Aquadest Production System as Steam Turbine Bottom Cycle I: Influence of Pressure of Cooling Water Tank and Pinch Point Temperature Difference of Condenser

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ABSTRACT. The condenser heat from the steam turbine system is discharged into the environment in a way that is likely to damage the environment. This paper simulates a system that produces aquadest with throttled 10% water of condenser output to the cooling water tank with vacuum pressure so as to produce water vapor. This water vapor is condensed in a cooling machine to produce aquadest. The cold water coming out of the cooling water tank is mixed with cooling water from the sea so the temperature is lower causing the condenser output water to be lower temperature (more environmentally friendly). This simulation varies the pressure of cooling water tanks and Pinch Points Temperature Difference (PPTD) of condenser. From the simulation it is found that the higher the pressure of the cooling water tank causes Specific Aquadest Production (SAP), and Energy Consumtion (EC) is getting smaller. The smaller PPTD leads to Specific Aquadest Production (SAP), Specific Energy Consumtion (SEC) and Energy Consumtion (EC) getting smaller. This simulation has the best result that is able to produce aquadest as much as 0.0133 [kg/s], increase the efficiency of steam power plant by 0.21%, and lower condenser water temperature by 0.9 °C.

1 Introduction

Currently in the coastal areas of Indonesia, especially in big cities and in many other places around the world is a clean water crisis. The clean water crisis includes drinking water and water for other needs, with a total need of clean water per person per day is 60 L [11]. The Government of Indonesia and other countries have made various efforts to overcome this clean water crisis. As many as 97% of the water in the earth is sea water that requires processing technology to convert it into fresh water to be used to meet the daily needs of humans. It needs to be done continuously development of environmentally friendly clean water treatment technology to solve this clean water crisis problem [2].

The engineers have done a lot of research to create water treatment tools. For example, seawater desalination technology by utilizing microbes is the process of desalination of sea water driven by the presence of microbial respiration [9]. There is also a seawater desalination technology using reverse osmosis method [8]. But reverse osmosis technology has a negative impact on the environment such as the impingement and entrainment of marine organisms [5]. The addition of solar panels to riverse osmosis devices can be an alternative to producing desalinationable drinkable water and with more efficient energy though limited to certain areas that meet the criteria [6]. A tool similar to this research is the utilization of condenser wastewater to produce water desalination using U-pipe [3].

This paper describes the simulation tool for generating aquadest. The method and process in this research is a new innovation that is by utilizing the waste of warm water of condenser output of the steam power plant. This waste is generally directly discharged into the sea without being used first. Warm temperatures can harm the surrounding marine ecosystem [1]. In this simulation some of the hot water waste from condenser output is flowed back into the system by conducting throttling process first so as to produce water vapor that can be condensed into aquadest. Akudes production is different from the production of desalination water that is on the production of aquadest using the phase change of water so that the resulting water is really pure [2]. This tool is able to produce aquadest with a very low cost. The addition of this tool to the steam power system does not degrade the performance of the power plant, even with changes in the condenser pressure will increase the power generated by the power plant [10]. The use of this tool also makes the hot water coming out

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of the condenser steam power plant has a lower temperature so it is more environmentally friendly.

In this simulation can be done with many variations such as: variations condenser pressure to increase turbine power [10], variations of pinch point temperature difference (PPTD) to optimize the performance of the condenser [12], variations in the amount of water directly discharged into the sea, as well as variations in water pressure within the cooling water tank to improve the efficiency of the production of aquadest and thermodynamic efficiency [7]. In this simulation, only variations on the pinch point temperature difference (PPTD) and the pressure of the cooling water tank are used. By changing the condenser pressure to 6.45 [kPa] and water out of the condenser is directly discharged into the sea as much as 90%.

