A Comparative Performance Analysis of Generator Driven By Backpressure and CondensingTurbines at PT. BAI

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Abstract*—The increasing demand for electricity, both for community and industrial needs, necessitates the optimization of energy resources. PT Bintan Alumina Indonesia utilizes a Steam Power Plant (PLTU) to support the processing of bauxite into alumina. This PLTU employs two types of steam turbines: backpressure and condensate turbines, driving generators with capacities of 30 MW and 33 MW, respectively. This study aims to compare the performance of the two turbine types based on key parameters such as isentropic efficiency, power consumption, steam flow rate, and energy output.The research methodology includes operational data collection from the Distributed Control System (DCS) in the control room, literature reviews, interviews, and data processing using thermodynamic calculations based on the Rankine cycle. Operational data were recorded periodically over a month, focusing on peak load conditions. Analysis reveals that the condensate turbine has a higher average isentropic efficiency compared to the backpressure turbine, at 64.22% and 61.07%, respectively. However, the backpressure turbine excels in steam consumption, making it more economical.The generator efficiency of both turbines shows results above 90%, with the highest efficiency observed in the generator driven by the backpressure turbine at 98.68%. This study provides recommendations for selecting turbine types based on operational requirements, considering energy efficiency and production capacity.

Keywords: backpressure turbine, condensate turbine, isentropic efficiency, PLTU, Rankine cycle.

I. INTRODUCTION

Electricity is a primary need that greatly supports human life in carrying out daily activities. Nationally, electricity demand is also increasing in line with population growth. Electricity is also the most important factor in the development ofthe industrial world and technological progress. As the demand for electrical energy increases, so does the demand for of resources that must be converted into electrical energy. Therefore, the implementation of energy efficiency programs has become a requirement that must be met to control the amount of consumption and exploitation of resources, both in terms of the production process and the use of electricity.

PT Bintan Alumina Steam Power Plant (PLTU) Indonesia is part of a private power plant that is predicted to become one of the largest power plants in Riau Islands. In the first phase, there are currently 6 units, two of which have a capacity of 33 MW and the others each have a capacity of 30 MW. In the first or initial phase, the electricity generated is used to supply power to the alumina plant, as the primary production of PT Bintan Alumina Indonesia involves the processing bauxite processed into alumina powder. Therefore, the current usage is only for the alumina processing needs of phase 1 and also to supply supporting needs such as for the power plant itself, then for the Gas Plant, Port, Offices, and Dormitories.

The use of two different types of turbines at the PT. Bintan Alumina Indonesia coal-fired power plant is the main focus of this study. The generator with a capacity of 33 MW uses a condensing turbine, while the generator with a capacity of 30 MW uses a backpressure turbine. condensing turbine, while the 30 MW generator uses a backpressure turbine. The author aims to understand why two different types of turbines are used and to compare their performance. Performance is inevitably linked to their efficiency in utilizing electrical energy. In this study, the author will collect data by monitoring the Distributed Control System (DCS) located in the control room. System (DCS) located in the control room.

Of the six generators, two serve as backups, and the other four operate normally. Currently, generator sets 1 and 2 are not operating, and generator set 4 with a condensate turbine drive and generator set 5 with a backpressure turbine drive will be observed. The performance of the power plant to be observed includes: Flow rate, Heat rate, Output Power (Load), Voltage, Frequency, and Power Factor. These parameters will be observed for one consecutive month at the same time, namely at 6:00 PM WIB, as this is the peak load period.

II. METHOD

A. Research Design

Based on the problems and objectives in Chapter 1, this final project uses quantitative descriptive and qualitative descriptive research methods. Quantitative research aims to obtain mathematical calculations in determining turbine generator performance. Meanwhile, qualitative research aims to analyze the factors that influence turbine generator performance.

In general, the steps taken to complete this Final Project are shown in Figure 1. The research stage flowchart is as follows:

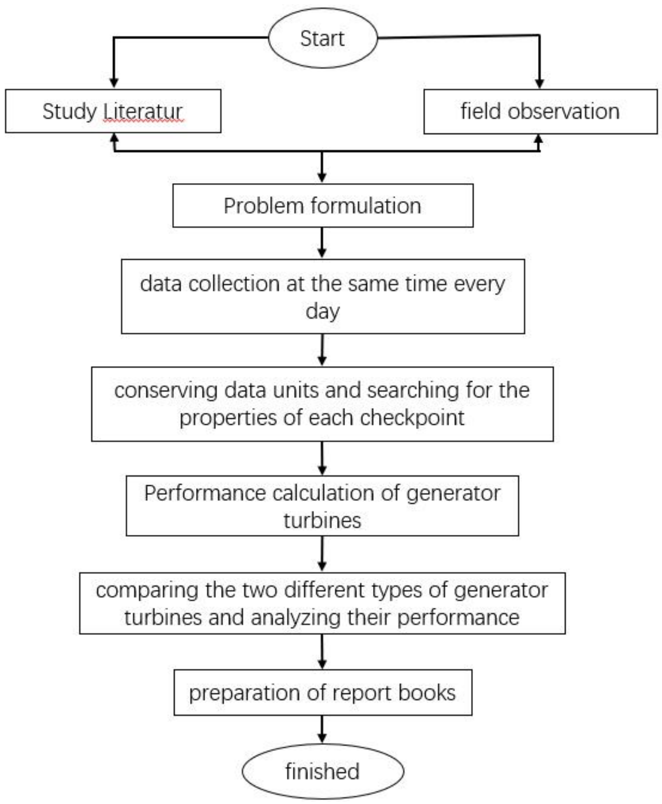

Figure 1. Flowchart

B. Data collection

In this study, several techniques were used for data collection, namely:

a) direct observation

The author collected data directly from the back pressure steam turbine at the PT Bintan Alumina Indonesia power plant. Pressure, temperature, and steam flow rate were recorded from the DCS screen in the control room.

b) indirect observation

The author collected data by obtaining data from the control room and also specification data on the generator and condensate steam turbine of Unit 04 and backpressure Unit 05. Generators Unit 04 and Unit 05 are of the QFW-33-2 and QFW-30-2 types, respectively. QFW itself is adopted from Mandarin and means a carbon brush-free boiler turbine generator set, with a power output of 33MW for unit 04 and 30MW for unit 05 with 2 poles. while the steam turbine condensate Unit 04 and backpressure unit 05 have models C30-8.83/1.1 and B25-8.83/1.1, with high temperature and high pressure types, single cylinder, impulse, back type steam turbine. The following are the specifications of the generator and back pressure steam turbine units 04 and 05 of the PT Bintan Alumina Indonesia power plant:

C. Research Variables

Research variables are quantities that can change and influence the results of a study. The existence of variables facilitates the analysis of problems. The variables used in this Final Project are:

a) Independent Variable

Independent variables are variables that influence the study. The variables in this study are based on operational data or parameter data shown on the DCS screen in the control room of the PT Bintan Alumina Indonesia power plant, namely:
1) Steam inlet pressure and steam outlet pressure in the steam turbine.
2) Steam inlet temperature in the steam turbine.
3) Steam flow rate and enthalpy.
4) Changes in the electrical load generated by the turbine.

b) Constant Variables

Constant variables are variables that are affected in the study. The constant variables in this study are:
1) Actual Steam Rate
2) Steam turbine efficiency

D. Equipment Specification Data

Table 1. Specification Data for Generator Units 4 and 5

category	Spesifikasi Generator Unit 04		Spesifikasi Generator Unit 05	
	Value	Unit	Value	Unit
Type	QFW-33-2		QFW-30-2	
voltage value	6300	V	6300	V
current value	3780	A	3437	A
speed value	3000	r/min	3000	r/min
frequency	50	Hz	50	Hz
output value	41,25	MVA	37,5	MVA
power value	33	MW	30	MW
excitation current	431	A	379,5	A
power factor	0,8		0,8	

Table 2. Specification Data for Condensing Turbine Unit 04 and Backpressure Generator Unit 05

category	Spesifikasi Turbin Unit 04 *Condesat*		Spesifikasi Turbin Unit 05 *Backpressure*	
	Value	Unit	Value	Unit
Type	C30-8,83/1,1		B25-8,83/1.1	
power value	30	MW	25	MW
inlet pressure value	8,83	Mpa	8,83	Mpa
extraction pressure value	1,1	Mpa	1,1	Mpa
speed value	3000	r/min	3000	r/min
inlet temperature value	535	℃	535	℃
extraction vapor rate value	80	t/h	165	t/h

E. Data Processing

After obtaining some data, the next step is data processing. Data processing to complete this research was carried out by describing the data and analyzing the actual steam rate and internal efficiency of the turbine so that the performance of the condensate and backpressure steam turbine unit 04 at the PT Bintan Alumina Indonesia power plant could be determined. The following are the data processing and calculation steps:

1) Processing data on pressure, temperature, electrical power, and steam flow rate. This data will be processed and used to calculate the actual steam rate and internal efficiency of the turbine.
2) Data on the power generated by the turbine with the steam rate required by the turbine to determine the actual steam rate. Then, the inlet and outlet pressure and temperature of the steam turbine are used to calculate the theoretical steam rate.
3) The results of the actual steam rate and theoretical steam rate calculations to obtain the internal efficiency of the turbine and the efficiency of the generator.

III. RESULT AND DISCUSSION

A. Research data

The research data was obtained from the data collection process after conducting research and field observations. The data was collected based on specification data and actual data on steam turbines. The specification data was based on the steam turbine operation manual at PT Bintan Alumina Indonesia. Meanwhile, the actual data was based on the operation of steam turbines in units 04 and 05 in November. The research results presented in tables and graphs are the results of primary data processing.

Table 3. Specification Data for Condensing Turbine Unit 04 and Backpressure Generator Unit 05

category	Spesifikasi Turbin Unit 04 *Condesat*		Spesifikasi Turbin Unit 05 *Backpressure*	
	Value	Unit	Value	Unit
Type	C30-8,83/1,1		B25-8,83/1.1	
power value	30	MW	25	MW
inlet pressure value	8,83	Mpa	8,83	Mpa
extraction pressure value	1,1	Mpa	1,1	Mpa
speed value	3000	r/min	3000	r/min
inlet temperature value	535	℃	535	℃
extraction vapor rate value	80	t/h	165	t/h

Table 4. Operational Data for Condensate Type Steam Turbine Unit 04

TIME	TURBIN NO.4					
	Steam Flowrate	Inlet Pressure	Inlet Temperature	Vacuum Pressure	Outlet Temperature	Debit Outlet Supply Alumina
	mi	Pi	Ti	Po	To	mo
	t/h	Mpa	℃	Kpa	℃	t/h
11.01 0:00	53.02	8.9	526.38	-94.69	36.09	0
11.01 1:00	65.93	9.1	531.82	-94.23	36.68	0
11.01 2:00	59.93	8.67	534.63	-94.39	35.83	0
11.01 3:00	63.99	8.96	532.06	-94.17	36.41	0
11.01 4:00	60.52	9.22	534.34	-94.22	36.42	0
11.01 5:00	71.96	8.55	529.93	-93.91	36.91	0
11.01 6:00	64.12	9.01	532.95	-94.23	36.32	0
11.01 7:00	56.39	8.91	533.9	-94.52	36.27	0
11.01 8:00	57.05	8.86	534.39	-94.28	36.04	0
11.01 9:00	59.15	9.02	532.98	-94.28	36.58	0
11.01 10:00	68.55	9.11	535.3	-94.31	36.86	0
11.01 11:00	61.08	9.22	530.98	-94.28	36.58	0
11.01 12:00	57.53	8.88	530.61	-94.42	37.02	0
11.01 13:00	62.45	9.04	531.28	-94.14	37.26	0
11.01 14:00	65.55	9.05	532.98	-94.28	36.58	0
11.01 15:00	61.22	8.98	532.98	-94.28	36.58	0
11.01 16:00	54.76	8.97	532.15	-94.37	36.26	0
11.01 17:00	51.62	8.99	540.21	-94.39	36.62	0
11.01 18:00	65.34	8.73	530.95	-93.94	37.28	0
11.01 19:00	67.53	8.77	535.47	-93.94	37.41	0
11.01 20:00	55.61	9.26	540.99	-94.38	36.8	0
11.01 21:00	59.19	8.99	537.24	-94.32	37.01	0
11.01 22:00	47.51	9.32	535.67	-94.78	35.95	0
11.01 23:00	65.74	8.85	536.51	-94.37	36.18	0

