PAISSANGANG: Publikasi Artikel Teknologi Sains dan Ilmu Terapan
Vol. xx No.xx
p-ISSN: xxx e-ISSN: xxx

Analysis of Condenser Vacuum Pressure Changes on the Electrical Load Generated by Unit 2 of Mamuju Coal-Fired Power Plant (PLTU)

S, Ilham[1], Amir Mahmud[2], Yusran[3]

[1]Teknik Mesin; Universitas Tomakaka; Mamuju; ilhams@gmail.com.
[2]Teknik Mesin; Universitas Tomakaka; Mamuju; Mahmudamir@gmail.com.
[3]Sistem Informasi; Universitas Tomakaka; Mamuju; yoesbone@gmail.com.
*Correspondence: e-mail: ilhams@gmail.com

INTISARI

PLTU Mamuju memiliki dua unit Pembangkit Listrik Tenaga Uap dengan kapasitas masing-masing 25 MW. Berdasarkan desain pembangkit listrik, unit 2 PLTU Mamuju memiliki tekanan vakum -90 kPa. Pada tekanan vakum kondensor unit 2, PLTU Mamuju mengalami penurunan tekanan pada vakum kondensor 1 sebesar -7 kPa, pada vakum kondensor 2 sebesar -9 kPa, dan pada vakum kondensor 3 sebesar -10 kPa. Penurunan nilai vakum kondensor ini disebabkan oleh beberapa faktor, yaitu kerusakan kipas *cooling tower*, keruntuhan rangka *cooling tower*, dan kebocoran pada tabung kondensor. Penelitian ini bertujuan untuk menganalisis pengaruh penurunan tekanan kondensor terhadap kinerja turbin, efisiensi siklus, dan total produksi listrik di PT PLN (Persero) Sektor Pembangkit Mamuju, khususnya pada unit 2. Hasil penelitian menunjukkan bahwa penurunan tekanan vakum kondensor menyebabkan penurunan kinerja turbin. Pada vakum kondensor 1, terjadi penurunan produksi sebesar 597.600 kWh, pada vakum kondensor 2 sebesar 596.560 kWh, dan pada vakum kondensor 3 sebesar 371.040 kWh. Total produksi listrik menurun sebesar 1.465.200 kWh.

Kata Kunci: PLTU Mamuju, Pembangkit Listrik Tenaga Uap, Tekanan Vakum, Kinerja Kondensor, Cooling Tower, Efisiensi Turbin.

ABSTRACT

PLTU Mamuju has two Steam Power Plant units, each with a capacity of 25 MW. Based on the plant's design, unit 2 of PLTU Mamuju has a vacuum pressure of -90 kPa. In unit 2's condenser vacuum pressure, PLTU Mamuju experienced a decrease in vacuum pressure by -7 kPa in condenser vacuum 1, -9 kPa in condenser vacuum 2, and -10 kPa in condenser vacuum 3. This reduction in vacuum pressure is caused by several factors, including damaged cooling tower fans, collapsed cooling tower structures, and leaks in condenser tubes. This study aims to analyze the impact of condenser pressure reduction on turbine performance, cycle efficiency, and total electricity production at PT PLN (Persero) Mamuju Power Plant Sector, particularly in unit 2. The results show that the decrease in condenser vacuum pressure leads to a decline in turbine performance. In *condenser vacuum 1, there was a production reduction of 597,600 kWh; in condenser vacuum 2, a reduction of 596,560 kWh; and in condenser vacuum 3, a reduction of 371,040 kWh. The total electricity production decreased by 1,465,200 kWh.*

Keywords: Mamuju Power Plant, Steam Power Plant, Vacuum Pressure, Condenser Performance, Cooling Tower, Turbine Efficiency.