2 Methods

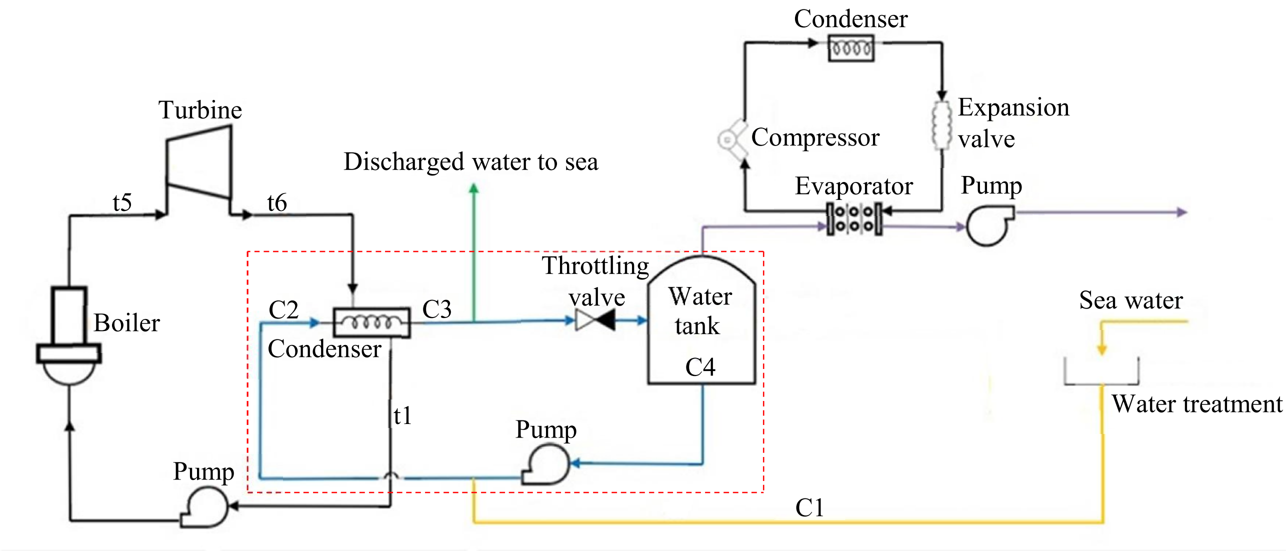


Fig. 1. Schematic Diagram of Throttling Process of Condenser Cooling Water of Steam Power Plant

From Fig. 1. It can be seen that this tool circulates the condenser cooling water of the steam power plant so that not all water coming out of the condenser is discharged back into the sea. This non-discharged cooling water enters the throttling process for expansion so that the pressure drops and enters the cooling water tank at point C4 in Fig. 1. Most of the expanded water temperature also decreases to the saturation temperature according to the pressure, whereas the energy from the previous temperature and pressure is used to evaporate a small portion of the other water. This water vapor is then condensed to produce aquadest. While the water in the cooling water tank is circulated again back into the system and mixes with additional water from the ocean to cool the condenser. Then the water coming out of the condenser is mostly discharged into the ocean and a small portion is circulated back to the system, and so on.

Design point data of steam turbine cycle in this simultion refers to X Steam Power Plant with 50 MW capacity with detail specification in Table 1. for 1 kg working fluid.

Table 1. Design Point Data of Steam Turbine Cycle

Parameter	Value
T_{t5}	510 °C
p_{t5}	8900 [kPa]
$s_{turbine}$	6.696 [kJ/kg.K]
$\dot{m}_{cooling\ water}$	148.13 kg per 1 kg working fluid
$p_{condenser}$ (pressure)	8.45 [kPa]
$\eta_{isentropic}$ (efficiency)	87 %
η_{th} (efficiency of steam power plant)	34.99 %
$T_{cooling\ water\ out\ from\ condenser}$	33.4 °C
PPTD	9.2 °C

3 Thermodynamics Simulation

3.1 The simulation process

This simulation is done by first transforming the data on the turbine in the design point. The condenser pressure is converted from 8.45 [kPa] to 6.45 [kPa] to obtain turbine power optimization, and by determining the percentage of condenser output water discharged directly to the sea by 90%. The next step is to look for other variables with the following formula and sequence:

1. The vapor mass fraction,

$$X_{vapor} = \frac{h_{c3} - h_{f\,c4}}{h_{fg\,c4}} \quad (1)$$

2. The cooling water mass enters the condenser,

$$m_{c2} = \frac{q_{in}}{C} \quad (2)$$

$$C = h_{c3} - A \times h_{f\,c2} - B - (1 - A) \times h_{c1} \quad (3)$$

$$A = \frac{(1 - \%\text{discharged}) \times (h_{g\,c2} - h_{c3})}{h_{fg\,c2}} \quad (4)$$

$$B = v_{c2} \times (101.325 - p_{c2}) \quad (5)$$

3. The water mass comes out of the cooling water tank,

$$m_{c4} = m_{c2} \times A \quad (6)$$

4. Discharged water mass,

$$m_{\text{discharged}} = \%\ \text{discharged} \times m_{c2} \quad (7)$$

5. Power of pump for water comes out of the cooling water tank,

$$P_{pump\ C4} = v_{C2} \times m_{C4} \times (101.325 - p_{C4}) \quad (8)$$

6. Mass of aquadest,

$$m_{aq} = \frac{X_{vapor} \times m_{C4}}{(1 - X_{vapor})} \quad (9)$$

7. Additional cooling water mass,

$$m_{C1} = m_{c2} - m_{c4} \quad (10)$$

8. The steam condensing power becomes aquadest,

$$P_{\text{comp}} = \frac{m_{aq} \times h_{fg\ c2}}{COP} \quad (11)$$

9. Energy Consumption (EC) to produce aquadest,

$$EC = P_{pump} + P_{comp} \quad (12)$$

10. Specific Energy Consumption (SEC) to produce 1 kg aquadest,

$$SEC = EC / m_{aq} \quad (13)$$

11. New steam power plant efficiency,

$$\eta_{th\ new} = \frac{(w_{net} \times \dot{m} - EC - P_{pump})}{q_{in}} \times \dot{m} \times 100\% \quad (14)$$