As can be seen in Table 4, the Operational Data for Steam Turbine Unit 04 is a type of condensate turbine. Basically, this type of condensate turbine will condense steam to remove energy and convert it back into water. This process creates vacuum pressure at the outlet so that no steam is available for further use. Under certain conditions, namely when the backpressure turbine type is unable to meet the alumina demand, the condensing turbine type is also used to supply steam to the alumina, but under normal conditions, steam is not supplied to the alumina; instead, all steam is condensed, so that the alumina supply outlet flow rate is 0 t/h.

a) Turbine Generator Efficiency Calculation Unit 04 and Unit 05

- ➢ Isentropic Efficiency Calculation (Ideal Conditions)
- ➢ Isentropic Efficiency Calculation (Real Conditions/Operation)

Using the known turbine specification data, the enthalpy of the turbine under isentropic conditions can be determined using the Thermodynamics Table. Outlet Condition Data:

- ◆ Vacuum Pressure = -94,69 KPa
  Air Pressure = 1 atm = 0,1 MPa
  = 100KPa
  Outward pressure (P2) = air pressure - vacuum pressure
  = 100KPa - 94,69 KPa
  = 5,41 KPa

- ◆ Exhaust Temprature (T2) = 36,09℃

With this data, the enthalpy value can be calculated using measurement point 2 for isentropic conditions, and the result is:

Table 5. Calculation Results using the Steam Calculator

Parameter	VALUE	UNIT
Saturated Steam Temperature	34.2856	°C
Latent Heat of Steam	2419.64	kJ/kg
Specific Enthalpy of Saturated Steam	2563.3	kJ/kg
Specific Enthalpy of Saturated Water	143.659	kJ/kg
Specific Volume of Saturated Steam	26.1672	m³/kg
Specific Volume of Saturated Water	0.001005	m³/kg

- ◆ H2s = 2563.3 kJ/kg
- ◆ m = 53.02 tons/hour
  = 14.73 kg/s 2.

Enthalpy Calculation under Actual Conditions (Real Conditions/Operating Conditions)

Data at 0:00 WIB

Po (outlet vapor pressure) = 5.31 kPa

Po (outlet vapor pressure) = 5.31 kPa

Pi (inlet vapor pressure) = 8.9 MPa

To (outlet vapor temperature) = 36.09 ℃

Ti (inlet vapor temperature) = 526.38 ℃

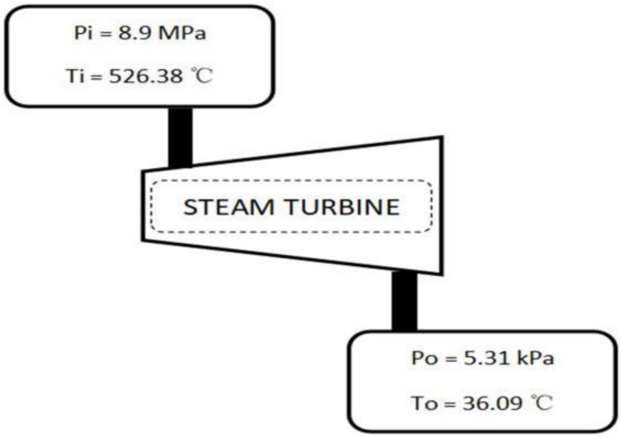

Figure 2. Steam Inlet and Outlet of Turbine Drive Generator Condensate Unit 04

Figure 2 above shows the energy conversion processin a steam turbine, with measurement data under actual conditions where Pi (inlet steam pressure) is recorded at 8.9 MPa and the temperature is 526.38℃, which is the superheated pressure and temperature that is expanded in the turbine to produce mechanical work, and the very low outlet steam pressure of 5.31 kPa is a vacuum condition and the outlet temperature is 36.09℃, which has been condensed to approach the ambient temperature.

Next, the steam turbine efficiency calculation can be performed, and the enthalpy value used in this calculation is the enthalpy obtained from the SteamTab program:

a) At point 1 (Actual Conditions)
Pi = 8.9 MPa
Ti = 526.38 ℃
Hi = 3454.54 KJ/Kg
Si (actual) = 6.7427 KJ/Kg.K

b) At point 2 (Actual Conditions)
Po = 5.31 kPa To = 36.09 °C
h2a = 2566.81 kJ/kg

c) At point 2s (Isentropic Condition)
Po = 5.31 kPa To = 36.09 ℃
hg = 2562.35 kJ/kg
Sf = 0.4886 kJ/kg·K
Sfg = 7.8874 kJ/kg·K
S2s = Si = 6.7427 kJ/kg·K

d) At point 2a (Actual Condition)
Po = 5.31 kPa
To = 36.09 ℃
hg = 2562.35 KJ/Kg
Sf = 0.4886 KJ/Kg.K
Sfg =7.8874 KJ/Kg.K
S2s = Si = 6.7427 KJ/Kg.K