1. INTRODUCTION

Electricity is a primary necessity in modern life, used for various household appliances, industries, and vehicles. Sources of electricity include water, wind, coal, solar, geothermal, nuclear, gas, diesel, waves, and biomass, which are converted into electrical energy through power generation systems. Technological advancements and digitalization have driven increased demand for electricity, including in West Sulawesi, in line with the government's plan to shift from fossil fuel-powered vehicles to electric vehicles. To meet this demand, various types of power plants such as hydroelectric power plants (PLTA), coal-fired power plants (PLTU), gas and steam power plants (PLTGU), gas engine power plants (PLTMG), wind power plants (PLTB), and diesel power plants (PLTD) are being constructed by both PLN and private companies. The government records show that the national electrification ratio has reached 99.28%, but there are still 542,124 households and 346 villages without access to electricity. Efforts to address this include the 35,000 MW electricity infrastructure acceleration program (ESDM RI). Coal-fired power plants (PLTU), utilizing Indonesia's abundant coal reserves (38.84 billion tons), are a primary choice as they can operate 24 hours a day regardless of weather conditions. The Mamuju PLTU, with a capacity of 2 x 25 MW, is equipped with key components such as a condenser, turbine, boiler, and boiler feed pump to enhance the plant's efficiency.

The condenser in a coal-fired power plant (PLTU) functions to condense exhaust steam from the turbine using seawater as the cooling medium, which is pumped by the Cooling Water Pump (CWP). This process creates a vacuum effect that facilitates steam flow to the hotwell, thereby improving turbine and plant efficiency. However, the condenser of Unit 2 at the Mamuju PLTU has experienced a performance decline, resulting in decreased turbine and plant efficiency. This study aims to identify the causes of changes in the condenser vacuum pressure and their impact on the power unit.

The research is limited to Unit 2 of the Mamuju PLTU using data from 2019 and 2022, focusing on generator loads of 20 MW–22.5 MW (80%–90%). The objective of this study is to determine the causes of changes in condenser vacuum pressure and to propose solutions to address these issues. The findings of this study are expected to serve as a reference for students or other researchers and assist the industry in understanding the causes and solutions for condenser vacuum declines to prevent similar issues in the future.

A Steam Power Plant (PLTU) is a power plant that relies on the kinetic energy of steam to generate electricity. The main component of this type of power plant is the generator, which is connected to a turbine. To rotate the turbine, kinetic energy from hot or dry steam is required. Steam power plants use various types of fuel, primarily coal, fuel oil, and MFO (Marine Fuel Oil) for initial startup.

The working principle of a PLTU involves a water-steam-water cycle, which is a closed-loop system. Water is heated in the boiler until it turns into steam. The steam then rotates the turbine, which is directly connected to the generator, causing the generator to spin and produce electricity. The residual steam from the turbine is condensed back into water in the condenser. The condenser operates under vacuum pressure to maintain low pressure, allowing the steam to flow easily into the condenser and be condensed efficiently (Dirmanto & Effendi, 2020).

The first-level energy conversion that takes place in a Steam Power Plant (PLTU) is the conversion of primary energy into thermal energy (heat). This process occurs in the combustion chamber of the PLTU boiler. The thermal energy is then transferred to the water in the boiler pipes to produce steam, which is collected in the boiler drum. The steam from the boiler drum is directed to the steam turbine. In the steam turbine, the steam's energy (enthalpy) is converted into mechanical energy to drive the generator. Finally, the mechanical energy from the steam turbine is converted into electrical energy by the generator (Ir. Djiteng marsudi, 2005).

One of the key elements in the electricity generation process is water. Water plays a crucial role in the operation of Steam Power Plants (PLTU). It not only serves as a coolant but also as a medium to produce the steam required to drive the generator turbines in a PLTU. Therefore, the availability of high-quality water is essential to maintaining the optimal performance of the PLTU for generating electricity efficiently

(Rahmawati et al., 2024). The water used in a PLTU includes freshwater for steam production and seawater as a cooling medium for the condenser. Many power plants, such as PLTUs, are located in coastal areas, facilitating access to large quantities of seawater as a condenser coolant. Today, technology enables the use of seawater as a condenser cooling medium to improve cost efficiency and reduce reliance on freshwater, which is limited in supply. However, the use of freshwater for the process does not always ensure optimal operations. Water parameters that do not meet standards can lead to issues and potential damage to equipment. Similarly, seawater as a cooling medium for the condenser significantly affects the cleanliness and safety of the equipment. Therefore, it is necessary to conduct water analysis during each process to ensure that the water used meets the required standards.

steam turbine is a prime mover that converts the potential energy of steam into kinetic energy, which is then transformed into mechanical energy in the form of the turbine shaft's rotation. The turbine shaft is directly connected, or with the assistance of reduction gears, to the mechanism it drives in industrial applications, such as electricity generation.

