THE ANALYSIS OF STEAM TURBINE EFFICIENCY BEFORE AND AFTER OVERHAUL ON THE UNIT 5 AT PT PERTAMINA GEOTHERMAL ENERGY AREA KAMOJANG

Bayu Tri Darurohman *) Indah Dhamayanthie, Elli Prastyo

Chemical Engineering D-III Study Program, AKAMIGAS BALONGAN, Indramayu 45216, Indonesia

*)E-mail: Bayu3daru@gmail.com

Abstract

The Kamojang Geothermal Power Plant (PLTP) is located in Laksana Village, Ibun District, Bandung Regency, West Java. Since 1982, with a production rate of 235 MW of electricity generated from PLTP Unit 1, Unit 2, and Unit 3 with a total installed capacity of 140 MW owned and operated by PLN and PLTP Unit 4 and Unit 5 of 95 MW owned and operated by PT Pertamina Geothermal Energy by utilizing geothermal energy in the form of steam supplied from wells made by Pertamina. This research is diverted to see the efficiency of the unit 5 turbine which has been overhauled for 15 days using the method of thermodynamic analysis to calculate the isentropic enthalpy ($h_{2s}$) and the turbine power after which the turbine efficiency will be obtained. Steam quality, turbine power, turbine work, actual turbine enthalpy outlet, and ideal enthalpy are parameters needed in the analysis to determine turbine performance before and after overhaul. The isentropic enthalpy ($h_{2s}$) value before overhaul is 2127.41 kJ/kg and after overhaul is 2145.91 kJ/kg. The value of Turbine power ($W_t$) before overhaul is 30702.88 kW and after overhaul is 36304.7 kW and Efficiency after overhaul has decreased by 1% from Efficiency before overhaul due to small isentropic efficiency based on the difference from the actual turbine power of each steam mass flow to isentropic power turbine.

Keywords: Isentropic enthalpy, Turbine power, Turbine Efficiency.

1. Introduction

PLTP Kamojang is one of the geothermal plants in Indonesia. PLTP Kamojang is able to generate electricity of 95 MW in Units 4 and 5 by PT Pertamina Geothermal Energy. Geothermal Power Plants must be able to maintain stable performance so that electricity production can reach maximum quality. The steam turbine is the main equipment for PLTP which plays an important role as a prime mover to convert heat energy in steam into mechanical energy in the form of turbine shaft rotation. Furthermore, the turbine shaft is coupled with the generator shaft to produce electrical energy. The reliability of the steam turbine can be seen from the performance of the steam turbine [1]. Steam turbine performance has parameters of thermal efficiency, turbine isentropic efficiency, turbine heat rate, and steam rate. However, over the length of the operating hours,

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</table>
The decrease in the efficiency value of the turbine will result in reduced work generated. In maximizing this efficiency, it is necessary to analyze the actual work on the ideal work resulting from the steam turbine. The efficiency calculated in this practical work is turbine efficiency, where turbine efficiency is a parameter which states the degree of success of the turbine component or system approaching the ideal design or process in units (%). To find out how the performance of turbines and generators at PLTP Kamojang, a study was conducted with the title Turbine Efficiency at PLTP Kamojang Unit V PT Pertamina Geothermal Energy.

Based on the title that we will discuss, the specific objectives of this Final Project Report are:

1. To know the Isentropic Enthalpy (h2s) before and after the overhaul on the Turbine Unit 5.
2. To know the value of Turbine Power (Wt) before and after the overhaul of the Turbine Unit 5.
3. To know the value of isentropic efficiency before and after the overhaul of the Turbine Unit 5 PLTP PT Pertamina Geothermal Energy in Kamojang Area.

2. Fundamental Theory

2.1 Geothermal

Geothermal is a natural heat resource found in the earth, which is the result of the interaction between the heat emitted by hot rock (magma) and the ground water around it, where heated liquid is trapped in rock that is located near the surface so that it can be economically utilized [2].

Geothermal area or geothermal field is an area on the surface of the earth within certain limits where there is geothermal energy in a certain hydrological rock conditions or called the geothermal system. Geothermal energy is generally found around volcanoes, both still active and dead / resting. If environmental conditions allow, surface water flowing through pores or rock fractures and in contact with hot rock will be trapped in reservoir-shaped rock that is above hot rock and covered by impermeable cap rock, so steam water and hot water will be confined to high temperature and pressure. To be able to extract and utilize geothermal sources from reservoirs in the earth, drilling activities and construction of storage pipes is necessary [2].