1. Menentukan Fraksi Uap Isentropik
$_2 = (_2 -)/$
= 0.7929

2. Determining the Actual Vapor Fraction
$$x_{2a} = (S_{2a} - S_f)/S_{fg}$$
= 0.7929

3. Determining the enthalpy value of h2s
$$h_{2s} = (h_f - X_{2s}.h_{fg})$$
= 2061.05 kJ/Kg

4. Energy Used by Steam Turbines Actual Conditions
$$wa = (h1 - h2a)$$
= 887.79 kJ/Kg

5. Energy Used by Steam Turbines under Isentropic Conditions
$$ws = (h1 - h2s)$$
= 1393.49 kJ/Kg

6. Isentropic Efficiency of Steam Turbines
$$\eta_{termal} = \frac{w_a}{w_s} x100\%$$
= 63.71%

7. Steam Turbine Operation Actual Conditions
$$Wa = mi\,x\,w_a$$
= 15.54 MW

8. Generator Efficiency
$$\eta_{generator} = \frac{P_{in}}{P_{out}} x100\%$$
= 79.01%

Table 6. Operational Data for Backpressure Steam Turbine Unit 05

WAKTU	TURBIN NO.5					
	Steam Flowrate	Inlet Pressure	Inlet Temperature	Outlet Pressure	Outlet Temperature	Debit Outlet Supply Alumina
	mi	Pi	Ti	Po	To	mo
	t/h	Mpa	℃	Mpa	℃	t/h
11.01 0:00	160.04	9.14	533.52	1.01	317.26	123.12
11.01 1:00	160.04	9.14	533.52	1.01	317.26	123.12
11.01 2:00	162.7	8.94	526.96	1	310.41	123.84
11.01 3:00	162.7	8.94	526.96	1	310.41	123.84
11.01 4:00	158.67	8.99	532.87	0.99	315	122.08
11.01 5:00	158.87	8.67	534.12	0.99	316.69	122.29
11.01 6:00	158.87	8.67	534.12	0.99	316.69	122.29
11.01 7:00	158.66	8.71	521.36	0.96	305.26	120.56
11.01 8:00	162.36	8.63	528.35	0.99	312.19	123.01
11.01 9:00	163.01	9.06	526.37	1	308.15	124.93
11.01 10:00	162	8.71	529.18	0.99	310.71	125.04
11.01 11:00	161.64	8.71	529.18	0.99	310.71	125.04
11.01 12:00	166.1	8.86	529.92	1	310.98	125.62
11.01 13:00	161.64	8.73	527.92	1	308.64	123.38
11.01 14:00	166.1	8.74	528.82	0.99	309.15	127.52
11.01 15:00	146.12	8.97	525.39	0.99	322.47	105.52
11.01 16:00	146.12	8.97	525.39	0.99	322.47	105.56
11.01 17:00	146.73	9.19	532.01	1.04	334.42	106.33
11.01 18:00	165.36	8.99	537.5	1	314.86	130.11
11.01 19:00	165.36	8.99	537.5	1	314.86	130.11
11.01 20:00	163.58	8.69	531.82	0.97	309.14	126.03
11.01 21:00	163.25	9.07	530.83	0.99	311.11	123.63
11.01 22:00	158.21	8.91	528.82	0.98	310.71	121.14
11.01 23:00	161.48	8.77	531.33	0.98	313.74	123.99

As can be seen in Table 5, the Operational Data for Steam Turbine Unit 05 is a type of back-pressure turbine. Back-pressure turbines are designed to allow steam output at higher pressures, which is not condensed so that it is available for use in industrial processes. This residual steam is usually used for heating and other purposes. Therefore, it can be seen in the table above that the outlet flow rate to the alumina in the back-pressure turbine varies according to industrial needs.

b) Calculations based on Turbine Specifications

Turbine unit 05 at the PT Bintan Alumina Indonesia power plant has the specifications listed in Table 1 above. Based on the specifications of turbine unit 05 listed in Table 5 and the specifications listed in Table 3 above, the following calculations were made.

◆ ***Enthalpy Specific Inlet***

The specific enthalpy value of the inlet (hi) is calculated using a vapor table calculator:
Pi = 9.14 MPa
Ti = 533.52°C

Table 7. Calculation Results using the Steam Calculator

Parameter	value	unit
Specific Enthalpy of Saturated Steam	3469.71	kJ/kg

Based on the data from the vapor calculator above, the enthalpy value of superheated vapor (hi) is known to be:

hi = 3469.71 kJ/kg

- ***Entropy Specific Inlet***

Based on the inlet temperature value of 533.52°C, the entropy value can be found using the following steam table:

$$Si = Si' + (Pi - Pi')\frac{Si'' - Si'}{Pi'' - Pi'}$$

$$Si = 6{,}8207 + (8{,}83 - 8{,}0)\frac{6{,}7886 - 6{,}8207}{9{,}0 - 8{,}0}$$

$$Si = 6{,}7940\ kJ/kg$$

- ***Entalpy Specific Outlet***

The specific enthalpy value (ho) is calculated using a vapor table calculator

Po= 1,1 Mpa

To = 282,8°C

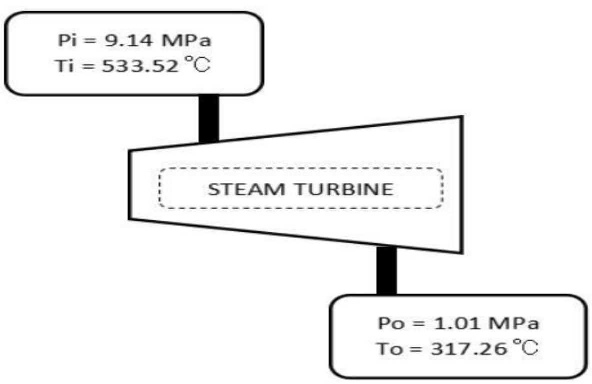

Figure 3. Steam Inlet and Outlet of Backpressure Turbine Generator Unit 05

Figure 3 above shows the energy conversion process in a backpressure steam turbine, with measurement data under actual conditions where Pi (inlet steam pressure) was recorded at 9.14 MPa and the temperature at 533.52°C These are the actual conditions of the turbine during operation, where the superheated pressure and temperature are recorded as they expand within the turbine, generating mechanical work. The steam exits at 1.01 MPa and an outlet temperature of 317.26°C. These values differ from those of a condensing turbine. With such outlet pressure and temperature, it can be confirmed that the steam is reused for the production process.

Next, the steam turbine efficiency calculation can be performed, and the enthalpy value used in this calculation is the enthalpy obtained from the SteamTab program:

a. At point 1 (Actual Conditions)
Pi = 9.14 MPa
Ti = 533.52 °C
hi = 3469.71 KJ/Kg
Si (actual) = 6.7940 KJ/Kg.K

b. At point 2 (Actual Conditions)
Po = 1.01 kPa
To = 317.26°C
h2a = 3111.56 KJ/Kg

c. At point 2s (Isentropic Conditions)
Po = 1.01 MPa
To = 317.26°C
hg = 2708.49 kJ/kg
Sf = 3.4219 kJ/kg·K
Sfg = 2.1396 kJ/kg·K
S2s = Si = 6.5557 kJ/kg·K

d. At point 2a (Actual Condition)
Po = 1.01 kPa
To = 317.26°C
hg = 2708.49 KJ/Kg
Sf = 3.4219 KJ/Kg.K
Sfg =2.1396 KJ/Kg.K
S2s = Si = 6.5557 KJ/Kg.K