A steam turbine consists of a disk surrounded by blades, referred to as vanes. These vanes rotate due to the impact of high-pressure steam from the boiler, which has been preheated using solid, liquid, or gaseous fuels. The steam is then regulated using a control valve to drive the turbine, which is directly coupled to a pump and similarly coupled to a synchronous generator to produce electrical energy (Abdi Seno, 2018).

The working principle of a steam turbine involves rotating the turbine blades due to the impact of high-pressure steam originating from the boiler, which has been preheated using solid, liquid, or gaseous fuels. The steam is then regulated using a control valve, which directs it to rotate the turbine that is directly coupled to a generator to produce electrical energy.

Steam enters the turbine through a nozzle. Within the nozzle, the thermal energy of the steam is converted into kinetic energy, and the steam undergoes expansion. The steam pressure upon exiting the nozzle is lower than when it entered, but conversely, the steam velocity upon exiting the nozzle is greater than when it entered. The steam exiting the nozzle is directed towards the turbine blades and flows through the gaps between them, following the curvature of the turbine blades. This change in steam velocity generates a force that pushes and subsequently rotates the turbine wheel and shaft.

The analysis of heat transfer in a condenser aims to determine the heat transfer rate (Q) and the effectiveness (ϵ) of the condenser at the company. As the condenser is a primary component in a Steam Power Plant (PLTU), its condition significantly affects the plant's production (Alfani et al., 2021).

A PLTU consists of at least four main components: pumps, boilers, turbines, and condensers. Additionally, it includes auxiliary components such as the forced draft fan (FD Fan), induced draft fan (ID Fan), mills, and electrostatic precipitator (ESP). The condenser is a device used to condense the exhaust steam from low-pressure turbines. Previously, the steam was used to rotate the turbine, and then it is condensed to change its phase back into water. This process aims to save water usage sustainably and to maintain water quality before it re-enters the boiler.

Steam condensation is facilitated by a vacuum condenser, which is designed to maintain the vacuum level within the condenser. This vacuum level is one of the critical parameters for the boiler. The pressure in this system is carefully maintained; if the vacuum pressure is low, it may cause backflow in the low-pressure turbine. According to Farida Wahyu (2018), the lower the pressure (vacuum), the lower the boiling point, which affects the heat transfer rate and the effectiveness of the condenser (Imansyah, 2024).

2. RESEARCH METHODS

This research was conducted at PT Rekind Daya Mamuju or the Mamuju PLTU, located in Talaba Hamlet, Belang Village, Kalukku District, Mamuju Regency, West Sulawesi. The research period covers the approval of the thesis title by the head of the study program, data collection, data processing, and the completion of the thesis preparation.

The data collection techniques involved several stages, including literature review by gathering information from journals, books, online media, and studies related to condenser vacuum systems in steam power plants. Additionally, two primary methods were employed: interviews with operators and employees of the Mamuju

PLTU to obtain detailed information, and field observations to directly observe and collect data relevant to the research.

Data obtained from the operations, engineering, and maintenance divisions of the Mamuju PLTU were analyzed based on literature reviews to determine necessary values such as vacuum pressure and the amount of steam entering the condenser. The analysis compared vacuum pressure values at loads of 50%, 80%, and 90%, particularly at a 12.5 MW load in 2019 and 2022. The collected data was processed using Microsoft Excel to ensure more accurate results.

3. RESULTS AND DISCUSSION

The results of this study indicate that under normal conditions, the power demand from PLN is 25 MW, with a maximum achievable capacity of 24.90 MW under abnormal conditions at vacuum level 1. At vacuum level 1, the condenser cooling inlet temperature on side A is 31.27°C and on side B is 31.05°C, while the condenser cooling outlet temperature on side A reaches 42.50°C and on side B 42.21°C. The condenser vacuum value at this level is -83.42.

At vacuum level 2, the maximum achievable capacity drops to 20.69 MW, with an inlet temperature of 35.88°C on side A and 35.66°C on side B, and an outlet temperature of 44.54°C on side A and 45.98°C on side B. The condenser vacuum value at vacuum level 2 is -81.08.