2.2 Turbine

![Turbine Unit 5](image)

Turbine is a tool or engine where the working fluid energy is used to rotate the turbine wheel. The turbine consists of 2 parts, namely the rotor (the rotating part / turbine wheel) and the stator (the non-rotating part / turbine housing). The turbine wheels are located inside the turbine housing and the turbine wheels will turn the load (generator, propeller, or other engine). The types of fluids used to drive the turbines include water, steam and gas. Basically, there are two types of turbines: turbines with an output pressure equal to the outside air pressure (Atmospheric Exhaust / Back Pressure Turbine) hereinafter referred to as turbines without a condenser and turbines with a condenser (Condensing Unit Turbine). In a turbine without a condenser, the fluid that comes out of the turbine is immediately discharged into the air, whereas in a turbine with a condenser the fluid that comes out of the turbine is flowed into the condenser to be condensed [3]. The turbine at the PT Pertamina Geothermal Energy Area Kamojang PLTP is a single casing multi-stage condensing turbine with 7 stages. The technical data or turbine specifications used are shown in table 1.

<table>
<thead>
<tr>
<th>Manufacture</th>
<th>Fuji Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Single casing multi-stage condensing type</td>
</tr>
<tr>
<td>Rated output</td>
<td>37260 kW</td>
</tr>
<tr>
<td>Main Steam pressure at main stop valve</td>
<td>6.5 bara</td>
</tr>
<tr>
<td>Main Steam Temperature at main stop valve</td>
<td>166.8°C</td>
</tr>
<tr>
<td>Exhaust Pressure</td>
<td>0.1 bara</td>
</tr>
<tr>
<td>Rated Speed</td>
<td>3000 rpm</td>
</tr>
<tr>
<td>Direction of rotation</td>
<td>Counter clockwise</td>
</tr>
<tr>
<td>Number of blading stages</td>
<td>Reaction stage 7</td>
</tr>
<tr>
<td>Emissivity Generator</td>
<td>0.971</td>
</tr>
</tbody>
</table>

The incoming steam moves axially through the moving blade and stationary blade, which eventually pushes the bearing mounted on the shaft (rotor) so that the turbine rotates, the coupled generator immediately spins. Then the remaining steam is flowed into the condenser.

2.3 Turbine Components

The components contained in the turbine include:

1. Bearing

Bearings or bearings function to withstand the force, which is divided into journal bearings which serve to hold and support the radial force of the rotor and thrust bearings to withstand the axial force of the rotor.
2. Blade
Blades, or blades, are divided into two types, namely moving and stationary blades which are formed by T-shaped legs. On the outer side, there are 2 moving blades to prevent erosion of the steam contained in water.

3. Lube Oil System
Lube oil or lubricating oil functions as a lubricant and coolant for turbines and generator bearings, but it is also used for control systems.

4. Tuning Gear
Tuning Gear functions to rotate the turbine shaft at start and shut down so that the turbine shaft does not curve due to uneven heat. The turning gear when turning the shaft is 5 rpm.

2.4 Dry Steam Cycle
The dry vapor fluid conversion system is the simplest and cheapest conversion system. The dry steam is flowed directly to the turbine and then after being utilized, it is flowed into the condenser (condensing turbine) [4].

![Figure 2 TS diagram for a dry steam conversion system](image)

Point 1 the phase of geothermal fluid is steam, while at point 2 the fluid is two phases. The process that the fluid takes from point 1 to point 2 is considered an isentropic process so that the entropy at point 1 is the same as the entropy at point 2. The steam mass flow rate needed to supply PLTP with a capacity P is determined using the following equation [4]:

\[ P_t = \frac{\dot{m} \cdot x \cdot (h_1 - h_2)}{1} \]  

Equation 1

With:
- \( \dot{m} \) = mass flow rate of vapor (kg/s)
- \( P_t \) = electric power (kW)
- \( \eta \) = turbine efficiency (%)
- \( h_1 \) = enthalpy at turbine input (kJ/kg)
- \( h_2 \) = enthalpy at actual state turbine output (kJ/kg)

