hour), and sludge (6,791.16 kg/hour), all processed at a temperature of 66°C. The mixture is then transferred to a digester, where it is shredded with the addition of 2,001 kg/hour of steam at 123ºC. Following digestion, the material enters the screw press at a rate of 22,401 kg/hour, where an additional 6,000 kg/hour of dilution water at 95ºC is introduced to facilitate the pressing process and prevent the pulp from becoming too compact.

The main output of the screw press is crude oil, comprising 7,838.39 kg/hour of oil, 5,370.27 kg/hour of water, and 6,792.34 kg/hour of sludge. The by-products, or pressed pulp, consist of 373.80 kg/hour of oil, 3,585.96 kg/hour of water, 808.92 kg/hour of kernel, 2,025.24 kg/hour of shell, and 1,606.08 kg/hour of fiber. Oil losses during pressing were measured using the Soxhlet extraction method. A 10 g sample of fiber was analyzed in the laboratory to determine its moisture content and residual oil. The fiber sample was oven-dried at 103°C for three hours to remove moisture and subsequently extracted with n-hexane for five hours to recover the remaining oil. The analysis showed an oil loss of 4.45% and a moisture content of 42.69%. These values are consistent with the standard oil loss range of 4–6% typically observed in industrial palm oil processing facilities (Rosmiati et al., 2024).

3.2 Energy Analisis and Conversion

Energy balance analysis and evaluation can be carried out by assessing energy conversion at each stage of the energy generation process, as shown in Table 4.

Table 4. Energy Conversion Analysis in the Energy Balance of Palm Oil Mills

Energy Conversion	Input	Output	Parameter	Value	Information
WTP → Boiler	Water	Steam	°C	98-100	BJ Air = BJ Uap
Boiler → Steam Turbin	Steam	Electricity	kg uap/kwh	24-28	
Steam → Processing	Electricity	TBS Proses	kwh/ton TBS	19-21	
Processing → Product	FFB	Fibre & Nut	%	65.5	Material Balance
Product → Fuel	Fibre & Nut	Fibre & Shell	% %	14.4 6.4	
Fuel → Boiler	Fibre & Shell	Kalor	kg/hours	4.354 1.935	Ready (MB)

Table 4 presents energy conversion data from one process stage to the next, based on assumed values that closely approximate actual conditions. These conversions are significantly influenced by temperature, pressure, and time, as reflected in the results of the energy analysis and conversion below.

Validation of Energy Balance Data in Palm Oil Mills:

1. Factory Processing Capacity : 30.23 Ton TBS/hours
2. Boiler Water Requirements : 19.70 m^3/jam
3. Steam Needs : 18.13 ton steam/hours
   - Boiler Working Pressure : 20.72 kg/cm^2
   - Boiler Working Temperatur: 215,67 °C Enthalpy : 668.81 kcal/kg fuel
   - Feed Water Temperature : 80°C Enthalpy : 80 kcal/kg fuel
   - Boiler Efficiency : 65%
4. Output Steam Turbine : 506 kWh SCC : 35.83 kg steam/kWh
5. Fuel is Available
   - Fibre (14.4%) : 4,354 kg fuel/hours Burning value: 2,710 kcal/kg fuel
   - Shell (6.4%) : 1,935 kg fuel/hours Burning value: 4,120 kcal/kg fuel

3.3 Energy Balance Evaluation

The measured steam turbine output current is 808.33 A. Using the power formula:

$$P = V\ x\ cos\theta\ x\ \sqrt{3}$$

$$P = 808.33\ x\ 380\ x\ 0.95\ x\ 1.73 = 506\ kW$$

The efficiency of the steam turbine relative to the installed capacity is therefore:

$$\eta = \frac{506}{800} x\ 100\% = 63.25\%$$

The relatively low electrical power usage is attributed to the station kernel's reliance on grid electricity supplied by PLN, which is charged to the PKO plant at approximately 100 kW.

Consequently, the specific electricity consumption, converted to the processing capacity of fresh fruit bunches (FFB), is calculated as:

$$\frac{506\ kWh}{30\ ton\ FFB/hour} = 16.74\ kWh/ton\ of\ FFB/ton$$

Based on the validation of the aforementioned energy data, a subsequent evaluation using a holistic energy balance calculation is presented as follows.

Water Tube Boiler Steam Efficiency Formula: $\eta = \frac{PU\ x\ (i.upl - i.am)}{BB\ x\ NP}\ x\ 100\%$

Energy Balance Calculation:

$$65 = \frac{18{,}140\ x\ (668.81 - 80)}{(4.354\ x\ 2.710) + (shell\ x\ 4.120)}\ x\ 100\%$$

$$Used\ Shell = \frac{10{,}681{,}013 - 7{,}668{,}782}{2.678} = 1.125\ kg\ fuel/hour$$

$$Remaining\ Shell = 1{,}935 - 1{,}125 = 810\ kg\ fuel/hour$$

The realization of remaining shells is 400 kg BB/hour, while the actual utilization of shells is 1,935 kg/hour − 400 kg/hour = 1,535 kg/hour. This indicates that there is still potential for an additional 810 − 400 = 410 kg/hour of remaining shells. The optimization of this potential can be achieved by operating the deaerator at a temperature of 98 °C. Under such conditions, the recovery of remaining shell by-products would be higher, thereby providing greater added value for the company.