4 Result and Discussion

4.1 Result and Discussion

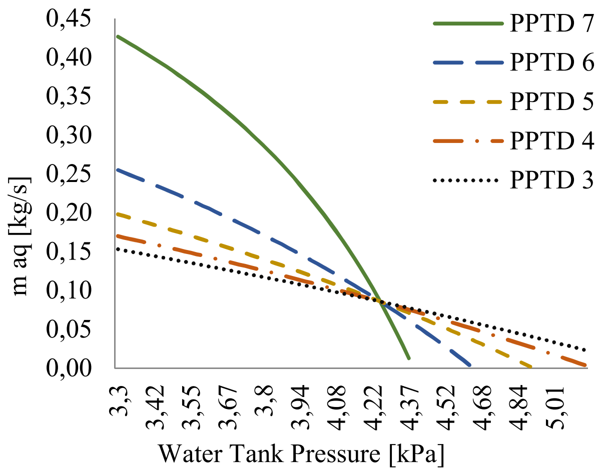
In this simulation is also changed the amount of PPTD to 5 ^{o}C and by making the condenser waste water as much as 90%. Condenser pressure is selected 6.45 kPa because at this pressure has a temperature of 37.5 ^{o}C so that with PPTD point 5 ^{o}C can still be cooled by sea water with temperature of 30 ^{o}C. With the results of the calculation as follows:

Table 2. Simulation Conditions Simulation Thermodynamics

Parameter	Value
T_{t5}	510 ^{o}C
p_{t5}	8900 [kPa]
$s_{turbine}$	6.696 [kJ/kg.K]
$\dot{m}_{cooling\ water}$	148.13 kg per 1 kg working fluid
T_{t6}	37.5 ^{o}C
p_{t5}	6.45 [kPa]
$T_{condenser}$	37.5 ^{o}C
$P_{condenser}$	6.45 [kPa]
T_{pump}	37.5 ^{o}C
P_{pump}	8900 [kPa]
$\dot{m}_{working\ fluid}$	1 [kg/s]
T_{C1}	30 ^{o}C
$\eta_{isentropic}$ (efficiency)	87 %
$q_{in\ from\ boiler}$ (heat in)	3255.3 [kJ/kg]
$w_{Turbine}$ (turbine energy)	1167.79 [kJ/kg]
$q_{out\ at\ condenser}$ (heat out)	2087.48 [kJ/kg]
w_{pump} (work of pump)	8.96 [kJ/kg]
$W_{netto\ turbine}$	1158.83 [kJ/kg]
X_{vapor}	0.0006
m_{C2}	213.7 [kg/s]
m_{C4}	21.36 [kg/s]
$m_{discharged\ water}$	192.33 [kg/s]
$P_{pump\ C4}$	2.07 [kW]
m_{aq}	0.0133 [kg/s]
m_{C1}	192.34 [kg/s]
P_{compp}	10.77 [kW]
EC	-14.34 [kW]
SEC	-1075.87 [kJ/kg]
$\eta_{th\ new}$	35.2 %

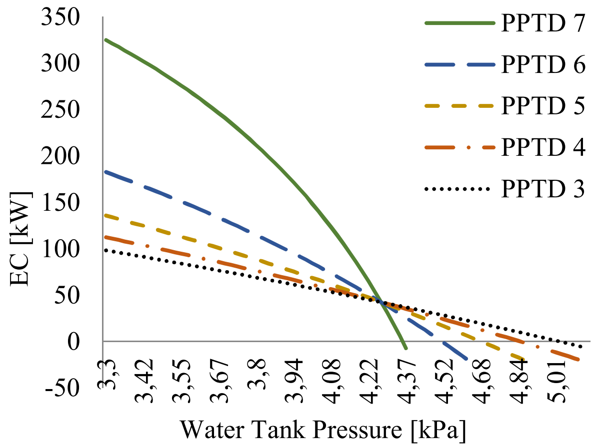
So by adding this tool as well as by lowering the condenser pressure from 8.45 kPa to 6.45 kPa on the condenser with PPTD point 5 °C and the reservoir tube pressure of 4.81 kPa and 90% of the condenser output water disposed, will cause turbine power efficiency to increase from 34.99% to 35.2%. With the change of condenser pressure and PPTD make SEC become negative meaning to produce 1 kg of diesel still excess turbine power from turbine initial condition.