In accordance with the Ts diagram above, this process occurs isobaric process or constant pressure. In this process, the \( X \) value (quality of the drought fraction) can be found using the formula [4]:

\[ X_2 = \frac{s_2 - s_f}{s_{g2} - s_f} \]  

Equation 2

With:
- \( X_2 \) = Steam Quality (%)
- \( S_1 \) = Steam entropy entering the turbine (kJ/kg•K)
- \( S_{g2} \) and \( S_{f2} \) = Entropy of vapor entering the condenser (kJ/kg•K)

With the known value of \( X_2 \) (quality of the drought fraction), the \( h_{2s} \) value can be calculated using the formula [4]:

\[ h_{2s} = h_{f2} + X_2 \cdot h_{fg2} \]  

Equation 3

With:
- \( h_{2s} \) = ideal enthalpy out of the turbine (kJ/kg)
- \( X_2 \) = Steam Quality (%)
- \( h_{f2} \) = Enthalpy out of the turbine under liquid conditions (kJ/kg)
- \( h_{fg2} \) = Enthalpy out of the turbine under mixed conditions (kJ/kg)

The process that the fluid undergoes from point 1 to point 2 is considered an isentropic process so that the entropy at point 1 is the same as the entropy at point 2, so that \( S_1 = S_2 \) where \( S_1 \) is the entropy of steam at the turbine entry pressure.

2.5 Laws I and II of Thermodynamics
The first law of thermodynamics is stated as: "Energy cannot be created or destroyed, but can be transformed from one form to another". In accordance with this law, the energy provided by heat must equal the external work done plus the gain in internal energy due to the increase in temperature. If heat is given to the system, the volume and temperature of the system will increase (the system will appear to be expanding and getting warmer). Conversely, if heat is taken from the system, the volume and temperature of the system will decrease (the system appears to shrink and feels cooler). This principle is an important natural law and one form of the law of conservation of energy.

Mathematically, the First Law of Thermodynamics is written as:

\[ Q = \Delta U + W \]  

Equation 4

<table>
<thead>
<tr>
<th>1st Advisor</th>
<th>2nd Advisor</th>
<th>English Spv</th>
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</thead>
<tbody>
<tr>
<td>Sign / date</td>
<td>NIM 16030037</td>
<td>Bayu Tri Darurohman</td>
</tr>
</tbody>
</table>
With:

\[ Q = \text{Kalor} \]
\[ W = \text{Ufriend} \]
\[ \Delta U = \text{Pinternal energy changes} \]

But the formula applies if the system absorbs Q heat from its environment and does W work on its environment.

The second law of thermodynamics states that it is impossible to make a heat engine that operates in a cycle to convert the heat energy obtained from a reservoir at a given temperature entirely into mechanical work. The second law of thermodynamics says that heat flow has a direction, namely from hot to cold and not all processes in the universe are reversible (reversible). Hence mechanical energy can also be converted to electrical energy with very good efficiency, as achieved by power generators (which operate at up to 99% efficiency) [5].

2.6 Turbine Expansion Process

In general, efficiency is defined as the ratio between output and input in a process. Efficiency is an important equation in thermodynamics to determine how well the energy conversion or transfer process occurs [6].

PLTP is designed to produce a certain amount of electrical energy output for a number of inputs. If all PLTP components have high efficiency, then the PLTP performance is said to be high so that the PLTP operating costs are also getting lower. If for some reason the PLTP’s performance drops, it means that the PLTP needs more main materials or gas to produce electrical energy output according to the design. As a result, operating costs are getting higher. Ideally, we want the heat energy (input) to be completely converted into electrical energy (output). In reality, it is impossible to do this because of the various losses that occur in almost every component of the PLTP. As a result of these losses, Turbine efficiency is a parameter which states the degree of success of the turbine component or system in approaching the ideal design or process in units (%) [7].