Energy Balance Calculation:

$$65 = \frac{18{,}140\ x(668.81 - 98)}{(4{,}354\ x\ 2{,}710) + (Shell\ x\ 4{,}120)}\ x\ 100\%$$

$$Used\ Shell = \frac{10{,}354{,}493 - 7{,}668{,}782}{2{,}678} = 1{,}003\ kg\ fuel/hour$$

$$Remaining\ Shell = 1{,}935 - 1{,}003 = 932\ kg\ fuel/hour$$

The difference in excess shell observed when the deaerator is operated indicates a higher potential recovery of shell by-products, which can contribute to increased added value for the company. The difference in excess shells when the Deaerator is operated can be observed in Table 5.

Table 5. The difference in Excess Shell when the Deaerator

Description	Shell Availeble (kg/hours)	Used Shell (kg/hours)	Remaining Shell (kg/hours)	Shell Production		Shell Price (Rp/kg)	Added Value (Rp/month)
				Day (21 hours/day)	Month (25 day/month		
80 °C	1,935	1,125	810	17,010	425,250	1,100	467,775,000
98 °C	1,935	1,003	932	19,572	489,300	1,100	538,230,000
Realization			400	8,400	176,400	1,100	194,040,000

The energy loss in shell fuel due to the non-utilization of the deaerator function at a temperature of 98 °C is calculated as (932 kg/hour – 810 kg/hour) × 4,120 kcal/kg BB = 502,640 kcal/hour. This corresponds to a financial loss of Rp. 538,230,000 − Rp. 467,775,000 = Rp. 70,455,000 per month. Furthermore, when compared with the realization of the remaining shells, the loss amounts to Rp. 538,230,000 – Rp. 194,040,000 = Rp. 344,190,000 per month.

IV. CONCLUSION

The energy scanning conducted at PTPN-IV Pabatu Palm Oil Mill shows that feedwater quality, steam temperature, and deaerator performance are critical factors influencing energy efficiency. Proper water treatment successfully reduced alkalinity, hardness, and silica to safe levels, but the malfunction of deaerator instruments resulted in lower feedwater temperature (80 °C), leading to additional fuel use and energy losses. Analysis confirmed that higher superheated steam temperatures improved both boiler and turbine efficiency, while the underutilization of shell fuel caused substantial financial losses, reaching up to Rp. 344,190,000 per month. These findings emphasize the importance of regular monitoring, maintenance, and optimization of thermal parameters to improve energy balance, reduce losses, and enhance the sustainability of palm oil mill operations.