1. Determining the Isentropic Vapor Fraction

$$_{2s} = (_{2s} - _{g})/_{g}$$

=1.4647

2. Determining the Actual Vapor Fraction

$$x_{2a} = (S_{2a} - S_f)/S_{fg}$$

=1.4647

3. Determining the enthalpy of h2s

$$h_{2s} = (h_f - X_{2s}.h_{fg})$$

= 443.82 kJ/Kg

4. Energy Used by Steam Turbines Actual Conditions

$$wa = (h1 - h2a)$$

= 1871.21kJ/Kg

5. Energy Used by Steam Turbines Isentropic Conditions Isentropic

$$ws = (h1 - h2s)$$

= 3025.89 kJ/Kg

6. Isentropic Efficiency of Steam Turbines

$$\eta_{termal} = \frac{w_a}{w_s}x100\%$$

= 61.84 %

7. Steam Turbine Operation Actual Conditions

$$Wa = mi\,x\,w_a$$

= 15.8 MW

8. Efficiency Generator

$$\eta_{generator} = \frac{P_{in}}{P_{out}}x100\%$$

=96.80%

B. Seteam turbine efficiency calculation results data

Table 8. Calculation of Isentropic Efficiency and Efficiency of the Condensate Type Generator Unit 04

WAKTU	OUTLET STEAM TURBIN (ISENTROPIK)			Efesiensi Isentropik	Kerja Turbin Uap Kondisi Aktual (Wa)	Daya Generator	Effisiensi Generator
	Po	To	entalpi (h2s)				
	Mpa	°C	kJ/kg		MW	MW	
12:00:00 AM	5.31	36.09	2061.05	63.71%	13.08	12.28	93.85%
1:00:00 AM	5.77	36.68	2064.17	64.07%	16.46	15.15	92.03%
2:00:00 AM	5.61	35.83	2063.09	64.43%	15.18	11.64	76.67%
3:00:00 AM	5.83	36.41	2064.58	64.18%	16.02	12.69	79.19%
4:00:00 AM	5.78	36.42	2064.24	64.24%	15.20	12.89	84.78%
5:00:00 AM	6.09	36.91	2066.34	64.18%	17.98	14.21	79.01%
6:00:00 AM	5.77	36.32	2064.17	64.22%	16.09	13.91	86.46%
7:00:00 AM	5.48	36.27	2062.20	64.22%	14.20	12.47	87.80%
8:00:00 AM	5.72	36.04	2063.83	64.37%	14.41	12.09	83.93%
9:00:00 AM	5.72	36.58	2063.83	64.17%	14.83	11.24	75.78%
10:00:00 AM	5.69	36.86	2063.63	64.24%	17.27	12.41	71.85%
11:00:00 AM	5.72	36.58	2063.83	63.98%	15.20	13.26	87.26%
12:00:00 PM	5.58	37.02	2062.88	63.95%	14.34	13.78	96.08%
1:00:00 PM	5.86	37.26	2064.78	64.01%	15.56	12.62	81.10%
2:00:00 PM	5.72	36.58	2063.83	64.16%	16.43	12.17	74.06%
3:00:00 PM	5.72	36.58	2063.83	64.18%	15.36	13.21	86.01%
4:00:00 PM	5.63	36.26	2063.22	64.14%	13.72	11.7	85.29%
5:00:00 PM	5.61	36.62	2063.09	64.58%	13.20	12.48	94.51%
6:00:00 PM	6.06	37.28	2066.14	64.14%	16.33	12.71	77.84%
7:00:00 PM	6.06	37.41	2066.14	64.54%	17.11	12	70.13%
8:00:00 PM	5.62	36.8	2063.15	64.54%	14.21	13.9	97.84%
9:00:00 PM	5.68	37.01	2063.56	64.37%	15.01	13.59	90.55%
10:00:00 PM	5.22	35.95	2060.44	64.17%	11.97	11.33	94.62%
11:00:00 PM	5.63	36.18	2063.22	64.46%	16.691	12.98	77.76%

Isentropic efficiency ranges from 63.71% to 64.54%, indicating that the steam expansion process in the turbine is not fully reversible. However, the variation is relatively small, which means that operating conditions are fairly stable. The actual turbine work ranges from 14.64 MW to 15.77 MW, while the generator power ranges from 11.24 MW to 15.15 MW. There is a direct relationship between turbine work and generator power, because the generator converts mechanical energy from the turbine into electrical energy. The greater the generator power produced, the better the efficiency. This can be seen in the highest generator efficiency occurring at 1:00 a.m. (97.84%) with an output power of 15.15 MW, while the lowest efficiency occurred at 10:00 p.m. (70.13%) with an output power of 11.24 MW.

Table 9. Calculation of Isentropic Efficiency and Efficiency of the Backpressure Type Generator Unit 05

WAKTU	OUTLET STEAM TURBIN (ISENTROPIK)			Efesiensi Isentropik	Kerja Turbin Uap Kondisi Aktual (Wa)	Daya Generator	Effisiensi Generator
	Po	To	entalpi (h2s)				
	Mpa	°C	kJ/kg		MW	MW	
12:00:00 AM	1.01	317.26	443.82	63.81%	15.93	12.28	77.07%
1:00:00 AM	1.01	317.26	443.82	61.84%	15.93	15.15	95.08%
2:00:00 AM	1	310.41	355.88	61.54%	16.18	11.64	71.94%
3:00:00 AM	1	310.41	355.88	61.54%	16.18	12.69	78.42%
4:00:00 AM	0.99	315	413.99	61.87%	16.00	12.89	80.58%
5:00:00 AM	0.99	316.69	436.30	61.93%	16.00	14.21	88.79%
6:00:00 AM	0.99	316.69	436.30	61.93%	16.00	13.91	86.91%
7:00:00 AM	0.96	305.26	292.93	61.32%	15.73	12.47	79.26%
8:00:00 AM	0.99	312.19	378.42	61.70%	16.29	12.09	74.21%
9:00:00 AM	1	308.15	328.15	61.51%	16.29	11.24	68.99%
10:00:00 AM	0.99	310.71	359.68	61.76%	16.44	12.41	75.47%
11:00:00 AM	0.99	310.71	359.68	61.76%	16.41	13.26	80.82%
12:00:00 PM	1	310.98	363.10	61.77%	16.84	13.78	81.81%
1:00:00 PM	1	308.64	334.12	61.71%	16.44	12.62	76.74%
2:00:00 PM	0.99	309.15	340.34	61.76%	16.95	12.17	71.81%
3:00:00 PM	0.99	322.47	514.11	61.21%	13.38	13.21	98.76%
4:00:00 PM	0.99	322.47	514.11	61.21%	13.38	11.7	87.47%
5:00:00 PM	1.04	334.42	630.55	61.26%	13.02	12.48	95.83%
6:00:00 PM	1	314.86	412.22	61.20%	17.21	12.71	73.85%
7:00:00 PM	1	314.86	412.22	61.20%	17.21	12	69.72%
8:00:00 PM	0.97	309.14	340.21	62.18%	17.05	13.9	81.51%
9:00:00 PM	0.99	311.11	364.75	62.18%	16.54	13.59	82.14%
10:00:00 PM	0.98	310.71	359.68	61.98%	15.93	11.33	71.14%
11:00:00 PM	0.98	313.74	287.29	61.98%	16.327	12.98	79.50%