The work produced by the turbine per unit mass of steam flowing through it is described by [8]:

\[ \dot{W}_t = h_1 - h_2 \] Equation 5

Information:
\[ \dot{W}_t = \text{Turbine Power} \]
\[ h_1 = \text{Enthalpy at turbine input (kJ / kg)} \]
\[ h_2 = \text{Enthalpy at actual state turbine output (kJ / kg)} \]

The power developed by the turbine is [8]:

\[ W_t = \text{rms. wt = rms (h}_1 - h_2) = \text{rms. } \eta \text{ (h}_1 - h_2s) \]

Information:
\[ W_t = \text{Turbine Power} \]
\[ \dot{W}_t = \text{Turbine Work} \]
\[ h_1 = \text{Enthalpy at turbine input (kJ / kg)} \]
\[ h_2 = \text{Enthalpy at actual state turbine output (kJ / kg)} \]
\[ \dot{m}_s = \text{Vapor mass flow rate (kg / s)} \]
\[ h_2s = \text{Enthalpy at ideal turbine output (kJ / kg)} \]
\[ \eta = \text{Turbine Efficiency (％)} \]

The gross electric power will be equal to the turbine power times the efficiency of the generator, namely [8]:

\[ W_e = \eta_g \cdot \dot{W}_t \] Equation 6

Information:
\[ W_e = \text{Gross / Gross Electrical Power} \]
\[ \eta_g = \text{Generator Efficiency (％)} \]
\[ \dot{W}_t = \text{Turbine Power} \]

In this process, the fluid with the vapor phase enters the turbine to do work. The ideal work of the turbine will be generated if the turbine operates adiabatically and reversibly, namely at constant or isentropic entropy. So that the turbine isentropic efficiency can be determined by comparing the actual turbine work with isentropic work as below [8]:

\[ \eta_{\text{turbin}} = \frac{h_1 - h_2}{h_1 - h_{2s}} \] Equation 8

Or Isentropic efficiency can be calculated using equation 6 and equation 7 from the value of the power generator compared to the isentropic power, namely [8]:

\[ \eta_{\text{turbin}} = \frac{\text{Power Generated}}{\text{Power Isentropis}} \times 100 \% = \frac{W_e / \eta_g}{\dot{m}_s (h_1 - h_{2s})} \times 100 \% \]

The thermodynamic properties of state 2 are determined by solving the equation. (8) using the turbine efficiency and fluid properties at the 2s state, the ideal turbine output state, which is easily calculated from the known pressure and entropy values at the 2s state. The ideal enthalpy is found from equation [8]:

\[ h_{2s} = h_{f_2} + [h_{g2} - h_{f2} \cdot \frac{s_{f2} - s_{f_2}}{s_{g2} - s_{f_2}}] \] Equation 9

When Baumann’s rule is included in the calculation, the following working equation appears for the enthalpy at the actual turbine outlet condition [8]:

\[ \text{When Baumann’s rule is included in the calculation, the following working equation appears for the enthalpy at the actual turbine outlet condition [8]:} \]
where the factor A can be determined by equation [8]:

\[ A = 0.425 \cdot (h_1 - h_2s) \] .......................... Equation 11

Information:

\( h_{f2} \) = enthalpy out of the turbine under liquid conditions (kJ / kg)
\( h_{g2} \) = enthalpy out of the turbine under gas or steam conditions (kJ / kg),
\( S_1 \) = entropy into the turbine (kJ / kg.K),
\( S_{f2} \) = entropy out of the turbine in liquid condition (kJ / kg.K),
\( S_{g2} \) = enthalpy out of the turbine under gas or steam conditions (kJ / kg.K)

3. Methodology

To support the final project and the studies that have been carried out, several methods of implementation can be carried out, namely:

3.1 Introduction

The final project research was carried out on January 30 - February 28, 2020 at PT Pertamina Geothermal Energy Area Kamojang. The data obtained is based on data from each tool at PT Pertamina Geothermal Energy Area Kamojang directly to become a data source in making the final project report.

3.2 Data retrieval

Data was collected on January 30 - February 28, 2020. Data before the Overhaul was carried out was taken on January 30 - February 8, 2020, while the data after the Overhaul was carried out was taken on February 19 - February 27, 2020. The research data obtained were temperature and pressure at the turbine inlet, steam and steam turbine outlets and steam mass flow rating.

3.3 Data processing

The data obtained is based on field data which is the source of data in making reports. Then it is processed by performing calculations using the ChemicaLogic SteamTab Companion application and table A-4 Appendix to determine the enthalpy and entropy values. Then, the calculation is carried out in several steps, namely the analysis of steam quality, actual enthalpy, ideal enthalpy, actual work, ideal work and turbine efficiency. The data and calculation results are then compiled and compiled using Microsoft Excel worksheets to present the information.