4.2 Power Plant Simulation Graph with Throttling Process Tool on PPTD Variation



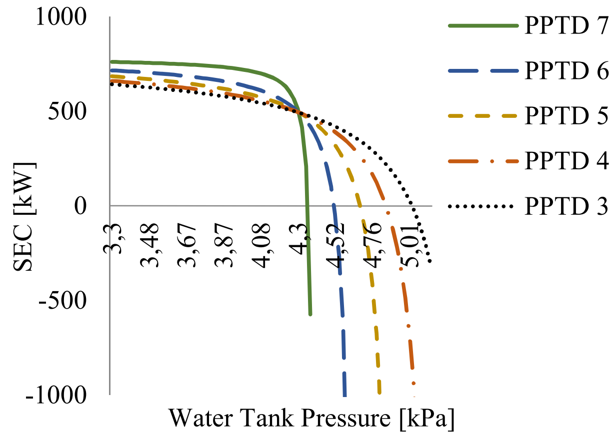
Graph 1. SAP Against Pressure of The Cooling Water Tank with 6.45 kPa Condenser Pressure

The smaller PPTD the resulting mass of the aquadest the less also for the other condition remains. This is because the smaller PPTD the cooling water required is less so that with the same percentage will result in a few more aquadest as well. At the same PPTD, the greater pressure on the cooling water tank will result in a smaller aquadest mass corresponding to an increasingly smaller percentage of the vapor mass that is not proportional to the required cooling water mass increase.



Graph 2. EC Against Pressure of The Cooling Water Tank with 6.45 kPa Condenser Pressure

EC is energy consumtion that is the energy needed to produce aquadest with this throttling process at that point. So that it is strongly influenced by the amount of steam produced, the more water vapor generated, the more energy it will take to condense it into aquadest because all the water vapor will be condensed into aquadest without being discarded so that the EC graph in Graph 2. has a shape similar to Graph 1. This EC also includes the energy required by the pump to pump cooling water out of the cooling water tank. At the same PPTD, the greater of pressure on the cooling water tank make greater the pumped water but the increase in the pump power is very small compared to the decrease in power by the cooling machine to condense vapor.



Graph 3. SEC Against Pressure of The Cooling Water Tank with 6.45 kPa Condenser Pressure

This SEC is the energy needed to produce as much as 1 kg of aquadest in this throttling process tool. This SEC is the EC reduced by the addition of turbine power due to the pressure drop on the condenser so that the SEC can be negative for the near-zero EC value as in Graph 3. In Graph 3. only PPTD 3-7 °C only has a negative SEC. This negative SEC is a good condition because to produce aquadest still leaves the excess turbine power.

Graphs 1., 2., And 3. taken only for conditions that produce distorted only so that seen on the graph on PPTD 10 °C, 9.2 °C and 8 °C has a graph line that is disconnected in the middle not to the right end of the X axis.

The larger the resulting aquadest will be better, but the system also considers the energy consumption to produce it so as to consider also the SEC value, so the lower the SEC value and the higher the SAP value is the best point.

From all simulation data it can be seen that the percentage of exhaust water does not affect the SEC but has an effect on EC and SAP, the smaller the percentage of waste water the EC and SAP are getting bigger. The pressure of the cooling water tank affects EC and SAP, the larger the cooling water tank pressure the EC and SAP are smaller. PPTD effect on SEC, EC and SAP, the smaller PPTD then SEC, EC and SAP also getting smaller. Decrease in condenser pressure will cause turbine power to become larger.

5 Conclusion

From the simulation results of X Steam Power Plant system combined with Throttling Process tool can be drawn conclusion as follows:

1. Using the throttling process of cooling water before entering the condenser of the steam power plant, referring to X Steam Power Plant with 50 MW capacity, will produce water vapor which is then condensed to aquadest with the lowest SEC (specific energy consumtion) of 820.89 kJ / kg to produce 1 kg of aquadest at constant condenser pressure and 90% waste water percentage.
2. Using the throttling process for 1% condenser of the steam power plant which in this case refers to X Steam Power Plant with 50 MW capacity, will produce 0.18 kg / s of aquadest even though the efficiency of Steam Power Plant decreased from 34.99% to 31.18%.
3. Using the throttling process at PPTD 5 ℃ by changing condenser pressure from 8.45 kPa to 6.45 kPa will increase turbine power efficiency from 34.99% to 35.2%, produce aquadest 0.0133 kg/s, and lowered the condenser effluent water temperature by 0.9 ℃.
4. The higher the pressure of the cooling water tank leads to SAP and EC is getting smaller. The smaller PPTD leads to SAP, SEC and EC getting smaller.

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