The isentropic efficiency value ranges from 61.63% to 62.20%. The variation in isentropic efficiency is very small, which means that the thermodynamic conditions of steam expansion in the turbine are quite stable. The enthalpy of the steam leaving the turbine ($h_{2}s$) also varies slightly, indicating minor changes in the turbine's operating conditions. Generator power ranges from 13.77 MW to 16.43 MW, indicating that most of the energy from the turbine is successfully converted into electricity. Generator efficiency ranges from 80.75% to 98.68%, with an average above 95%, indicating that the conversion of mechanical energy into electricity is working well. The greater the generator power produced, the better the efficiency. This can be seen in the highest generator efficiency occurring at 02:00 (98.68%), while the lowest efficiency occurred at 20:00 (80.75%). High generator efficiency indicates that the generator is working in optimal conditions with minimal mechanical or electrical power loss.

C. Power Consumption Operational Data for Generator Units 04 and 05

Table 10. Power Consumption in Drive Generators

November	Konsumsi Daya Genenerator Unit 04		Konsumsi Daya Genenerator Unit 05	
	Generator 04	Reaktor 04	Generator 05	Reaktor 05
1-Nov	309960	63756	369432	78876
2-Nov	337680	65016	351288	80136
3-Nov	344736	62748	372456	82152
4-Nov	300384	65520	381024	80640
5-Nov	319032	65016	375984	80892
6-Nov	330120	65520	366408	79884
7-Nov	363888	67788	360864	79632
8-Nov	351288	65520	359856	80388
9-Nov	311472	67788	387072	80388
10-NOV	348264	67032	404208	80892
11-Nov	318528	66780	395136	82656
12-Nov	322056	65268	373968	85176
13-Nov	380016	77616	350280	85428
14-Nov	380520	94248	350280	86184
15-Nov	417312	95256	335664	85428
16-Nov	438480	99288	400680	82908
17-Nov	345744	99792	359856	84672
18-Nov	387072	101556	365904	87444
19-Nov	424368	101052	348768	87192
20-NOV	394128	113148	362880	87948
21-NOV	402696	121212	355320	87444
22-Nov	430416	121968	340704	86940
23-Nov	416808	123228	355320	78876
24-Nov	358344	122472	362376	36540
25-Nov	379512	121716	358344	37044
26-Nov	398160	106848	356328	36540
27-Nov	341208	98784	362376	36792
28-Nov	413280	99540	350784	35784
29-Nov	404208	95760	348768	36036
30-NOV	350784	88704	353808	35532

In addition to generator efficiency and isentropic efficiency, the performance comparison between the two generators can be seen from the comparison of the electrical power consumption used for the production process. Table 10 shows the power consumption values for the two types, which have a significant difference, namely that the power consumption in the backpressure type generator is greater than the power consumption in the condensate type generator.

D. Operational Data on Steam Consumption in Type Turbines Iondensat Units 04 and 05

Table 11. Steam Consumption in Condensate Type Turbine Unit 04 and Backpressure Type Turbine Unit 05

Waktu	Konsumsi Uap Turbin Unit 04 (TON)	Konsumsi Uap Turbin Unit 05 (TON)
1-Nov	1473	3861
2-Nov	1560	3727
3-Nov	1589	3865
4-Nov	1444	3940
5-Nov	2269	3787
6-Nov	1540	3838
7-Nov	1641	3804
8-Nov	1460	3787
9-Nov	1388	3956
10-Nov	1602	4081
11-Nov	1491	4013
12-Nov	1512	3871
13-Nov	1716	3698
14-Nov	1730	3661
15-Nov	1837	3535
16-Nov	1919	3974
17-Nov	1619	3703
18-Nov	1732	3716
19-Nov	1865	3624
20-Nov	1766	3730
21-Nov	1793	3655
22-Nov	1889	3578
23-Nov	1844	3670
24-Nov	1638	3735
25-Nov	1717	3779
26-Nov	1788	3769
27-Nov	1549	3804
28-Nov	1664	3736
29-Nov	1627	3696
30-Nov	1456	3747

Steam consumption is also a factor to consider in determining the performance of condensing turbine generators and backpressure turbine generators, so that a company understands how to apply these two types. Table 11 shows that steam consumption in backpressure turbine generators is three times greater than in condensate turbine generators. This is clearly because the backpressure type is designed so that the turbine still produces output steam that can be reused in the production process.

E. Inlet Steam Flow Analysis

Based on the operational data above, it can be analyzed that the two types of turbines used to drive generators at PT Bintan Alumina Indonesia have very different inlet flow rates. On November 1, from 00:00 to 23:00, the generator with a condensing turbine drive had a steam flow rate ranging from 47.51 tons/hour to 71.96 tons/hour, while the generator with a backpressure turbine drive had a steam flow rate ranging from 146.12 tons/hour to 166.1 tons/hour. This is because in the condensing turbine type, almost all the steam is used to generate power in the generator, and the remaining steam is then condensed into water vapor, so it can also be seen that the steam outlet flow rate in the condensing turbine is 0. Meanwhile, backpressure turbines with an inlet steam flow rate that is almost three times that of condensate turbines still have an outlet steam flow rate ranging from 105.52 tons/hour to 130.11 tons/hour.

This is because the steam from the unit 05 turbine generator is supplied to the alumina plant for processing bauxite into alumina powder, although under certain conditions the unit 04 generator can also supply steam. This is because the steam in the generator turbine unit 05 is supplied to alumina for processing bauxite into alumina powder, although under certain conditions the generator unit 04 can also supply steam to alumina but with a smaller flow rate, similar to a backpressure turbine. Based on this operational data, it can also be determined how much steam flow each unit requires to generate 1 MW of power. Figure 15 is a graph comparing the steam requirements with the power generated between units 04 and 05.