3.4 Results Evaluation

From the data obtained, data processing is carried out to determine the enthalpy, entropy and turbine work values in the Geothermal Power Plant system. The results of the analysis carried out are used as the basis for evaluating the performance of the efficiency value and turbine work before overhaul and after overhaul in the PLTP system.

4. Results and Discussion

The research was conducted on January 30 - February 28, 2020. Data before the Overhaul was carried out was taken on January 30 - February 8, 2020, while the data after the Overhaul was carried out was taken on February 19 - February 27, 2020. The research data needed were temperature and pressure at the turbine inlet, steam and steam turbine outlets and steam mass flow rating.

4.1 Flow Diagram of PLTP Unit 5 PT PGE Kamojang Area

Draw a flow diagram of the PLTP using existing technical data in each condition.

![Flow diagram of PLTP Unit 5](image)

**Figure 3** Flow diagram of PLTP Unit 5

Figure 1 is a state where the steam first enters the high pressure turbine or is called the turbine inlet. Figure 2 is a state where the steam that has been used to rotate the high pressure turbine shaft (exhaust steam) is released into the condenser.

4.2 Isentropic Efficiency Calculation of PLTP Unit 5 Turbine Before Overhaul

The operational data for the PLTP PT Pertamina Geothermal Energy in the Kamojang area before the overhaul is shown in Table 2.
Table 2 Turbine Inlet and Outlet Data on January 30 - February 8, 2020

| Temperature | Pressure | Flow Rate | Gross Kcal/h
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>5.9</td>
<td>0.099</td>
<td>44.63</td>
</tr>
<tr>
<td>31</td>
<td>5.9</td>
<td>0.099</td>
<td>44.63</td>
</tr>
<tr>
<td>32</td>
<td>5.9</td>
<td>0.099</td>
<td>44.63</td>
</tr>
<tr>
<td>33</td>
<td>5.9</td>
<td>0.099</td>
<td>44.63</td>
</tr>
<tr>
<td>Average</td>
<td>5.9</td>
<td>0.099</td>
<td>44.63</td>
</tr>
<tr>
<td>Absolute</td>
<td>6.7</td>
<td>0.099</td>
<td>61.17</td>
</tr>
</tbody>
</table>

From the pressure data above, we can find the incoming enthalpy \( h_1 \) and incoming entropy \( S_1 \) values from the calculation using the ChemicaLogic SteamTab Companion application for turbine steam inlet data.

Table 3 Superheated Water Vapor Turbine Steam Inlet Data

ChemicaLogic SteamTab Companion used again to find the value of gas phase enthalpy \( h_2g \), liquid phase enthalpy \( h_2f \), liquid phase entropy \( S_2f \) and gas phase entropy \( S_2g \) described in Table 4 as turbine steam output data.

Table 4 Saturated Water Turbine Outlet Steam Data

4.2.4 Turbine Work Calculation (\( Wt \))

The turbine work calculation is determined by equation 5 as follows:

\[
W_t = \frac{We}{\eta_g}.
\]

\[
W_t = \frac{29812.5 \text{ Kw}}{0.971}.
\]

\[
W_t = 30702.88 \text{ Kw}.
\]

4.2.6 Turbine Isentropic Efficiency Calculations (\( \eta_{turbine} \))

So that the turbine isentropic efficiency can be determined by equation 2.9 as below:

\[
\eta_{turbine} = \frac{\text{Power Generated}}{\text{Power Isentropic}} \times 100\% = \frac{\frac{We}{\eta_g} - 100}{\eta_{isentropic}}.
\]

\[
\eta_{turbine} = \frac{29812.5 \text{ Kw}}{0.971}.
\]

\[
\eta_{turbine} = 79\%.
\]
5.3 Isentropic Efficiency Calculation of PLTP Unit 5 Turbine After Overhaul

The operational data for the PLTP PT Pertamina Geothermal Energy in the Kamojang area after the overhaul is shown in Table 5.