SUGGESTIONS & INPUT

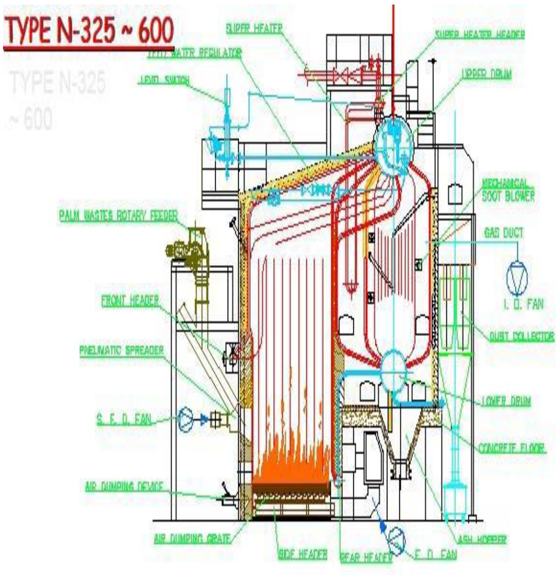
1. Optimization of Steam Turbine Power

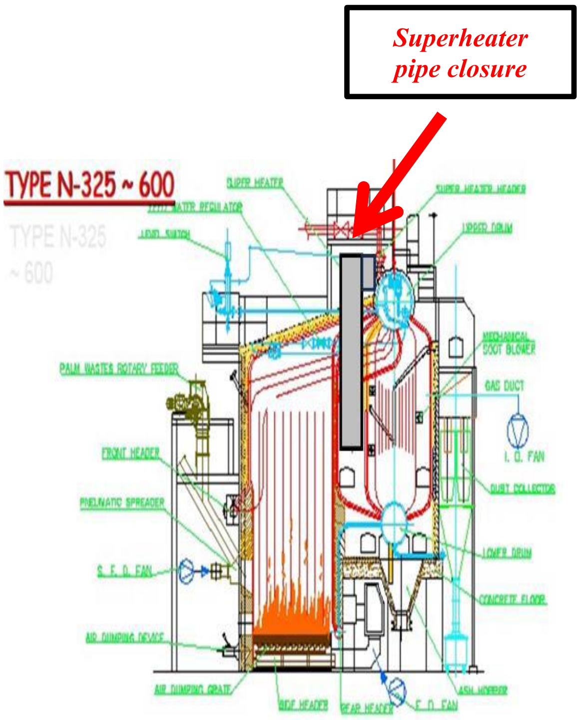
   Maximize the utilization of steam turbine power to reduce dependency on electricity purchases from PLN. Based on the industrial electricity tariff as of May 7, 2025 (Rp 1,644.52/kWh), the potential savings calculation is:

$$100\ kWh\ x\ 21\frac{hour}{day}x\ 25\frac{day}{month}xRp\frac{1.644,52}{kWh} = Rp\ 86{,}337{,}300/month$$

2. Boiler Modification

   Renovate one (1) unit of superheater boiler into a saturated boiler, as all three available steam turbines operate with saturated steam. The modification can be carried out by closing the superheater pipe and header, then connecting the boiler drum header pipe directly to the main steam pipe leading to the steam turbine. This alteration requires approval from the IPNKK (Industrial and Manpower) authority and must be supported by detailed work drawings.




Superheater pipe closure

REFERENCES

Arsil, F., Edwar, F., & Mailani, F. (2024). Analisis Efektifitas Mesin Screw Press Menggunakan Metode Overall Equipment Effectiveness di PT Socfindo Bangun Bandar. *Sinergi Polmed: Jurnal Ilmiah Teknik Mesin*, 5, 121-128. https://Doi.Org/10.51510/Sinergipolmed.V5i2.1680

Husnawati, Bhernama, B., & Tarmizi. (2022). Analisis Air Boiler dengan Parameter pH, Alkalinitas, TDS, Hardness dan Silika di PT. Beurata Subur Persada. *Amina*, 3, 62-68. https://Doi.Org/10.22373/Amina.V3i2.2002

Novriska, B., Damanik, R., Rachmiadji, I., Lestari, S., Mirnandaulia, M., Meldha, Z., Anwar, D., & Annisa, R. (2024). Efisiensi Penggunaan Kalor pada Sterilizer Tipe Vertikal Kapasitas 14 Ton/ Jam di PT. XYZ.

Ramadhan, M. H., & Andika, J. (2024). Desain Sistem Kontrol Level Deaerator Menggunakan Kontrol Cascade dan Logika Fuzzy di Pembangkit Listrik Tenaga Uap Muara Karang. *Jurnal Teknologi Elektro Universitas Mercu Buana*, *15*(1), 78-82.

Rosmiati, Kurnia, D., & Lumbantoruan, S. (2024). Perhitungan Oil Losses pada Ampas Press di Proses Pengepresan Unit Screw Press PT.XYZ. *Jurnal Vokasi Teknik*, *2*(1), 1-5.

Siswanto, J. E., Hikayat, A., & Anwar, Z. (2023). Analisa Pengaruh Temperatur Uap Superheated terhadap Peforma Boiler di PT. Perkebunan Nusantara VI PKS Aur Gading Batanghari Jambi. *Jurnal Teknik Mesin Dan Industri*, *2*(1), 64-69.

Suprianto, S., & Nusantara, R. (2024). Identifikasi Hambatan Pemanfaatan Limbah Cangkang dan Serabut Sawit sebagai Bahan Bakar Biomassa di Pabrik Kelapa Sawit Sambas. *Pedontropika : Jurnal Ilmu Tanah Dan Sumber Daya Lahan*, *10*, 39-49. https://Doi.Org/10.26418/Pedontropika.V10i1.71636

Yuliyani, I., Salsabila, S. F., & Maridjo. (2024). Pengaruh Deposisi dan Erosi pada Sudu-Sudu terhadap Kinerja Turbin PLT Panas Bumi Patuha. *Jurnal Teknik Energi*, *13*(1), 16-23.

Zebua, H. A. I. S. (2024). *Analisis Perawatan Mesin Sterilizer Pabrik Kelapa Sawit Menggunakan Overall Equipment Effectivenes di PT. Perkebunan Nusantara Regional II Dolok Sinumbah*.

Zulfadlillah, Fathani, M., Noval, M., Irwana, & Saputra, M. (2024). Penerapan Sistem Manufacturing 4.0 dengan Integrasi Internet of Things (Iot) untuk Optimalisasi Efisiensi Produksi. *Jurnal Ilmiah Teknik Mesin Elektro Dan Komputer*, *4*, 159-164. https://Doi.Org/10.51903/Juritek.V4i1.4041