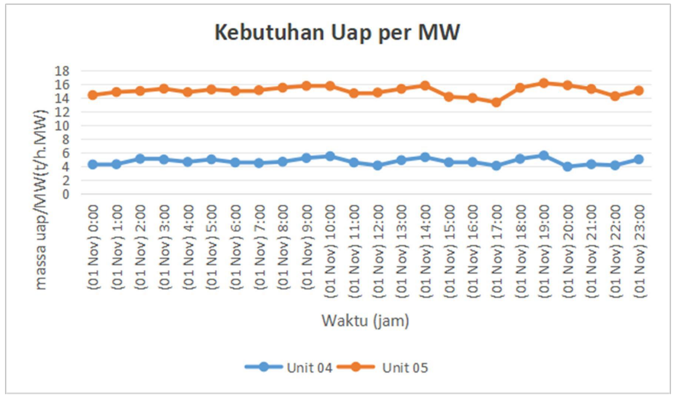

Figure 4. Steam Demand Chart per MW

Based on the graph above, it can be seen that unit 04 requires an average steam flow of 4.76 t/h to generate 1 MW of power, while unit 05 requires an average steam flow of 10.31 t/h to generate 1 MW of power. Therefore, it can be said that unit 05 requires twice as much steam to generate the same MW of power output.

F. Analysis of Isentropic Efficiency and Efficiency Generator.

Previously, to determine the isentropic efficiency of units 04 and 05, calculations needed to be performed, requiring several data such as equipment specification data and operational/actual data to determine the actual conditions compared to isentropic conditions. This data includes Steam Turbine Inlet Pressure (Mpa), Steam Turbine Inlet Temperature (℃), Steam Turbine Outlet Pressure (Mpa), and Steam Turbine Outlet Temperature(℃). To simplify the process of finding the enthalpy and entropy values from each data point collected, the SteamTab application and Steam Calculator can be used.

For example, on November 1 at 00:00, based on operational data in unit 04, the inlet pressure Pi = 8.9 MPa with an inlet temperature Ti = 526.38 ℃. Using a steam calculator, the inlet enthalpy hi = 3454.54 KJ/Kg is obtained, and using SteamTab, the entropy Si (actual) = 6.7427 kJ/kg·K. At point 2 (Actual Condition), the outlet pressure Po = 5.31 kPa with an outlet temperature To = 36.09 °C. Using a steam calculator, the inlet enthalpy h2a = 2566.81 kJ/kg. Meanwhile, to determine the enthalpy value under isentropic conditions, using specification data, the isentropic enthalpy value h2s = 2061.05 kJ/kg was obtained, with a steam turbine isentropic efficiency of 63.71%, turbine power of 15.54 MW, and generator efficiency of 79.01%. For the second calculation and measurement, conducted at the same time and date using the same formula on unit 05 based on operational data, the inlet pressure Pi = 9.14 MPa with inlet temperature Ti = 533.52 ℃ and inlet enthalpy hi = 3469.71 kJ/kg, and the actual entropy Si = 6.7427 KJ/Kg.K. At point 2 (Actual Conditions) Outlet pressure Po = 1.01 MPa with outlet temperature To = 317.26 ℃, the inlet enthalpy h2a = 3111.56 kJ/kg is obtained. Based on specification data, the isentropic enthalpy h2s = 443.8247 kJ/kg is obtained, with a steam turbine isentropic efficiency of 61.84%, a turbine power of 15.8 MW and generator efficiency of 96.80%. The following graph is a tool for determining the comparison of isentropic efficiency and generator efficiency of the two units.

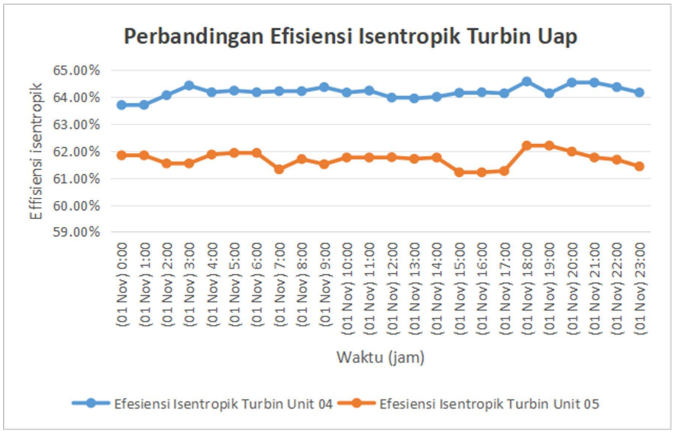

Figure 5. Isentropic Efficiency Comparison Chart Steam Turbine

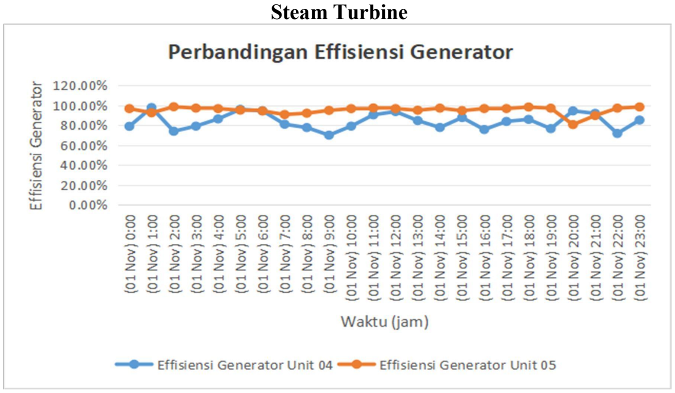

Figure 6. Generator Efficiency Comparison Chart

Based on the graph above, the comparison value of the efficiency of unit 04 is greater than the efficiency of unit 05, even though the difference in value is very small because the isentropic efficiency of both units is still around 60%. This is in contrast to the efficiency of the generator, where the comparison of the efficiency of the generator unit 05 is greater than unit 04. Therefore, the performance of unit 04 based on isentropic efficiency calculations is better than unit 05 because there are major factors such as heat transfer from the system to the environment and vice versa. Ideally, the process that occurs in a turbine is adiabatic, where there is no heat exchange between the system and the environment. Efficiency itself describes how close a real process is to the ideal isentropic process, but this is very difficult because it is almost impossible. Meanwhile, based on generator efficiency, Unit 05 is greater than Unit 04 because the active power generated by Unit 05 is greater than that of Unit 04. The difference in power itself is due to the amount of steam required by the alumina; the less steam required by the alumina, the smaller the active power in Unit 04 because the inlet steam pressure will be reduced. Additionally, the magnitude of the turbine's work also affects the generator's performance. Therefore, the steam pressure in Unit 05 will be increased, and vice versa.