Table 5 Turbine Inlet and Outlet Data for 19 February - 27 February 2020

<table>
<thead>
<tr>
<th>Tongal</th>
<th>INPUT</th>
<th>OUTPUT</th>
<th>Flow Rate (G%)</th>
<th>Gross</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P (bar)</td>
<td>T (°C)</td>
<td>P (bar)</td>
<td>T (°C)</td>
</tr>
<tr>
<td>50</td>
<td>5.45</td>
<td>166.0</td>
<td>0.28</td>
<td>46.7</td>
</tr>
<tr>
<td>20</td>
<td>5.45</td>
<td>166.0</td>
<td>0.28</td>
<td>46.7</td>
</tr>
<tr>
<td>21</td>
<td>5.45</td>
<td>166.0</td>
<td>0.28</td>
<td>46.7</td>
</tr>
<tr>
<td>22</td>
<td>5.45</td>
<td>166.0</td>
<td>0.28</td>
<td>46.7</td>
</tr>
<tr>
<td>23</td>
<td>5.45</td>
<td>166.0</td>
<td>0.28</td>
<td>46.7</td>
</tr>
<tr>
<td>24</td>
<td>5.45</td>
<td>166.0</td>
<td>0.28</td>
<td>46.7</td>
</tr>
<tr>
<td>25</td>
<td>5.45</td>
<td>166.0</td>
<td>0.28</td>
<td>46.7</td>
</tr>
<tr>
<td>26</td>
<td>5.45</td>
<td>166.0</td>
<td>0.28</td>
<td>46.7</td>
</tr>
<tr>
<td>27</td>
<td>5.45</td>
<td>166.0</td>
<td>0.28</td>
<td>46.7</td>
</tr>
<tr>
<td>28</td>
<td>5.45</td>
<td>166.0</td>
<td>0.28</td>
<td>46.7</td>
</tr>
<tr>
<td>29</td>
<td>5.45</td>
<td>166.0</td>
<td>0.28</td>
<td>46.7</td>
</tr>
<tr>
<td>30</td>
<td>5.45</td>
<td>166.0</td>
<td>0.28</td>
<td>46.7</td>
</tr>
<tr>
<td>Average</td>
<td>5.45</td>
<td>166.0</td>
<td>0.28</td>
<td>46.7</td>
</tr>
</tbody>
</table>

From the pressure data above, we can find the incoming enthalpy ($h_1$) and incoming entropy ($S_1$) values from the calculation using the ChemicaLogic SteamTab Companion application.

Table 6 Superheated Water Vapor Turbine Steam Inlet Data

<table>
<thead>
<tr>
<th>T1 (°C)</th>
<th>P1 (bar)</th>
<th>h1 (kJ/kg)</th>
<th>S1 (kJ/kg °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>166.0</td>
<td>6.50</td>
<td>2758.24</td>
<td>6.7</td>
</tr>
</tbody>
</table>

ChemicaLogic SteamTab Companion used again to find the value of gas phase enthalpy ($h_2$), liquid phase enthalpy ($h_f$), liquid phase entropy ($S_f$) and gas phase entropy ($S_g$) as described in Table 7 as turbine steam outlet data.

Table 7 Saturated Water Turbine Outlet Steam Data

<table>
<thead>
<tr>
<th>T (°C)</th>
<th>P2 (bar)</th>
<th>h2s (kJ/kg)</th>
<th>h2 (kJ/kg)</th>
<th>S2 (kJ/kg °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>267.2</td>
<td>0.1117</td>
<td>2274.08</td>
<td>198.9</td>
<td>0.07</td>
</tr>
</tbody>
</table>

5.3.1 Steam Quality Calculations

Calculation of the quality of the condenser output vapor can be solved using equation 8 as follows:

$$X_2 = \frac{S_1 - S_{f2}}{S_g - S_{f2}}$$

$$X_2 = \frac{67.4 \text{ kJ/kg} - 0.67 \text{ kJ/kg}}{8.12 \text{ kJ/kg} - 0.67 \text{ kJ/kg}}$$

$$X_2 = 0.81$$

5.3.2 Ideal Enthalpy Calculation ($h_{2s}$)

The ideal enthalpy calculation for the turbine output ($h_{2s}$) can be determined by equation 9, namely:

$$h_{2s} = h_f + X. (h_{g2} - h_{f2})$$

$$h_{2s} = h_f + 198.9 \text{ kJ/kg} + 0.81.2387,96 \text{ kJ/kg}$$

$$h_{2s} = 2145.91 \text{ kJ/kg}$$

5.3.3 Actual Turbine Outlet Enthalpy Calculation ($h_2$)

Using Baumann’s equation with equation 10 for the enthalpy at the actual turbine outlet conditions:

$$h_2 = \frac{h_1 - A \left[ 1 - \frac{h_{f2}}{h_{g2} - h_{f2}} \right]}{1 + \frac{A}{h_{g2} - h_{f2}}}$$

where the factor $A$ can be determined by the equation:

$$A = 0.425 \cdot (h_1 - h_{2s})$$

$$A = 0.425 \cdot (2758.24 \text{ kJ/kg} - 2145.91 \text{ kJ/kg})$$

$$A = 260.24$$

$$h_2 = \frac{2758.24 \text{ kJ/kg} - 260.24 \left[ 1 - \frac{2586.86 \text{ kJ/kg} - 198.9 \text{ kJ/kg}}{260.24} \right]}{1 + \frac{2586.86 \text{ kJ/kg} - 198.9 \text{ kJ/kg}}{260.24}}$$

$$h_2 = 2272.11 \text{ kJ/kg}$$

5.3.4 Turbine Work Calculation ($w_t$)

The turbine work calculation is determined by equation 5 as follows:

$$w_t = h_1 - h_2$$

$$w_t = 2758.24 \text{ kJ/kg} - 2272.11 \text{ kJ/kg}$$

$$w_t = 486.13 \text{ kJ/kg}$$

5.3.5 Calculation For Turbine Power ($W_t$)

The calculation for turbine power is determined by equation 6 because it is known that the gross power ($W_e$) and the efficiency of the generator ($\eta_g$) as data from the company, namely:

$$W_e = \eta_g \cdot W_t$$

$$W_t = \frac{W_e}{\eta_g}$$

$$W_t = \frac{35252 \text{ Kw}}{0.971}$$

$$W_t = 36304.7 \text{ Kw}$$

5.3.6 Turbine Isentropic Efficiency Calculations ($\eta_{turbin}$)

So that the turbine isentropic efficiency can be determined by equation 8 as below:

$$\eta_{turbin} = \frac{\text{Power Generated}}{\text{Power Isentropic}} \times 100\% = \frac{W_e}{\frac{W_e}{\eta_g \cdot (h_1 - h_{2s})} \times 100\%}$$

$$\eta_{turbin} = \frac{35252 \text{ Kw}}{76.03 \text{ kg/s} \left( \frac{2758.24 \text{ kJ/kg}) - 2145.91 \text{ kJ/kg}}{2758.24 \text{ kJ/kg}} \right)}$$

$$\eta_{turbin} = 78\%$$
5.4 Calculation Results of Isentropic Efficiency

Based on the results of the above calculations with data before and after the overhaul, it is shown in Table 8.

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Unit</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Steam</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Press</td>
<td>Bar</td>
<td>6.75</td>
<td>6.30</td>
</tr>
<tr>
<td>Temp</td>
<td>°C</td>
<td>166.58</td>
<td>166.66</td>
</tr>
<tr>
<td>Flow Rate</td>
<td>kg/s</td>
<td>61.17</td>
<td>76.03</td>
</tr>
<tr>
<td><strong>Exhaust Steam Turbin</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Press</td>
<td>Bar</td>
<td>0.099</td>
<td>0.117</td>
</tr>
<tr>
<td>Temp</td>
<td>°C</td>
<td>44.67</td>
<td>47.5</td>
</tr>
<tr>
<td>Enthalpy Isentropic (h2s)</td>
<td>kg/kj</td>
<td>2127.41</td>
<td>2145.91</td>
</tr>
<tr>
<td><strong>Daya Turbin Design</strong></td>
<td>kW</td>
<td>37260</td>
<td></td>
</tr>
<tr>
<td><strong>Daya Turbin (Wt)</strong>*</td>
<td>kW</td>
<td>30702.88</td>
<td>36304.7</td>
</tr>
<tr>
<td><strong>Daya Kotor Gross (Wg)</strong></td>
<td>kW</td>
<td>29812.3</td>
<td>31252</td>
</tr>
<tr>
<td>Efficiency (η)</td>
<td>%</td>
<td>79</td>
<td>78</td>
</tr>
</tbody>
</table>

Table 8 The calculation results

**Graph 1** Comparison Chart Isentropic Enthalpy (h2s)

Judging from the graph 1 isentropic enthalpy tends to be higher than after the overhaul because there is a difference between the inlet and outlet pressures with this difference affecting the isentropic enthalpy results. So that the difference from the comparison isentropic Enthalpy (h2s) before and after the overhaul there was an increase isentropic Enthalpy (h2s) of 18.8 kJ/kg. This is due to the difference in the value of the liquid enthalpy (h2) and the two-phase enthalpy (hfg2) due to the difference in pressure between the conditions before and after the overhaul. Higher pressure will affect the enthalpy value [4].