At vacuum level 3, the maximum achievable capacity decreases further to 15.46 MW. The inlet temperature on side A at this level is 35.92°C and on side B is 35.76°C, while the outlet temperature on side A is 44.53°C and on side B is 45.82°C, with a condenser vacuum value of -80.23. The assumed electricity selling price to PLN is IDR 1,600/kWh.

Table 1. Interview Results

Number	Interviewer	Respondent
1	Apa yang menyebabkan beban PLTU Mamuju tidak bisa 100%?	PLTU Mamuju tidak mampu dibebani 1005 (25 MW) karena kenaikan nilai vacuum condensor.
2	Apa-apa saja yang mempengaruhi	Yang mempengaruhi nilai vacuum kondensor adalah terjadinya kerusakan

	kenaikan nilai vacuum kondensor?	pada fan cooling tower no 4, ambruknya rangka cooling tower, kerusakan pada turbin kondensor sehingga banyak tersumbat.
3	Apa saja kerugian akibat kondisi tersebut?	Menurunnya pendapatan Perusahaan dari penjualan Listrik karena ketidakmampuan memenuhi permintaan beban PLN.

Daily Electricity Production Calculation

The calculation of daily electricity production under abnormal conditions with various vacuum levels shows significant differences. At abnormal vacuum level 1, the total electricity production reaches 24.90 MW or 24,900 kW, generating 597,600 kWh per day. At abnormal vacuum level 2, the power that can be produced drops to 20.69 MW or 20,690 kW, generating 496,560 kWh per day. At abnormal vacuum level 3, the produced power decreases further to 15.46 MW or 15,460 kW, with a total daily production of 371,040 kWh. Meanwhile, the electricity demand from PLN is 25 MW or 25,000 kW, generating 600,000 kWh per day.

Daily Electricity Sales Calculation

The daily electricity sales calculation also shows a decrease due to the changes in vacuum levels. At abnormal vacuum level 1, with a total production of 597,600 kWh, the daily electricity sales reach IDR 956,160,000. At vacuum level 2, with a total production of 496,560 kWh, the daily electricity sales decrease to IDR 794,496,000. At vacuum level 3, with a total production of 371,040 kWh, the daily electricity sales amount to IDR 593,664,000. On the other hand, PLN's demand of 600,000 kWh will generate daily electricity sales of IDR 960,000,000.

Revenue Loss Calculation

Revenue loss due to decreased electricity production can be calculated by subtracting the total electricity production from the PLN load demand, then multiplying by the electricity selling price. At abnormal vacuum level 1, the revenue loss is IDR 3,840,000 per day, due to the production difference of 600,000 kWh and 597,600 kWh. At abnormal vacuum level 2, the revenue loss increases to IDR 165,504,000 per day, resulting from a production difference of 103,440 kWh. At abnormal vacuum level 3, the revenue loss reaches IDR 366,336,000 per day, due to a production decrease of 228,960 kWh.

Table 2. Data Analysis Results

No	Power Plan Condition	Total Electricity Production	Electricity Sales	Revenue Loss
		Kwh	Rp/Day	Rp/Day
0	PLN Demand	600.000	960.000.000	0
1	Abnormal Vacuum Level 1	597.600	956.160.000	3.840.000
2	Abnormal Vacuum Level 2	496.560	593.664.000	165.504.000
3	Abnormal Vacuum Level 3		593.664.000	366.336.000

The above calculations show a decrease in daily electricity production due to changes in the condenser vacuum value.

Figure 1. Daily Total Electricity Production

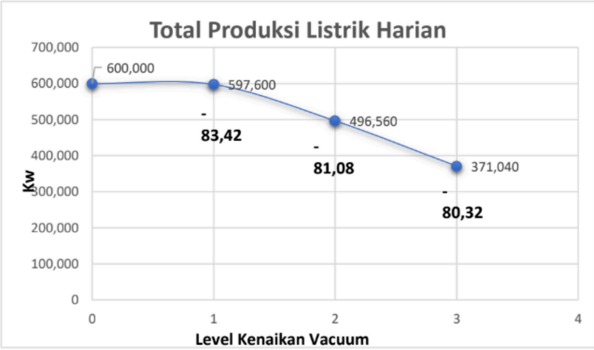

Figure 1 shows a decrease in daily electricity production as the condenser vacuum level increases. Under normal conditions, the Mamuju PLTU produces 600,000 kWh/day (100%). However, at vacuum level 1 (-83.42 KPa), daily electricity production decreases to 597,600 kWh/day (99.6%). At vacuum level 2 (-81.08 KPa), electricity production further drops to 496,560 kWh/day (82.59%), and at vacuum level 3 (-80.32 KPa), daily electricity production is only 371,040 kWh/day (61.86%). The total decrease in electricity production is 39% due to the increase in the condenser vacuum level.