G. Comparative Analysis of Electricity Load Consumption and Steam Consumption.

Electricity Load Consumption and Steam Consumption were recorded once a day at 24:00, so the data collected was at different times from the others. During the 30 days of recording in November, it can be seen that the average steam consumption values for generators 05 and 06 are nearly identical, with unit 04 at 367,349 kWh and unit 05 at 363,871 kWh. Reactor consumption in unit 04 is 88,998 kWh and in unit 05 is 72,214.8 kWh. Reactor electricity consumption refers to the electricity used by the reactor itself, while generator consumption is the electricity used for alumina. From a design perspective, the turbine generator driving the condensate system is more complex than the backpressure type due to the additional pumps, resulting in higher equipment consumption. Higher electricity consumption also affects the performance of both units because as electricity consumption increases, the generator's performance decreases.

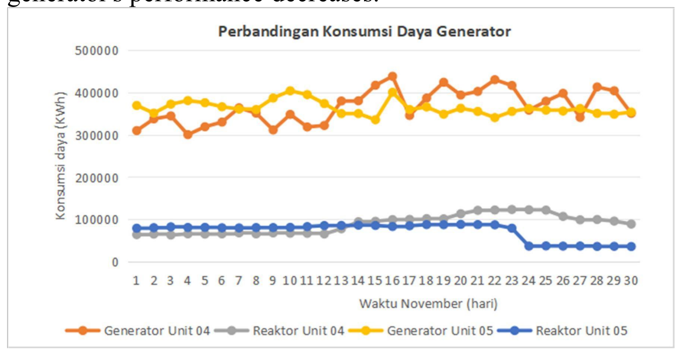

Figure 7. Power Consumption Comparison Chart in Generators

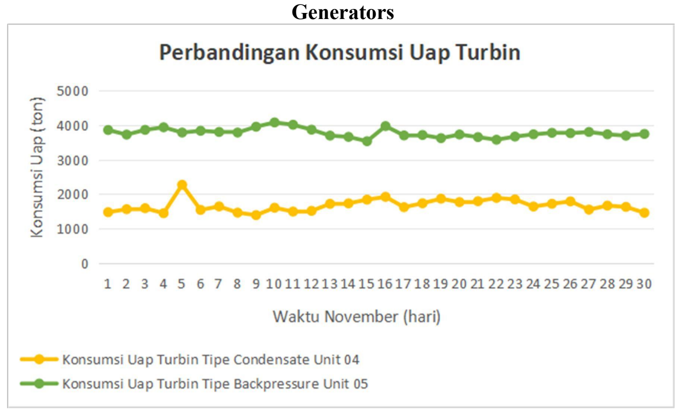

Figure 8. Steam Consumption Comparison Chart in Turbines

Based on the steam consumption graph above, it can be seen that the steam consumption of unit 05, which is a backpressure type, is greater than that of unit 04, which is a condensate type. This is because the turbine is designed so that the remaining steam can still be reused for other production processes. However, based on performance from the perspective that the turbine is only a generator driver to produce electricity, it can be said that unit 05 has poorer performance than unit 04 in terms of electricity consumption. However, from the perspective of turbine performance solely as a generator driver for electricity generation, it can be stated that Unit 05 has poorer performance than Unit 04 in terms of steam consumption. Therefore, to balance the performance of both units for electricity production, Unit 04 with the condensate type is highly suitable, and for steam production, it is strongly recommended to use Unit 05 with the backpressure type. For this reason, PT Bintan Alumunia Indonesia only has two types of condensate turbine generators and four backpressure turbine generators.

IV. CONCLUSIONS AND RECOMMENDATIOON

A. Conclusions

1. Comparison of Steam Flow Rate Condensate turbines require a smaller average steam flow rate (4.76 t/h per MW) compared to backpressure turbines (10.31 t/h per MW). Backpressure turbines produce more outlet steam for reuse in the production process. In this case, it can be seen that to generate the same amount of electricity, backpressure turbines will require higher operational costs compared to condensate types because they require a lot of steam, which means that fuel requirements will also increase.
2. Isentropic Efficiency and Generator, Unit 04 type condensate has a slightly higher average isentropic efficiency (64.22%) compared to Unit 05 backpressure type (61.70%). Conversely, Unit 05 has a higher average generator efficiency of (84.01%) compared to Unit 04 (95.16%). Several factors influence the efficiency values, namely pressure and temperature. If the steam pressure and temperature increase, the efficiency value also increases.
3. Electricity and Steam Consumption, Unit 05 has higher steam consumption due to its design that supports the reuse of residual steam for alumina production. Generator and reactor electricity consumption is higher in unit 04, because the condensate system design requires more additional equipment.
4. Selecting efficient turbines that are suitable for process requirements can reduce fuel consumption and emissions, supporting the company's sustainability initiatives. Production efficiency in condensate turbines can generate more electrical energy, which can increase production efficiency. However, if the company has steam requirements for other processes, backpressure turbines may be more suitable because the waste steam can be utilized, increasing the overall efficiency of the system.

B. Recommendations

1. Optimize generator usage by using unit 04 to generate electricity due to its better steam consumption efficiency and using unit 05 to support steam production needs in the alumina process.
2. Reduce electricity consumption by checking the condensate system design on unit 04 to reduce high electricity consumption, for example by increasing the efficiency of additional pumps.
3. Monitoring and Maintenance: Perform routine maintenance to maintain isentropic efficiency and generator performance at optimal levels. Use tools such as SteamTab periodically to measure enthalpy and entropy, ensuring operating conditions are close to optimal values.
4. Evaluate the Energy Use System and consider implementing an additional heat recovery system to improve overall efficiency, especially in unit 05, to reduce energy loss.

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