**Graph 2** Comparison Chart Turbine Power (Wt)

**Graph 3** Isentropical Efficiency Comparison Chart (η)

In graph 3 the graph shows a decrease in efficiency after an overhaul of 1%. This decrease occurs due to a decrease in pressure on the inlet tubin and an increase in actual work. Several factors that affect the efficiency of the turbine include temperature and pressure of steam entering the turbine. Ideally, the steam entering the turbine is superheated and leaving the tubin is still saturated steam. At the PLTP, the incoming steam is saturated and the steam coming out of the turbine has partially condensed. The result of this condensation is that there is heat loss, where the greater the heat loss, the lower the efficiency. The difference in mass flow rate (ms) is the actual data from companies before and after the overhaul [4].

**Graph 4** Isentropical Efficiency Comparison Chart (η) and Turbine Power Before Overhaul

Judging from graph 2 above, the resulting turbine power is higher than before the overhaul and is closer to the Turbine Design Power position, this is because before the overhaul the incoming flowrate is equal to 61.17 kg/s with the Main Control Valve (MCV) open at 91.4% and after the overhaul, the incoming flowrate is 76.03 kg/s with the Main Control Valve (MCV) open at 45% but able to approach the Turbine Power Design position with an increase Turbine Power (Wt) of 5601.82 kW from before the overhaul. The difference between the incoming enthalpy (h1) and isentropic enthalpy (h2s) means that the determination of factor A is different from the conditions before and after the overhaul. The greater the A value, the greater the enthalpy value of the actual turbine outlet (h2) [4].
Conducted research on turbine unit 08. Discuss the efficiency. Though the isentropical efficiency was hapaganted with isentropic date 3. Sign / 3.

1. For future researchers, it can discuss the efficiency of the turbine with a comparison of the efficiency of several years ago if there is no overhaul.
2. If later researchers want to discuss turbine efficiency research, they can use other methods or calculate turbine thermal efficiency.

Acknowledgement

Thank you to PT Pertamina Geothermal Energy Area Kamojang for receiving me well for carrying out my final project in the January - February 2020 period and thanks to everyone who has contributed during the implementation of my final project.

References


5. Conclusions and Suggestion

5.1 Conclusion

Based on the Final Project and writing reports that have been done, conclusions can be drawn, as follows:

1. The isentropic enthalpy value ($h_2$) before the overhaul is $2127.41$ kJ / kg and after the overhaul of $2145.91$ kJ / kg conducted research on turbine unit V at PLTP Kamojang from January 30 - February 28 2020. There is a higher difference than after the overhaul with a difference of $18.8$ kJ / kg, due to the difference between the inlet and outlet pressure. This affects the isentropic enthalpy results.
2. From the calculation of the value of turbine power ($\dot{W}_t$) before the overhaul of $30702.88$ Kw and after the overhaul of $36304.7$ Kw, there is an increase in turbine power ($\dot{W}_t$) after the overhaul of $5601.82$ Kw, it is because there is a difference between the turbine inlet flowrate with a difference of $14.86$ kg / s so that it affects the turbine power results.
3. From the results of data calculations, the turbine isentropic efficiency value can be determined by comparing the power generated with isentropic power, the efficiency value for before overhaul is $79\%$ and for after overhaul is $78\%$. Efficiency after overhaul has decreased by $1\%$ from the efficiency before overhaul because the size of the isentropic efficiency is influenced by the difference from the actual turbine power of each steam mass flow to the isentropic power of the turbine, the smaller the difference, the greater the efficiency, the greater the difference, the smaller the efficiency.

5.2 Suggestion

After carried out the Final Project for two months at PT Pertamina Geothermal Energy Area Kamojang, the compilers have suggestions that are expected to build. The suggestions include:

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