Figure 2. Daily Electricity Sales

Figure 2 shows a decrease in daily electricity sales as the condenser vacuum level increases. Under normal conditions, the daily electricity sales of the Mamuju PLTU reach IDR 960,000,000/day (100%). However, at vacuum level 1 (-83.42 KPa), electricity sales decrease to IDR 956,160,000/day (99.6%). At vacuum level 2 (-81.08 KPa), electricity sales further decline to IDR 794,496,000/day (82.59%), and at vacuum level 3 (-80.32 KPa), daily electricity sales are only IDR 593,664,000/day (61.86%). The total decrease in electricity sales amounts to IDR 366,336,000.

Figure 3. Daily Revenue Loss

Figure 3 shows a decrease in daily electricity production due to the increase in condenser vacuum value, which causes the Mamuju PLTU to lose revenue. At vacuum level 1, the revenue loss reaches IDR 3,840,000/day, at vacuum level 2 it is IDR 165,504,000/day, and at vacuum level 3 it is IDR 366,336,000/day. The increase in vacuum value is caused by several factors, including damage to the cooling tower fan no.4 in the gearbox, which obstructs cooling, the collapse of the cooling tower frame, which makes heat absorption ineffective, and leaks in the condenser tubes due to scale cleaning, which leads to suboptimal steam condensation. As a result, the inlet temperature of the condenser cooling water increases from 31.27°C to 35.88°C, and the condenser temperature rises from 57.31°C to 61.13°C, causing the vacuum value to reach -80.32 KPa.

4. CONCLUSION

The increase in condenser vacuum value caused the Mamuju PLTU's capacity to drop from 100% to 61.81%, resulting in a daily revenue loss of IDR 366,336,000, from the expected IDR 960,000,000 to IDR 593,664,000. The main causes of the vacuum increase are damage to the cooling tower fan no. 4 gearbox, the collapse of the cooling tower frame, which reduces heat absorption effectiveness, and leaks in the condenser tubes due to scale cleaning, which hinders steam condensation and significantly increases the vacuum value.

5. REFERENCE

Abdi Seno. (2018). *Turbin Uap (Mesin Penggerak Utama)*. PIP Semarang. https://doi.org/6025694524

Alfani, T. ., Razak, A., & Rismawati, D. (2021). ANALISIS PERPINDAHAN PANAS PADA KONDENSOR DENGAN KAPASITAS AIR PENDINGIN 35860 m3/JAM. *SINERGI POLMED: Jurnal Ilmiah Teknik Mesin*, *2*(2), 62–70. https://doi.org/10.51510/sinergipolmed.v2i2.30

Dirmanto, S. S., & Effendi, A. R. (2020). Analisis Perubahan Tekanan Vakum Kondensor Terhadap Kerja Turbin Dan Produksi Listrik PLTU Unit 1 Sebalang Menggunakan Simulasi Cycle Tempo. *Jurnal Powerplant*, *8*(1), 1–29.

Imansyah, J. (2024). *Analisis Perubahan Tekanan Vakum Kondensor Terhadap Laju Perpindahan Panas dan Efektivitas Kondensor PLTU Suralaya Unit 6*. *34*(3), 19–26.

Ir. Djiteng marsudi. (2005). *Pembangkit tenaga listrik* (M. Wayan Santika, ST. & S. Lemeda simartama (eds.)). Erlangga.

Rahmawati, A. U., Wikendi, L., Maryanty, Y., & Yusuf, N. K. (2024). *ANALISIS PROSES KIMIA DALAM SIKLUS UAP AIR DI PLTU PAITON UNIT 1 DAN 2*.

10(9), 562–571.